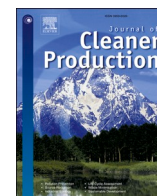




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Preliminary quantitative assessment of the multidimensional impact of the COVID-19 pandemic on Sustainable Development Goals

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ABSTRACT

The intersectoral impacts of the COVID-19 pandemic on humanity raises concerns about its implications for sustainable development. Here, we examine a global quantitative impact of COVID-19 pandemic on Sustainable Development Goals (SDGs) across all 17 goals using 65 proxy indicators across 72 countries collected from April 2020 to February 2021. Our data-driven analysis indicated that adverse impacts of the pandemic have been particularly concerned on gender equality (Goal 5), affordable and clean energy (Goal 7), decent work and economic growth (Goal 8), sustainable cities and communities (Goal 11), and responsible consumption and production (Goal 12) with global scores estimated to be -0.38 , -0.21 , -0.28 , -0.22 and -0.16 , respectively. Country income level was a variable that strongly differentiates the responses to the pandemic (e.g., lower incomes had 14 negative goals compared to 11 and 4 negative goals assigned to middle- and high-income countries, respectively). However, Goals 5 and 8 were highly impacted worldwide regardless of income status. Furthermore, countries that had already higher performance in SDGs were less impacted by the pandemic, highlighting the importance of progress on the SDGs in increasing societal resilience to pandemics. The findings provide insights into the reinforcement of recovery policies (e.g., protecting vulnerable groups and transitioning to a green economy) and a basis for a quantitative discussion on the sectors to be prioritized.

1. Introduction

The first case of COVID-19 was reported in Wuhan, China on December 29, 2019, although the origin is still undetermined (Andersen et al., 2020). Initially, SARS-CoV-2 had been perceived as a health hazard, and no one could envisage the devastation this virus would cause until the WHO announced that it had become an epidemic on March 11, 2020 (Sachs et al., 2020; Ranjbari et al., 2021). Due to the rapid spread of documented and undocumented COVID-19 infection as well as the emergence of mutant strains (Lauring and Hodcroft, 2021; Li et al., 2020), a number of countries implemented strict measures to prevent the spread of the virus (e.g., lockdown, social distancing, wearing a mask, etc.) (López and Rodó, 2020). Since then, the multidimensional impacts of this pandemic have manifested in all walks of

life, and the world is now facing diverse and unexpected socio-economic and environmental challenges (Diffenbaugh and Field, 2020; Fuso Nerini et al., 2020).

Various intersectoral challenges have simultaneously emerged besides health as a spillover effect from the pandemic and associated policy implementation. For example, in addition to school closure and stay at home policy, disruptions and restrictions in many of industrial and service sectors (e.g., tourism, trade and aviation) and their supply chains resulted in a 4.2% decline in global GDP per capita (Sachs et al., 2020). This global recession has also plunged an additional 88–115 million people into extreme poverty, and 82–132 million people into malnutrition (FAO, 2020). In addition, 1.5 billion students lost access to schooling (Sachs et al., 2020). Women have faced an increase in domestic violence and an increased burden of unpaid domestic duties (UN

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Women, 2020a). On the contrary, the pandemic could be viewed as an opportunity for sustainable transformation through increased reliance on digital communications as well as digital economy (Pradhan and Subedi, 2021). In addition, reduced industrial activities and restricted mobility have resulted in positive impact on the environment (e.g., CO₂ emissions cut-off) (Le Quéré et al., 2020). Also, the pandemic boosted the international collaboration in terms of personal protection products (PPP) and vaccine distribution (Wang and Huang, 2021). Furthermore, governments responded to the COVID-19 pandemic via the support for citizens' basic needs, the preservation of jobs and businesses survival, and the reinforcement of the health and care sectors (Fonseca and Azevedo, 2020).

In this context, United Nations (UN) in 2015 adopted the 2030 Agenda for Sustainable Development, providing a framework for "peace and prosperity for people and the planet, now and into the future." (Fonseca and Carvalho, 2019). The UN Member States then agreed upon the Sustainable Development Goals (SDGs), which strike a balance among economic, social, and environmental development (Fonseca and Carvalho, 2019). The SDGs provide an indication and measure of progress towards the achievement of sustainable development (Barbier et al., 2017). However, even before the pandemic, progress on the Sustainable Development Goals (SDGs) was inadequate, despite the fact that various sustainability-related initiatives had been implemented around the world (Rosati and Faria, 2019; Nature Editorial, 2020; Aly et al., 2022; Pizzi et al., 2020). Even today, sufficient funding (~2% of the global GDP) has not been secured to keep the SDGs on track, and the financial gap is expected to further expand due to the recession (Sachs and Schmidt-Traub, 2020). Therefore, although the UN has declared 2020–2030 as the Decade of Action for the SDGs, the global spread of the pandemic is likely to further impede the way forward (Nundy et al., 2021; Hannah Ritchie, 2021; Nature EDITORIAL, 2021). This underscores the need for an evidence-based assessment of the impact of COVID-19 on the SDGs, thereby prioritizing sectors to be addressed with limited resources and strengthening existing recovery policies (e.g., protection of vulnerable groups and green transition) (OECD, 2020a).

Since the outbreak of the COVID-19 pandemic, studies have been undertaken to assess its impact on the SDGs progress particularly using qualitative approaches. For example, the long-term adverse impacts of COVID-19 are noted for 60% of the SDG targets (Naidoo and Fisher, 2020), which is likely to be severe unless targets are sufficiently advanced before the pandemic. Another evidence-based qualitative analysis has shown that while a number of targets (90%) could be negatively impacted, some targets (40%) have the opportunity to move forward amid the pandemic (Nerini et al., 2020). In addition, there are local studies that survey the impact of COVID-19 on SDGs in some countries. For example, Joshi et al. (2021) found that the poverty rate amid the pandemic was augmented to 18% in Nepal, exceeding the national target (less than 5%). Another study in Nigeria indicated that the pandemic boosted the number of poor, increased the unemployment rate, deteriorated the educational quality, and limited the access to health care which poses threats to SDGs fulfillment (Fagbemi, 2021). Furthermore, the spillover effects of COVID-19 pandemic such as trade-offs and synergies among the targets (particularly negative cascade effects) have also been shown (Shulla et al., 2021). For example, Fonseca et al. (2020) found that poverty (SDG1) and health (SDG3) have synergetic relationships with most of the other SDGs, and thus these two goals are expected to receive highly negative impacts by the pandemic (Nerini et al., 2020).

These qualitative assessments have consistently indicated that the poor, vulnerable, and marginalized are the most affected groups during a pandemic, while there are still mixed views on the extent of the impact and prioritization of the targets (Naidoo and Fisher, 2020; Sachs et al., 2020). Furthermore, the impact of the pandemic is likely to be spatially heterogeneous, varying from country to country due to various socio-economic factors (e.g., country's economy, technology development, national policy, etc.), but this has not been adequately examined yet.

The UN Sustainable Development Report 2021 (Sachs et al., 2021) conducted quantitative assessment indicating the adverse impacts on various sectors of SDGs such as rising poverty rates (Goal 1) and economic recession (Goal 8). However, many of the indicators used were obtained prior to COVID-19, highlighting the need for further updates depending on the data availability and timeliness (Sachs et al., 2021).

Furthermore, it has been pointed out that the current SDG indicators developed by the Inter-agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs), while comprehensive, are not sufficient to assess the real situation in some aspects of sustainable development. For example, environment-related indicators used in the SDGs could not necessarily reflect the actual situation of biodiversity conservation (Zeng et al., 2020). Therefore, Zeng et al. (2020) highlight the importance of adopting proxy indicators in order to truly assess the actual environmental and economic situation in the SDGs framework. Likewise, Xie et al. (2020) used data extracted from the Multi-Regional Input-Output (MRIO) as a proxy indicator for the SDGs target to assess the impact of international trade on the SDGs progress. Thus, there is a need to unify SDG database from multiple sources to offer a reliable and accurate representation of SDG interactions (Warchold et al., 2022).

Hence, the aim of this study is to serve the first quantitative inference of the multifaceted impacts of the pandemic on all 17 SDGs on a global scale, by synthesizing the most recent data available from grey literature (e.g., United Nations [UN] reports) and peer-reviewed publications as comprehensive as possible and then linking these data with SDG targets. Then, we adopted the emerging methodology to quantitatively assess the impact of the COVID-19 pandemic on the SDGs by calculating the effect of pandemic-related proxy indicators on the SDGs scoring to reflect the actual consequence of the pandemic's impact. By following this method, we introduced a country-wise quantitative assessment regarding the impacts of the pandemic on the 17 SDGs in the early stage of the pandemic period. We estimated the most impacted goals and provided the underlying potential reasons. Furthermore, we examined how the income and the region affect the impacts. Moreover, we defined the most affected countries based on calculation of COVID-19 impact score. Additionally, we provided a global assessment of the COVID-19 impact indicator in different stages (i.e., pre-pandemic, peak stage, and pandemic mitigation).

2. Methods

The utilization of some proxy indicators was carried out in this study as a consequence of the unfamiliar and unusual circumstances that all the world has experienced amid the pandemic such as travel restriction, school closure and mask waste. However, the selected COVID-19 impact indicators should not be considered substitutes for the UN official SDGs indicators. The selected indicators serve only to quantitatively infer the impact of the pandemic on the official UN SDGs targets. The same procedure was previously adopted by Lim and Allen (2016) via utilization of 33 proxy health-related indicators, in addition to Zeng et al. (2020) who assessed the quality of environmentally related SDG goals by using proxy indicators. The method was described in detail in the following four steps:

Step 1: Data collection and selection.

The indicators were collected based on the following criteria: i.e., (i) relevance to SDG targets and comparability across countries, (ii) statistical validity, and (iii) availability of trusted data sources (Table S1). Literature based selection was adopted for the COVID-19 impact indicators along with expert judgement by all co-authors, where COVID-19 impact indicators were selected for each of the 17 SDGs (Table S1) and rationale of indicator selection and assigning to corresponding SDG target (Table S2) were carefully addressed by all co-authors from different fields (e.g., water and sanitation, energy, climate, ecology and social science, etc.). Table S2 summarizes the literature explanation

beyond assigning the proxy impact indicator to the corresponding UN SDG target. The selected SDG targets in Table S2 are the targets which have a direct relationship with COVID-19 impact indicators. However, all SDG targets have interconnection relationships among each other (i.e., synergism and/or tradeoff) which should be also considered to figure out indirect relationship. Impact indicators were collected from sources such as grey literature belonging to international organizations (e.g., UN, World Bank, World Health Organization), research institutions (e.g., Oxford University), and peer-reviewed publications (Table S1 and Table S2 in Supplementary Information for the full list of resources and justification for the selection criteria). The collected country-wise COVID-19 impact indicators covered the period from April 2020 to February 2021. Noting that the available timeline scale from 2015 to 2020 of the selected indicators was assigned as the base line while estimating the COVID-19 impact. The list of indicators selected consists of 65 indicators related to the 55 targets of the SDGs, with each goal covered by at least two targets (up to nine targets, Fig. S1a). This unbalanced distribution owing to the lack of data availability. This challenge is also faced with the official UN indicators as highlighted by Ritchie (2018), as we can get 20 of the 27 recent indicators that cover SDG3, while only 2 of the 11 indicators are recently available for SDG5. Nonetheless, the available indicators would still provide a quantitative trend to the performance of each country toward SDGs fulfillment.

Second, we selected 72 countries which have at least 35 indicators. This number was carefully determined based on the balance between the coverage of countries and indicators and represents more than half of the total number of indicators collected and more than two-thirds of the number of indicators for the country with the highest coverage. The representativeness of the selected countries was achieved in terms of income and/or regional categories. In this study, we listed 31 countries in Europe and Central Asia, 10 countries in East Asia and the Pacific, 10 countries in Latin America and the Caribbean, 9 countries in Sub-Saharan Africa, 5 countries in South Asia, 5 countries in the Middle East and North Africa, and 2 countries in North America. Regarding income categories, low-income (LICs), middle-income (MICs), and high-income countries (HICs) account for 9.7%, 43.1%, and 47.2%, respectively. Based on the world bank database, the number of LICs, MICs and HICs in 2022 was 28 (12.9%), 108 (49.8%) and 81 (37.3%), respectively, which is close to the ratios adopted in this study, suggesting a minimized bias on the proportion of different income classes we studied.

Step 2: Normalizing indicators.

The selected indicators were normalized to allow intercomparison at the target and goal levels. The selected indicators have either only positive impact (scale type 1), negative impact (scale type 2), or both positive and negative impact depending on the country's performance (scale type 3). Thus, following three scales were adopted: i.e., 0.0 to 1.0 for scale type 1, -1.0 to 0.0 for scale type 2, and -1.0 to 1.0 for scale type 3. Representative examples of each scale were as follows: i.e., income support (IN3, scale type 1) which captures government interventions to support the reduced income during a pandemic; number of new poor due to the COVID-19 pandemic; and people in need (IN2, scale type 3), where a change in this indicator in positive direction shows a positive impact toward achieving the corresponding targets while a change in negative direction indicates the opposite. As described in equation below (Zeng et al., 2020), the absolute values for these indices were normalized from 0 to 1.0, where the 97.5th percentile or higher was set as the maximum value of 1.0 and the 2.5th percentile or lower as the minimum value of 0 to eliminate extreme values such as outlier (Xu et al., 2020): i.e.,

$$|x'| = \frac{|x| - \min(|x|)}{\max(|x|) - \min(|x|)}$$

where x' is the normalized value of the specific indicator x for the country examined, $\min(x)$ is the lower bound (i.e., 2.5th percentile), and $\max(x)$ is the upper bound (i.e., 97.5th percentile). Then, negative sign was reassigned for scale type 2. In case of scale type 3, normalization was performed by separating positive and negative values and all normalized indicators were then aggregated by reassigning positive or negative sign. The normalized indicators are based on the 'Champion area' approach, where the top or bottom performers among the countries selected were identified by 1 and -1, and the performance of the remaining countries take values in the range between -1 and 1. This approach is especially practical in case that the upper or lower bounds for each indicator cannot be determined independently due to the lack of available data and has proven feasible previously such as by United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) (Bidarbakhhtnia, 2020).

Step 3: Aggregating the normalized indicators.

The quantitative impact of COVID-19 on each of the 17 goals was assumed to be reasonably represented by the arithmetic mean (average) of the corresponding normalized targets. As shown in Fig. 1, the impact on each goal for a specific country (referred to as impact score) is the average of normalized COVID-19 impact indicators assigned to this goal in this country. In addition, we calculated the impact of COVID-19 in regional, continental, income category and global levels, in which COVID-19 impact in region scale (average scores of the countries in specific region), COVID-19 impact in continental scale (average scores of the countries in specific continent), COVID-19 impact for income category (average scores of the countries in specific income category), global goal score (average scores of all studied countries in this goal) and global overall score (average scores of the 17 global goals). The use of arithmetic means for score calculation was described in the SDGs report 2020 (Sachs et al., 2020). Equal weighting for indicators and goals is considered reasonable, given that all SDG targets and goals are equally important as part of the 2030 Agenda (Xu et al., 2020).

Step 4: Clustering analysis.

Cluster analysis was used to figure out countries with similar performance and the relationship between them in terms of the selected indicators. The similarity was represented by the spearman's rank correlation (r_s) between any two countries based on their performance in the COVID-19 impact indicators to generate a correlation matrix as presented in Fig. 1. Spearman correlation was utilized owing to the monotonic relationship between the performance of different countries. Then, a dendrogram was developed based on the correlation matrix to describe the similarity (i.e., r_s) of COVID-19 impact in each country (Fig. S2). Countries were clustered by the complete linkage method and countries with a shorter distance suggest that they share a similar response to COVID-19 (in terms of changes in indicators).

2.1. Dashboard

The dashboard is provided as the supplementary material, which may support policymakers and stakeholders to assess the most affected targets and goals and to build their own recovery plans (Dataset S1).

3. Results and discussion

3.1. Overview of the impact of COVID-19 pandemic on Sustainable Development Goals

Our data collection and screening resulted in 65 proxy indicators that cover all 17 SDGs across 72 countries (Table S1 and Dataset S1). We normalized each indicator ranging from -1.0 to 1.0 across the countries

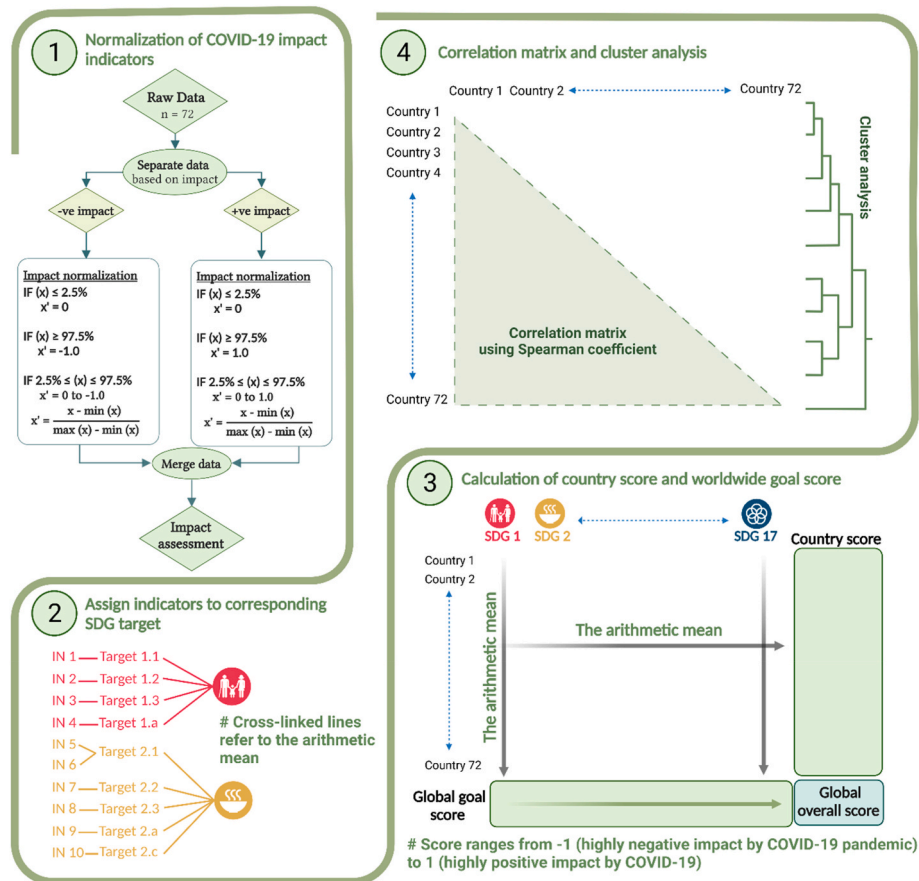


Fig. 1. Steps for the quantitative assessment of COVID-19 impacts on SDGs.

and allocated them to the corresponding goals and targets. Importantly, the indicators we collected do not necessarily represent the conclusion of COVID-19 pandemic impacts; rather, they indicate the impacts noticeable and quantifiable at a relatively early stage of the pandemic (i.e., from April 2020 to February 2021). Thus, the following results should be interpreted as the most comprehensive but not definitive assessment of the quantified impacts to date (see Methods for further details).

Taking an average of the corresponding target scores for each goal over the 72 countries, 9 out of 17 goals showed negative scores in the global average (Fig. 2a). ‘Gender equality (Goal 5)’ and ‘decent work and economic growth (Goal 8)’ were estimated to be the most negatively

impacted goals (global impact scores of -0.375 and -0.283 , respectively), mainly because almost all the selected countries showed negative scores (Fig. 2b). Two-thirds of the countries studied were adversely affected in terms of ‘affordable and clean energy (Goal 7)’, ‘sustainable cities and communities (Goal 11)’, and ‘responsible consumption and production (Goal 12)’ with global impact scores ranging from -0.222 to -0.159 .

Using a clustering analysis based on the dissimilarity matrix from the 65 normalized indicators (see Methods), we found that income is a strong variable to differentiate the responses to the COVID-19. High-income countries (HICs) in Europe and Central Asia, North America, and

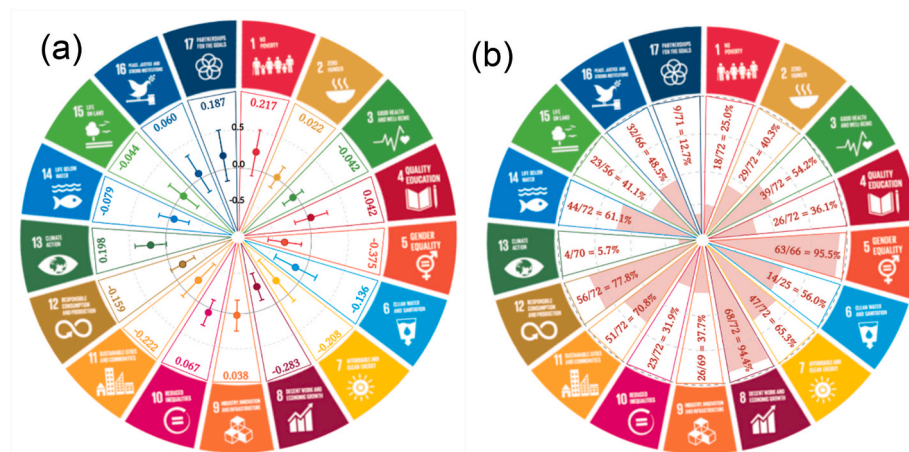


Fig. 2. A global synthesis of the current perceivable, globally quantifiable impacts of COVID-19. (a) The impact of COVID-19 pandemic on 17 goals. The error bars represent standard deviation of each goal. (b) Proportion of countries negatively impacted by COVID-19 pandemic on each goal.

East Asia and the Pacific (Cluster 2 and 4 in Fig. 3) showed positive responses, particularly on Goals 1, 7, 13, and 15, but faced challenges in Goals 5 and 8. In contrast, Clusters 1 and 5 encompass many of the low- and middle-income countries (LICs and MICs) in Latin America, Sub-Saharan Africa, the Middle East and North Africa, and South Asia, including the worst-performing bottom five countries. These countries severely worsened Goals 7, 11, 12 and 14 in addition to Goals 5 and 8, indicating that all low-, middle- and high-income countries were unable to cope with the impact on Goals 5 and 8. Furthermore, the lower incomes showed more negative scores in many goals, and the number of negatively impacted goals increased as income levels declined (e.g., 4, 11 and 14 goals for high-, middle- and low-income countries, respectively, Fig. 3). In Sub-Saharan Africa, 13 goals were adversely impacted, which was much higher than 5 goals being negative in the Europe and Central Asia (Table S3). Fig. 4 revealed the continental COVID-19 impact on SDGs, higher negative goals were assigned to Africa, Latin America and Asia. On the other hand, low negative impacts of COVID-19 were allocated in North America, Oceania and Europe, respectively.

There was a strong and significant correlation between the SDG overall score reported by UN and the overall impact score determined in this study (i.e., Spearman's rank correlation coefficient $r_s = 0.78$ and $p = 1.1 \times 10^{-16}$, Fig. 5). Clearly, countries with the UN SDG overall scores of 80% or higher were performed better in our analysis. On the other hand, countries with the UN SDG overall scores below 70% (particularly for LICs and MICs) were negatively scored. The result underscores the importance of past SDGs progress prior to the onset of COVID-19 in building social resilience against pandemics and is consistent with the notion that steering toward a more just and sustainable society is a preventive measure to avoid social, economic and environmental disruptions in the pandemic situation. This agreed with Bhowmick (2021) who suggested that the countries with high SDGs fulfillment were able to efficiently alleviate the impacts of the pandemic because of better infrastructure, higher living standard, stable economy, better labor market, zero poverty and hunger, and robust health and education systems.

3.2. Major impacts on Sustainable Development Goals

This section describes the main results for the goals with large negative scores (i.e., gender, energy, economy, sustainable cities, consumption and production) as well as health and poverty, which are considered other important victims of the pandemic (Nerini et al., 2020). A full description on the results of pandemic's impact on all goals can be found in Supplementary Information.

Health. The severity of the pandemic with respect to health-related goal (i.e., Goal 3: good health and well-being) was quantified by nine proxy indicators, and the global impact for this goal was determined to be -0.042 (Fig. 2a). The global average was negative only slightly, but many of the selected countries (54.2%) showed negative scores, as is evident from its large deviation among countries (Fig. 2b). Many of LICs and MICs struggled with this goal, recording relatively large negative impact scores (-0.126 and -0.149 , respectively, Fig. 6).

Among the selected indicators, negative scores were found for indicators such as child mortality (global impact score of -0.120 for Target 3.2), infection (-0.336 for Target 3.3), mental health (-0.252 for Target 3.4), postponement of vaccination campaigns for other diseases (-0.725 for Target 3.8) and mask waste (-0.560 for Target 3.9), respectively (Table S3). The results can be reinforced by literature. For example, the number of COVID-19 infections has reached 230 million by September 2021, and the number of fatalities was 4.7 million (World Health Organization, 2021). As a result, health care systems in many countries are on the verge of collapse or have already collapsed. Furthermore, even though COVID-19 is a physical disease, the policies implemented to prevent its spread (such as social distancing) can affect mental health, which is already evident from the increase in the number of suicides during the SARS epidemic in 2003 ("Keep mental health in

mind," 2020). In addition, the health care system is overburdened, and care for other diseases is inadequate (e.g., postponement of malaria vaccination campaigns in sub-Saharan Africa) (Sherrard-Smith and Hogan, 2020). Masks are an important shield to protect us from infectious diseases, but if accumulated mask waste is mishandled, it can cause significant long-term damage to the environment, especially in densely populated areas (such as South Asia) (Waste Management during the COVID-19 Pandemic, 2020).

While COVID-19 is a health-related pandemic, the global impact on Goal 3 was calculated to be relatively marginal (i.e., -0.042). This is because negative impacts were alleviated by other positive indicators such as reduced traffic accidents (global impact score of 0.379 for Target 3.6), air quality (0.248 for Target 3.9), medicine research (0.181 for Target 3.b) and health funds (0.240 for Target 3.c) (Table S3). For example, mobility restriction due to pandemic led to a reduction of traffic accidents (e.g., a 62.9% reduction in mobility in the province of Tarragona, Spain, during COVID-19 lockdown led to a 74.3% reduction in traffic accidents (Saladié et al., 2020)). Another positive effect of the lockdown policy has been a reduction in air pollutants such as particulate matter (PM), NO_2 , and SO_2 (He et al., 2020). In addition, government funds have been invested in strengthening the health and medical sectors against COVID-19 infection and medical research has been intensified to develop treatments, therapies and vaccines for SARS-CoV-2 (International Monetary Fund, 2020).

In regional scale, Latin America and Caribbean region showed the worst performance with a negative score of -0.204 at the end of May 2020. Among them, Brazil (-0.395) and Argentina (-0.383) performed the worst, with negative scores in health-related indicators such as the number of infected cases, mental health, and high mask waste, as well as delays in vaccination campaigns for other diseases (and tobacco production in case of Brazil) (Dataset S1). Most parks in Latin America have been closed (Brazil, Peru, Colombia, Chile, etc.) (Cortinez-O'Ryan et al., 2020). Furthermore, due to COVID-19, there was a $\sim 14\%$ shortage of child immunizations (including diphtheria, tetanus, and pertussis vaccine (DTP3)) in Latin America and the Caribbean, especially in Brazil, Bolivia, Haiti, and Venezuela (Sidhu and Abad-Vergara, 2020).

Gender. In our analysis, gender equality (Goal 5) received the lowest global impact score (-0.375) and the largest proportion of countries examined (95.5%) were negatively impacted. In this goal, four indicators for three targets were selected to represent the prevalence of gender inequality during the pandemic: i.e., female mortality by COVID-19 (Target 5.1), female nurses and midwives (Target 5.1), violence against women (Target 5.2) and more responsibility at home (Target 5.4), and all these indicators showed negative impact at global scale (e.g., global impact scores of -0.288 , -0.658 , -0.170 and -0.431 , respectively, Table S3). The adverse impact on LICs (impact score of -0.271 for Goal 5) was seen due to the increased household workload (-0.712 for Target 5.4) and women working in the health sector (-0.479 for Target 5.1). HICs had also negative scores for the same indicators (i.e., -0.060 and -0.789 , respectively) in addition to the COVID-19 female mortality rate (-0.430 for Target 5.1), resulting in impact score of -0.357 on Goal 5. Gender equality was most severely affected in MICs (impact score of -0.420), where all four indicators also showed negative scores. However, there was no statistical significance at all income levels, underscoring the global concern (Fig. 6).

Being on the front lines of COVID-19 control, women are at a higher risk of contracting the virus, as $\sim 70\%$ of healthcare workers (e.g., 85% of nurses and 50% of physicians) are women, and this proportion is high in developed countries (Rivera et al., 2020). According to the data collected in this study, the impact score for female nurses and midwives in HICs (-0.789) was lower than MICs and LICs (e.g., -0.609 and -0.479 , respectively) (UN women, 2020b). Furthermore, recent UNDP brief highlighted the increase in the number of women subjected to domestic violence since the onset of the pandemic (e.g., 30% in France and 25% in Argentina) (UNDP, 2020a). The number of fatalities due to domestic abuse against women during the pandemic doubled the

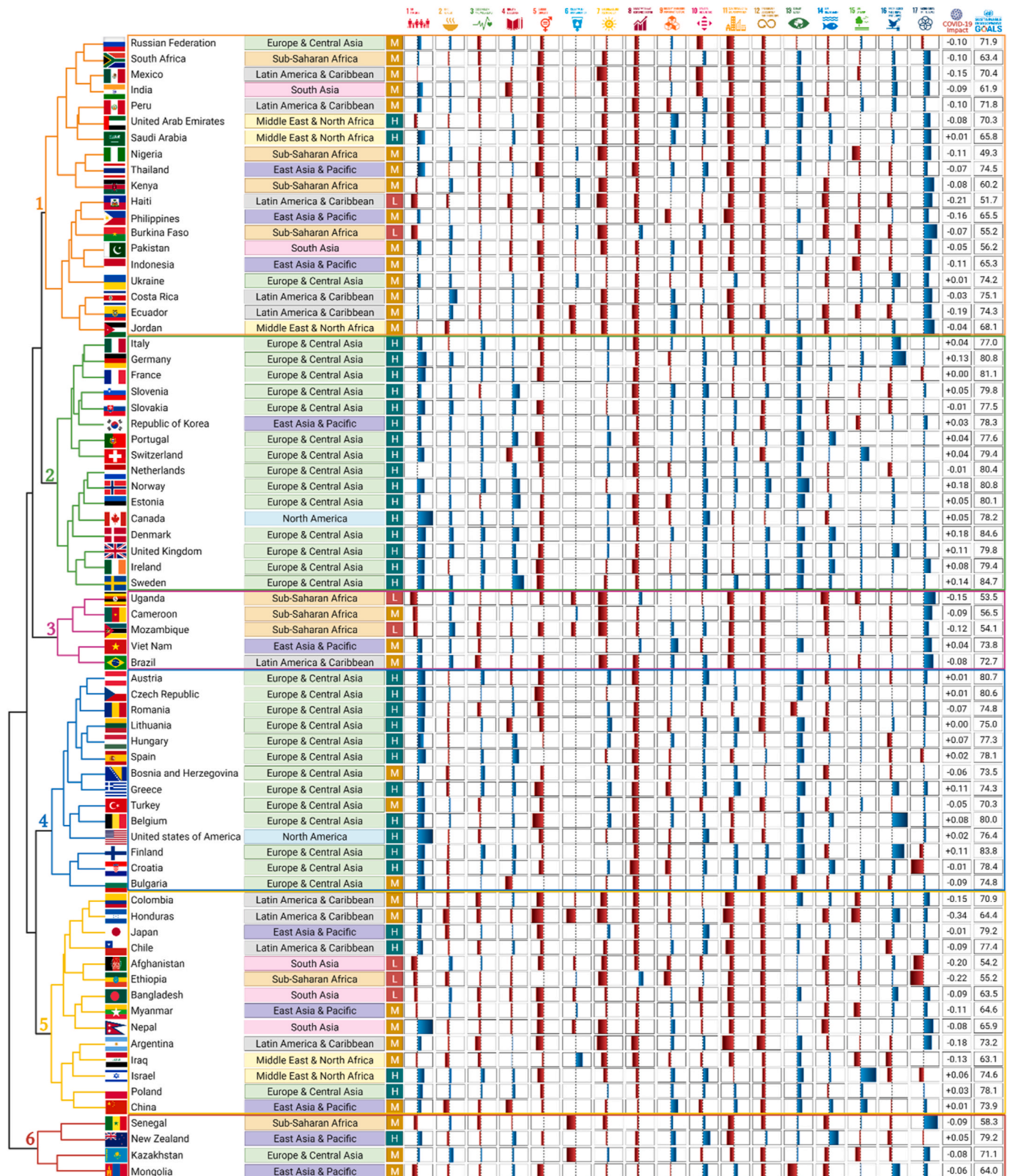


Fig. 3. Clustering analysis based on Spearman's rank correlation for 65 indicators between any two countries. Country clusters representing similarity in terms of response to COVID-19 impact were shown with the region, income category and the country performance (overall impact score) during the COVID-19 pandemic. The length of the bar indicates the relative magnitude of the goal impact. Blue bar shows positive score, while red bar for negative score. Regarding the income category, H, M and L represent high-, middle- and low-income levels, respectively. The number inserted in dendrogram shows cluster number.

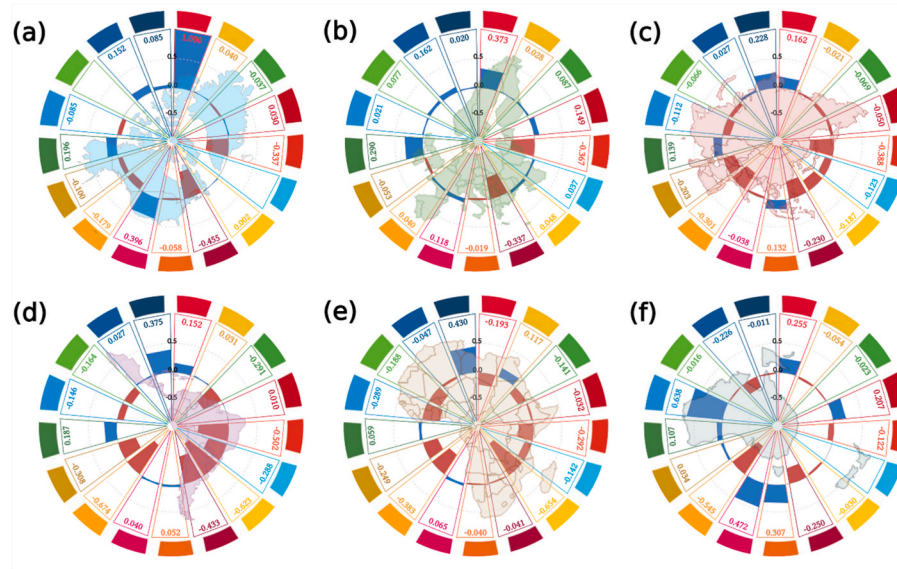


Fig. 4. Continental COVID-19 impact on SDGs (a) North America, (b) Europe, (c) Asia, (d) Latin America, (e) Africa and (f) Oceania.

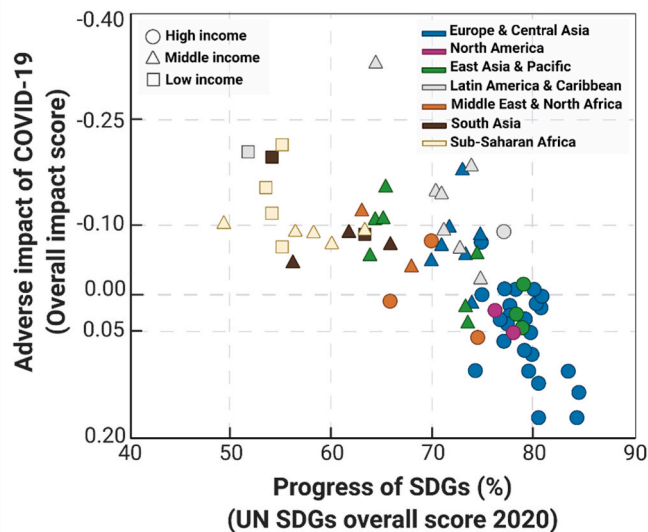


Fig. 5. Relationship between the SDGs overall score for each country (reported by UN in 2020, horizontal axis) and the impact of the COVID-19 pandemic on the SDGs (overall impact score as determined in this study, vertical axis). The plots are also categorized by region and income level. Note that Spearman's rank correlation coefficient (r_s) = 0.78 and $p = 1.1 \times 10^{-16}$ for all dataset (Dataset S1), $r_s = 0.44$ and $p = 0.009$ for HICs, $r_s = 0.24$ and $p = 0.20$ for MICs, and $r_s = 0.29$ and $p = 0.54$ for LICs. The UN SDGs overall scores are shown in Table S4. Also note that the UN SDG overall score for a specific country is the arithmetic mean of the country scores in goals from 1 to 17.

average of the past 10 years in the U.K. (Roesch et al., 2020). In addition, the closure of schools has increased women's workload at home (e.g., homeschooling and childcare) and limited their work such as academic activities. For example, during the pandemic, the number of papers published by male researchers increased from 68.3 to 73.4%, while the number declined from 31.7 to 26.6% for female researchers (Inno et al., 2020).

By region, the high impact was seen in South Asia and Latin America and the Caribbean (Fig. 4) with score of -0.495 and -0.452 respectively, and Bangladesh and Honduras were the most affected countries (Dataset S1). This is in line with the recent UN Women's report which

stated that in the Bangladeshi health system, 94% of the staff are female nurses and midwives, and that even before the crisis, women were 3.4 times more likely than men to be burdened with unpaid care work ("COVID-19 Bangladesh 2020: Rapid Gender Analysis,"). Furthermore, in Bangladesh, violence against women during the pandemic was 51–69% worse in March–April 2020 compared to the same period in 2019 (UNDP, 2020b).

Poverty and Economy. Regarding the impact of the COVID-19 pandemic on poverty (Goal 1), our analysis indicated that the LICs faced major challenges in terms of the number of new poor (impact score of -0.500 for Target 1.1), people in need (-0.346 for Target 1.2) and funding needed to confront COVID-19 (-0.396 for Target 1.a) (Table S3). The impact on this goal was found to be more severe, as income levels declined (e.g., -0.316 for LICs, Fig. 6). Even before the advent of COVID-19, 60% of the world's poor (433 million people) were in sub-Saharan Africa, where the majority of LICs are located (Bank, 2020). However, the United Nations Industrial Development Organization (UNIDO) noted that COVID-19 newly generated 22.6 million people falling into extreme poverty in sub-Saharan Africa (Cantore et al., 2020). Mitigating the impact of pandemic on poverty is subjected to the ability to financially support vulnerable populations, as in well-financed countries (e.g., MICs and HICs scored 0.432 and 0.851 for Target 1.3 [income support], respectively). By country, Haiti, Burkina Faso, Uganda, and Afghanistan had the worst impact on poverty in the Latin America and Caribbean, Sub-Saharan Africa, and South Asia regions, respectively (Dataset S1). Egger and Miguel (2021) conducted household surveys in nine countries in these regions and found a 68% (median) drop in income and insufficient government assistance to cover the losses and maintain the same standard of living as before the pandemic.

As for Economy (Goal 8), developed and emerging countries were sluggish during the pandemic, exacerbating progress on this goal. The selected indicators showed all negative scores (e.g., -0.437 for GDP [Target 8.1], -0.357 for reduced working hours [Target 8.5], -0.065 for unemployment rate [Target 8.5] and -0.181 for tourism expenditure [Target 8.9], Table S3), resulting in an adverse impact in almost all selected countries (94.4% of countries) with a global impact score of -0.283 for Goal 8 (Fig. 2). By income category, HICs were most severely affected (impact score of -0.326), followed by MICs (-0.292) and LICs (-0.040) (Fig. 6). Developed countries were strongly stressed in terms of GDP (Target 8.1) and tourism (Target 8.9), with impact scores of -0.764 and -0.194 , respectively, which were higher than MICs (-0.304 and -0.174) and LICs (0.304 and -0.133).

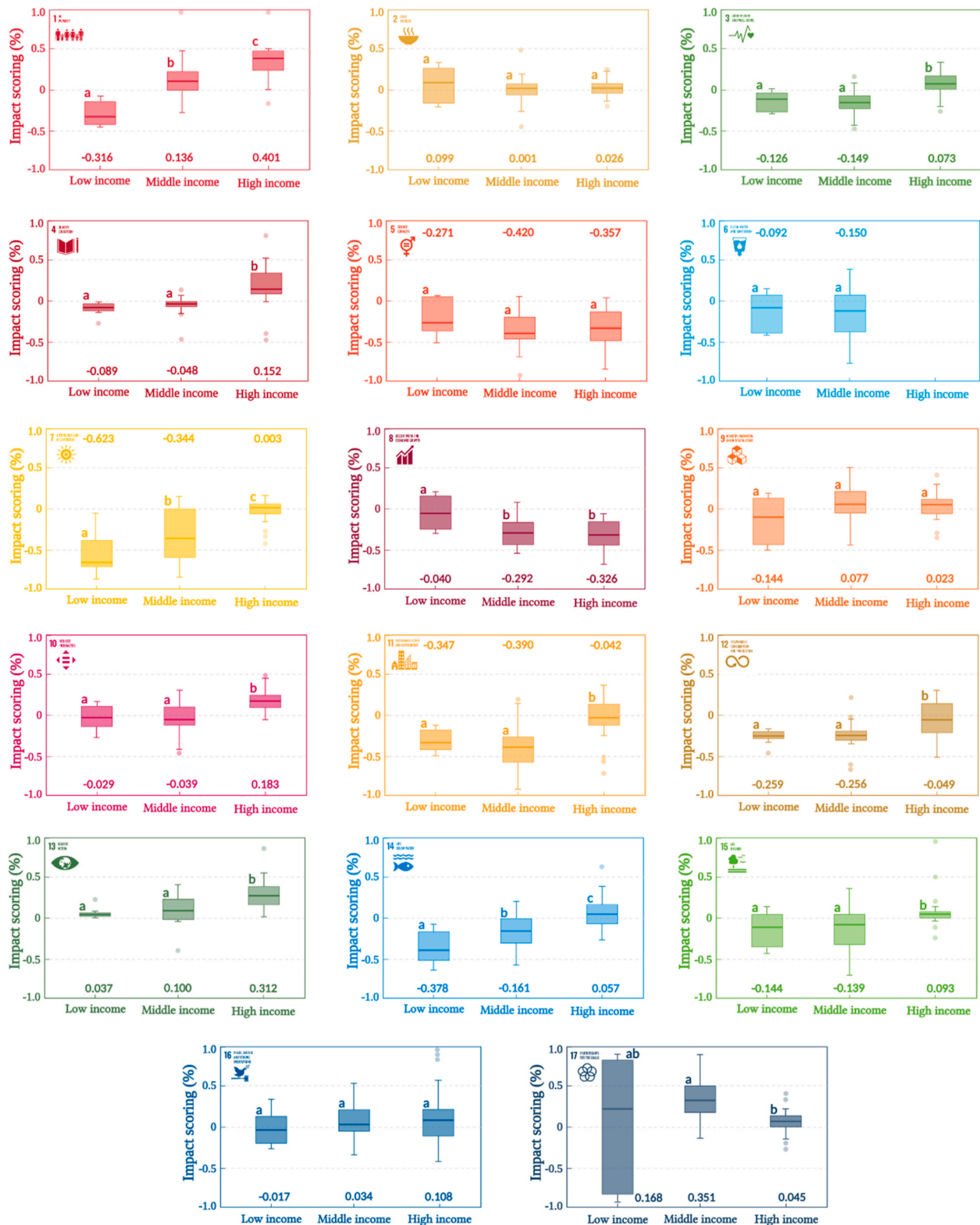


Fig. 6. The impact of COVID-19 on each goal based on income category ($n = 34$ for high-income country, $n = 31$ for middle-income country, and $n = 7$ for low-income country). A box and whisker plot represent the five statistics: i.e., the minimum, first quartile, median, third quartile, and maximum values for each income category. The different alphabets indicate statistically significant differences by income level according to the Tukey's HSD test.

In the G-20 countries, based on a single- or double-hit scenario, GDP was estimated to contract in the range of 5.8–7.3% between December 2019 and April 2020, with employment decline ranging from a low of 8–9% in Japan and Republic of Korea to a maximum of 40% in Mexico (OECD, 2020b). The global economic recession was amplified by the

spread of virus infections in the industrial giants such as China, the U.S., Germany, Japan, and Republic of Korea, the top five exporters with ~38% share of the global market, which disrupted production processes as well as supply chains (World Integrated Trade [Río Castro et al., 2021](#)). Thus, emerging economies that import industrial materials and

products from these countries were also affected, along with a decline in demand (Guan and Wang, 2020). Furthermore, the tourism sector experienced significant economic losses due to travel restrictions and stringent quarantine measures for travelers (UNWTO, 2020).

By region, the largest impacts on SDG 8 were concentrated in North America (impact score of -0.455), Latin America and the Caribbean (-0.430), and Europe and Central Asia (-0.339) (Fig. 4). Among these regions, the United States, Argentina, and Croatia showed the worst performance, with impact scores of -0.439 , -0.543 and -0.705 respectively. On the other hand, the minimal impact of -0.041 was observed in Sub-Saharan Africa (Dataset S1). These results are indeed consistent with UNIDO's recent report, which found that the most affected economies were the developed economies (-7.8%), followed by the emerging and developing economies of Europe and Latin America and the Caribbean (-7.7% and 7.0% , respectively). In contrast, the least affected economies were the emerging and developing economies of Asia (-4.9%) and Sub-Saharan Africa (-5.2%) (Cantore et al., 2020).

Energy. Many countries (65.3%) struggled to make progress on Goal 7 during the pandemic, with global impact score of -0.208 (as determined by the five indicators covering the three targets, Fig. 2). Lower income countries suffered from this goal (Fig. 6), since access to energy services (Target 7.1) and energy efficiency (Target 7.3, representing ratio of energy utilized relative to energy input) showed negative scores, i.e., -0.899 and -0.558 for LICs and -0.455 and -0.425 for MICs, respectively (Table S3). Amid the lockdown period, governments around the world were forced to provide support to the poor and marginalized groups because of reduced income and inability to pay living expenses (e.g., subsidize electricity bills in most of Latin American countries such as Mexico (Luis and Pérez, 2020)). Such financial expense further reduced the ability of countries to invest in their energy sectors including energy efficiency ("Global Energy Review, 2020," 2020), which is the major reason behind the adverse impact on Goal 7 in middle and low-income countries. The International Energy Agency (IEA) estimated that investment in the energy sector declined by 18.3% in 2020 (Oxford Business Group, 2020), which prevent the development of energy infrastructure (e.g., 600 million people in Africa already lack access to electricity even before the pandemic) (Irerri and Mathai, 2021).

For HICs, the overall impact was relatively small due to improvement of renewable energy (Target 7.2) including increase in solar and wind energy for power generation. Our analysis showed that the indicator for wind and solar share (IN 37) scored 0.142 for HICs and 0.125 for MICs (Table S3), though some countries have seen a decline in this market (e.g., Austria, Portugal and Spain) (Carbon Brief, 2020). European countries have been increasingly dependent on wind and solar energy for electricity demand in 2020, accounting for 23% of total production (Carbon Brief, 2020). The solar energy market needs to grow at an annual rate of 13% in order to achieve Target 7.2, but due to the COVID-19 pandemic, the market in the first half of 2020 declined by 26% compared to 2019, with South Asia recording the largest decline by 60% (GOGLA, 2019).

By region, Sub-Saharan Africa (e.g., Burkina Faso, Cameroon, Ethiopia), Latin America and the Caribbean (e.g., Argentina, Haiti, Honduras, Mexico), and South Asia (e.g., Nepal) had the lowest SDG 7 scores of -0.654 , -0.650 , and -0.420 , respectively (Dataset S1). Amid the closure period, governments were forced to provide support to the poor and marginalized groups because of reduced income and inability to pay living expenses (e.g., electricity bills in most of Latin American countries such as Mexico (Luis and Pérez, 2020)). Likewise, in the sub-Saharan Africa region, the reduction in energy demand (in large part due to issues of access and affordability) ranged from 4 to 15%, and also some countries were forced to waive electricity bills to support their citizens during the pandemic, which significantly reduced the funds available to expand and improve electricity infrastructure (Boulle and Dane, 2020).

Sustainable Cities, Consumption and Production. Goal 11 for sustainable cities and communities faced major challenge during the pandemic

where 70.8% of countries were negatively impacted, resulting in global impact score of -0.222 (as determined by the six indicators, Fig. 2). The negative impacts were related to the increasing medical solid waste such as masks (impact score of -0.560 for Target 11.6) as well as decrease in the number of passengers and users of transportation (-0.394 for Target 11.2), and closure of parks (-0.042 for Target 11.2) (Table S3). MICs and LICs were substantially affected with impact scores of -0.390 and -0.347 for Goal 11 (Fig. 6), respectively, and major driver was the increase in mask waste (impact scores were -0.500 for LICs and -0.699 for MICs, compared to -0.439 for HICs, Table S3). By region, Latin America and the Caribbean performed the worst (score of -0.644), followed by Sub-Saharan Africa (score of -0.383), with Argentina and South Africa performing the worst in these regions (Dataset S1).

The global production of mask industry augmented from 0.79 to 166 billion USD from 2019 to 2020, producing ~ 52 billion masks by the end of 2020. The increased production of masks can be also a trade-off for the health of the oceans (Goal 14), with a recent report estimating that $\sim 3\%$ of the masks produced end up in the ocean, causing 4680 to 6240 tons of plastic pollution (Bondaroff and Sam, 2020). Additionally, the unprecedented measures taken during the pandemic coupled with social distancing policy implementation had a significant impact on sustainable transportation systems, which rely primarily on public and shared mobility (Diao et al., 2021). The impact to this goal was slightly alleviated via improvement of air quality and utilization of urban green and public spaces (Table S3). Undoubtedly, green spaces served as social buffer in many countries, absorbing the stress from restrictions on social interaction due to lockdown policies (del Río Castro et al., 2021; Xie et al., 2020).

Goal 12 for responsible consumption and production was worsened substantially in 77.8% of countries with global impact score of -0.159 (based on the three indicators spanning 3 targets), not only by drastic increase in mask waste (impact score at -0.560), but also by the inflation in Consumer Price Index (CPI, impact score at -0.032), which represents the cost of goods and services consumed by households (Fig. 2 and Table S3). About 68% of the countries covered in this study were found to face an increase in household expenses with significant impact in LICs (impact score of -0.215) followed by MICs (impact score of -0.068) (Fig. 6). A recent UN report warned that the CPI has been rising since the outbreak of the pandemic, increasing the risk of inflation in LICs and MICs (UN, 2020). Prices for food and medical supplies rose substantially during the pandemic due to panic buying of critical commodities such as food and drugs (e.g., in Latin America) (Ebrahimy et al., 2020). Also, McKee and Stuckler (2020) indicated that as the duration of the pandemic extend, people particularly in LICs and MICs will become economically insecure (such as income, housing and food), which in turn can deteriorate their mental health (i.e., Goal 3). In terms of the regional impact, there was a large negative impact in Latin America and the Caribbean (score of -0.322), followed by Sub-Saharan Africa (-0.249) and South Asia (-0.246). Food and medical prices rose substantially during the pandemic, likely due to panic buying of critical commodities such as food and medical supplies (especially in Latin America) (Ebrahimy et al., 2020).

3.3. Qualitative and quantitative views

Qualitative assessments of the impact of COVID-19 on the achievement of the SDGs have been intensively studied so far, yielding common and mixed views on the affected goals. In the 2020 UN report (Sachs et al., 2020), for example, the impact of the pandemic was classified as 'still unclear' for Goals 12, 13, 14 and 15, 'mixed or moderately negative' for Goals 4, 5, 6, 7, 9, 11, 16 and 17 and 'highly negative' for Goals 1, 2, 3, 8 and 10. Another study suggested that about two-thirds of the targets are either fully or partially threatened (e.g., Goals 4, 5, 6, 7, 8, 10, 11, 12, 14, 16 and 17), and that if some of the targets are well implemented before the pandemic, their impacts could be minimized (e.g., Goals 1, 3 and 15); otherwise the pandemic impact could exacerbate

their achievement (Naidoo and Fisher, 2020). Fuso Nerini et al. (2020) indicated that while most of targets (90%) are negatively impacted, there is an opportunity to move forward for some targets during the pandemic (40%). More recent qualitative study has shown that Goals 3, 4, 8, 12 and 13 are not only worsened, but also have spillover impacts that potentially hinder the achievement of other goals (e.g., Goals 5, 9, 10, 11 and 17) (Shulla et al., 2021). While there are some differences among these studies, they all agree that the poor, vulnerable and marginalized people are the most affected groups during the pandemic (Naidoo and Fisher, 2020; Nerini et al., 2020; Sachs et al., 2020; Shulla et al., 2021). Another qualitative evaluation for the interconnectedness between COVID-19 pandemic and SGDs performed by (Shulla et al., 2021). The study discovered spillover with negative impacts being noticed in SDGs 5, 9, 11 and 17. Also, Flor and Friedman, (2022) highlighted the magnification of gender inequality amid the pandemic via a range of observations (e.g., 26% of women lost their job compared with 20.4% for men, girls dropped out of school 1.21 higher than boys and women subjected to violence 1.23 higher than men). More recently, the UN SDGs report 2021 (Sachs et al., 2021) was released, indicating that Goal 1 has deteriorated due to the increasing poverty rates particularly in Sub-Saharan Africa. In addition, the economic recession has worsened progress on Goal 8. There were also negative impacts on Goals 4 and 5. As for the climate goal (Goal 13), the temporary positive effect of reducing CO₂ emissions in developed countries (such as North America) has been emphasized. However, due to the limited data available and the timeliness of the data sources, the report points out that the assessment needs to be updated periodically. The UN Department of Economic and Social Affairs noted that the pandemic has a

devastating impact on all the goals, and therefore increased investments in data collection are required to estimate the magnitude of the pandemic impact for response preparedness and support SDGs progress (Min and Perucci, 2020).

From the quantitative analysis in this study, we found some similarities with previous qualitative views. For example, our study showed that most of the targets and goals were negatively impacted, but some were positive (Nerini et al., 2020). Also, countries that had made sufficient progress on SDGs before the pandemic were capable of mitigating or adapting to the severe impacts of the pandemic (Naidoo and Fisher, 2020). Our quantitative study, further, delved deeper into country-specific data to determine the magnitude and extent of a pandemic's impact, and found that the impact of COVID-19 pandemic on the SDGs represents a multidimensional nexus across social, economic, environmental, and spatial dimensions. Goal 5 and Goal 8 were identified as major global challenges, and LICs including sub-Saharan Africa were shown to struggle with many additional goals. Such findings provide insights to reinforce existing recovery policies such as protection of vulnerable groups and transition to a green economy (OECD, 2020a). Overall, our findings form the basis for a quantitative discussion on the global spread of the pandemic's impact and sectors that need to be prioritized.

3.4. Global performance after mitigating the pandemic impacts

Major challenges that faced the international community at the beginning of the pandemic in 2020 began to diminish gradually in the subsequent years. As depicted from Table 1, though infected cases with

Table 1
Global alteration of some indicators with pandemic mitigation from 2019 to 2022.

Goal No.	Indicator	2019	2020	2021	2022	Unit	Reference
Goal 1	Number of new poor	641	714	684	657	Million people	Mahler et al. (2022)
Goal 2	Food production	20,949	21,669	21,826	19,408	million ton	UNIDO (2022)
Goal 2	Food price index	95.6	99	125	147		FAO (2022)
Goal 3	Infected cases by COVID-19	–	82,939,207	204,189,665	261,861,222	Capita	WHO (2022)
	Death by COVID-19	–	1,928,500	3,521,399	891,738	Capita	WHO (2022)
Goal 3	COVID-19 Vaccination	–	–	19,690	1.2 × 10 ¹⁰	Doses	WHO (2022)
Goal 4	Number of students affected by school closure	–	888	405	N.A.	Million children	UNICEF (2022)
Goal 5	Global Gender Equality Index	68.6	68.0	70.4	N.A.		World Population Review (2022)
Goal 6	Water supply; sewerage, waste management	13,541	13,413	14,274	11,552	Million people	UNIDO (2022)
Goal 7	Renewable net capacity additions	192	277	294	N.A.	GW	IEA (2021)
Goal 8	GDP growth (annual %)	2.6	–3.3	5.8	N.A.	%	World Bank (2022)
	Change in workplaces visits	N.A.	–16.4	–4.8	12.2	%	Google Mobility (2022)
	Working hours lost due to the COVID-19 crisis	–	8.6	3.9	N.A.	%	ILOSTAT (2022)
	Unemployment rate	9.9	11.4	11.4	11.0	%	ILOSTAT (2022)
Goal 9	Total manufacturing	25,312	25,024	25,845	22,435	Million people	UNIDO (2022)
	Industry research	6185	7324	9449	7368	Manuscript	ScienceDirect (2022)
Goal 10	Entry restrictions	–	219	228	29	Country	IOM UN Migration (2022)
Goal 11	Change in transit stations visits	N.A.	–38.1	–24.2	–11.4	%	Google Mobility (2022)
	Change in parks visits	N.A.	–35.7	–19.8	–4.5	%	Google Mobility (2022)
	Air pollution (PM10)	25.9	23.9	26.2	29.1	µg/m ³	Air Quality Index Project (2022)
	Air pollution (NO ₂)	8.6	7.2	7.9	9.8	ppb	Air Quality Index Project (2022)
	Air pollution (SO ₂)	3.4	3.6	3.6	4.0	ppb	Air Quality Index Project (2022)
Goal 12	Consumer Price Index (% Change with previous year)	N.A.	7.2	8.9	10.1	%	IMF (2022)
	Mask waste	N.A.	97.6	87.8	41.9	%	IHME (2022)
	SDGs research	2008	2981	4527	3850	Manuscript	ScienceDirect (2022)
Goal 13	Change in fossil CO ₂ emissions	0.7	–5.4	–0.8	N.A.	%	Global Carbon Project (2021)
	Climate publication	50,804	56,831	69,713	53,894	Manuscript	ScienceDirect (2022)
Goal 14	Marine Research	19,191	22,857	27,646	22,643	Manuscript	ScienceDirect (2022)
Goal 15	Forest loss	3.8	4.2	3.8	N.A.	Mha	Global Forest Watch (2022)
Goal 16	Number of fatalities	149,068	132,579	149,383	1096 (July 2022)	Capita	ACLED (2022)
	Number of disorder events	35,240	33,683	37,779	21,540 (July 2022)	Event	ACLED (2022)
Goal 17	Fund from developed countries	325,532	337,609	349,375	N.A.	Million \$US	OCHA (2022)

COVID-19 were almost doubled in the second and third years of the pandemic, mortality rates declined owing to the high vaccination coverages amid this period. Most of proxy COVID-19 impact indicators represent recovery status. More interestingly, Goal 5 and 8, which were under significant stress in the first year, showed a slight enhancement, although concerns still remain to ensure that these goals are in the right way for recovery of pandemic impact. For example, Global gender report (World Economic Forum, 2022) highlighted that the gender gap has been close to 68.1% in 2022. However, we are still far from achieving full parity (132 years to parity compared with 136 years in 2021). The gender gaps in the health, education, economic participation, and political empowerment were reduced by percentages of 95.8, 94.4, 60.3 and 22.0%, respectively. Moreover, based on the Global Economic Prospects, the economic growth is forecasted to be accelerated at some regions such as Middle East and North Africa, South Asia and Sub-Saharan Africa in 2022 (which will be subjected to slow down in 2023). The growth in East Asia and Pacific and Latin America and the Caribbean will be slow in 2022 and slightly increase in 2023. On the other hand, the growth in Europe and Central Asia is forecasted to slow in both 2022 and 2023 (World Bank Group, 2022). It was also noted that international cooperation via funds from developed countries, as well as research and development are continually expanding as listed in Table 1.

On the other hand, concerns were shifted to environmental impacts, where the unregulated return of economic activity can lead to the boosting of pollutants concentrations (e.g., PM10 and NO₂) in the atmosphere, the augmentation of CO₂ emission and forest loss. Worries also must be considered for the fate of mask waste that is, with a lower percentage, but still in use. The Carbon Monitor noticed a strong rebound of emissions in 2021, where global emissions in 2021 were boosted by 4.8% compared with previous year (Davis and Liu, 2022). The major threats nowadays are associated with Goal 1 and 2, since the number of poor is still higher than pre-pandemic conditions and the food price is unprecedentedly increasing. These threats increase the burdens of the poor and marginalized groups to cover their basic needs for living (Mahler et al., 2022). Moreover, in Goal 16, based on the Armed Conflict Location & Event Data (ACLED), a sharp increase was observed in the number of civilian deaths and civilian targeting events as a result of political violence in 2021 and 2022 (ACLED, 2022).

New policies for better recovery must prioritize care for the poor and marginal groups. Most of these marginal groups are located in Latin America and Caribbean, South Asia, and Sub-Saharan Africa regions. Prioritized recovery can be accomplished via international cooperation and financial support. The IMF estimates that a financial package of US \$200 billion will be needed to mitigate the impact of the pandemic on LICs. Such financial support should be provided with a view to providing a better economic environment, improving governance, and enhancing domestic revenue mobilization (Chabert et al., 2021). In addition, strengthening international cooperation in the field of research will also be a pillar of the recovery plan (Editorials, 2021). Moreover, green economy must be adopted. A recent report released by the Organization for Economic Co-operation and Development (OECD) highlighted the importance of developing a tariff system to incentivize green investments which will provide more green jobs and strengthen GDP (OECD, 2020a). Moreover, the pandemic emphasized on the demand for more robust and resilient supply chains, which will lead to shorter, more flexible, and adaptable supply chains with fewer tiers (Fonseca and Azevedo, 2020).

4. Conclusions

Our data-driven analysis indicated that adverse impacts of the pandemic have been particularly concerned on Goal 5, 7, 8, 11, and 12. In addition, country income level was a variable that strongly differentiated the responses to the pandemic (e.g., lower incomes had more negative impacts), but Goals 5 and 8 were highly impacted worldwide

regardless of income status. This demonstrated that the poor class and women were extremely struggling amid this pandemic, raising the question about the past-achievement in goals-related to these groups (i.e., SDGs 1, 5 and 8). Consequently, poor and women need to bear in mind while devising our recovery plan. Interestingly, our analysis revealed that countries already had higher performance in SDGs were less impacted by the pandemic, highlighting the importance of progress on the SDGs in building societal resilience. On the other hand, at the third year of pandemic, COVID-19 impact was likely mitigated in Goals 5 and 8, while Goals 1, 2, 13 and 16 became under stress and needed urgent interventions to relieve the adverse effect. Future work should consider the return of the unregulated economic activity and its impact on environmental goals. In addition, different recovery plan scenarios could be examined under system dynamics with feedback loops to ensure that no goals are indirectly negatively affected.

4.1. Limitations of this study

- 1 The data collection period is from April 2020 to February 2021. Therefore, our analysis focuses on the perceivable and quantifiable changes at the relatively early stage of the pandemic at a country-wise scale. However, for global scale we introduced annual alterations in the COVID-19 impact indicators from pre-pandemic era to peak pandemic impact and finally when the pandemic impact was relieved.
- 2 A low or positive score should not be interpreted as the COVID-19 has a marginal or positive impact on advancing the goal for all the countries. An average score should always be interpreted together with the variability among countries and sectors.
- 3 Of the 65 indicators collected in this analysis, one country has the largest coverage with 49 indicators, followed by three countries with 47 indicators. Even in these top countries, however, the set of indicators are not necessarily identical.
- 4 The numbers of targets to which indicators have been assigned are not evenly distributed along the goals (SI Appendix, Fig. S1), with some goals having 9 targets (e.g., Goal 3) and others having 2 targets (e.g., Goal 4).

CRedit authorship contribution statement

Mohamed Elsamadony: Conceptualization, Methodology, Data curation, Visualization, Writing – original draft. **Manabu Fujii:** Conceptualization, Methodology, Writing – review & editing. **Masahiro Ryo:** Methodology, Writing – review & editing. **Francesco Fuso Nerini:** Methodology, Writing – review & editing. **Kaoru Kakinuma:** Methodology, Writing – review & editing. **Shinjiro Kanae:** Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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