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SDG Final Decade of Action: Resilient Pathways to Build Back Better from High-Impact Low-Probability (HILP) Events

Felix Kwabena Donkor [1,*], Stergios-Aristoteles Mitoulis [2], Sotirios Argyroudis [3,*], Hassan Aboelkhair [4], Juan Antonio Ballesteros Canovas [5], Ahmad Bashir [6], Ginbert Permejo Cuaton [7], Samo Diatta [8], Maral Habibi [9], Daniel Hölbling [10], Lance Manuel [11], Maria Pregnolato [12], Rodrigo Rudge Ramos Ribeiro [13], Athanasios Sfetsos [14], Naeem Shahzad [15] and Christiane Werner [16]

1 College of Agriculture and Environmental Sciences (CAES), University of South Africa (UNISA), Johannesburg 1709, South Africa
2 Department of Civil Engineering, University of Birmingham, Birmingham B15 2TT, UK
3 Department of Civil and Environmental Engineering, Brunel University London, Uxbridge UB8 3PH, UK
4 Department of Geography and Geographical Information Systems, Faculty of Arts, Tanta University, Tanta 31527, Gharbia, Egypt
5 Museo Nacional de Ciencias Naturales, Spanish Research Council (CSIC), 28006 Madrid, Spain
6 Department of Geology, Nawakadal School, Srinagar 190002, India
7 Division of Environment and Sustainability, The Hong Kong University of Science and Technology, Kowloon 999077, Hong Kong SAR, China
8 Laboratory of Ocean, Environment and Climate Science, Department of Physics, Assane SECK University of Ziguinchor, Ziguinchor 27000, Senegal
9 Department of Geography and Regional Science, University of Graz, 8010 Graz, Austria
10 Department of Geoinformatics—Z_GIS, University of Salzburg, 5020 Salzburg, Austria
11 Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, TX 78712, USA
12 Department of Civil Engineering, University of Bristol, Bristol BS8 1TR, UK
13 Getulio Vargas Foundation (FGV), São Paulo 01310-000, Brazil
14 National Center for Scientific Research Demokritos, 15341 Agia Paraskevi, Greece
15 Department Water Resources & Engineering, National University of Sciences & Technology, Islamabad 44000, Pakistan
16 Ecosystem Physiology, University Freiburg, 79110 Freiburg, Germany
* Correspondence: felixdonkor2002@yahoo.co.uk (F.K.D.); sotirios.argyroudis@brunel.ac.uk (S.A.)

Abstract: The 2030 Sustainable Development Goals (SDGs) offer a blueprint for global peace and prosperity, while conserving natural ecosystems and resources for the planet. However, factors such as climate-induced weather extremes and other High-Impact Low-Probability (HILP) events on their own can devastate lives and livelihoods. When a pandemic affects us, as COVID-19 has, any concurrent hazards interacting with it highlight additional challenges to disaster and emergency management worldwide. Such amplified effects contribute to greater societal and environmental risks, with cross-cutting impacts and exposing inequities. Hence, understanding how a pandemic affects the management of concurrent hazards and HILP is vital in disaster risk reduction practice. This study reviews the contemporary literature and utilizes data from the Emergency Events Database (EM-DAT) to unpack how multiple extreme events have interacted with the coronavirus pandemic and affected the progress in achieving the SDGs. This study is especially urgent, given the multi-dimensional societal impacts of the COVID-19 pandemic amidst climate change. Results indicate that mainstreaming risk management into development planning can mitigate the adverse effects of disasters. Successes in addressing compound risks have helped us understand the value of new technologies, such as the use of drones and robots to limit human exposure. Enhancing data collection efforts to enable inclusive sentinel systems can improve surveillance and effective response to future risk challenges. Stay-at-home policies put in place during the pandemic for virus containment have highlighted the need to holistically consider the built environment and socio-economic exigencies when addressing the pandemic's physical and mental health impacts, and could also aid in the context of increasing climate-induced extreme events. As we have seen, such policies, services, and technologies, along with good nutrition, can significantly help safeguard health and well-being in

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pandemic times, especially when simultaneously faced with ubiquitous climate-induced extreme events. In the final decade of SDG actions, these measures may help in efforts to "Leave No One Behind", enhance human–environment relations, and propel society to embrace sustainable policies and lifestyles that facilitate building back better in a post-pandemic world. Concerted actions that directly target the compounding effects of different interacting hazards should be a critical priority of the Sendai Framework by 2030.

Keywords: climate extremes; sustainable development goals; disaster risk reduction; COVID-19; resilience; HILP

1. Introduction

1.1. The Nexus of Sustainable Development and Climate/Extreme Events

Disaster risk reduction (DRR) includes aspects and development sectors related to 25 global targets in 10 of the 17 Sustainable Development Goals (SDGs) [1]. We are already witnessing more extreme events due to climate change. At the same time, projections show an increase in the frequency, severity, and spatial extent of climate extremes by the end of this century [2,3], impeding progress towards sustainability. Effective policies help address the complex challenges posed by disasters. The Sendai Framework for Disaster Risk Reduction thus seeks to support the global community to better manage the compound threats and cross-cutting issues attributed to extreme events [1]. Integrating relevant resilience measures, such as DRR interventions, into development policies can help limit socio-economic risks related to extreme weather and climate events. Such measures facilitating long-term sustainable development in the context of a changing climate (Figures 1 and 2) can become a priority of the Sendai Framework by 2030 [4].

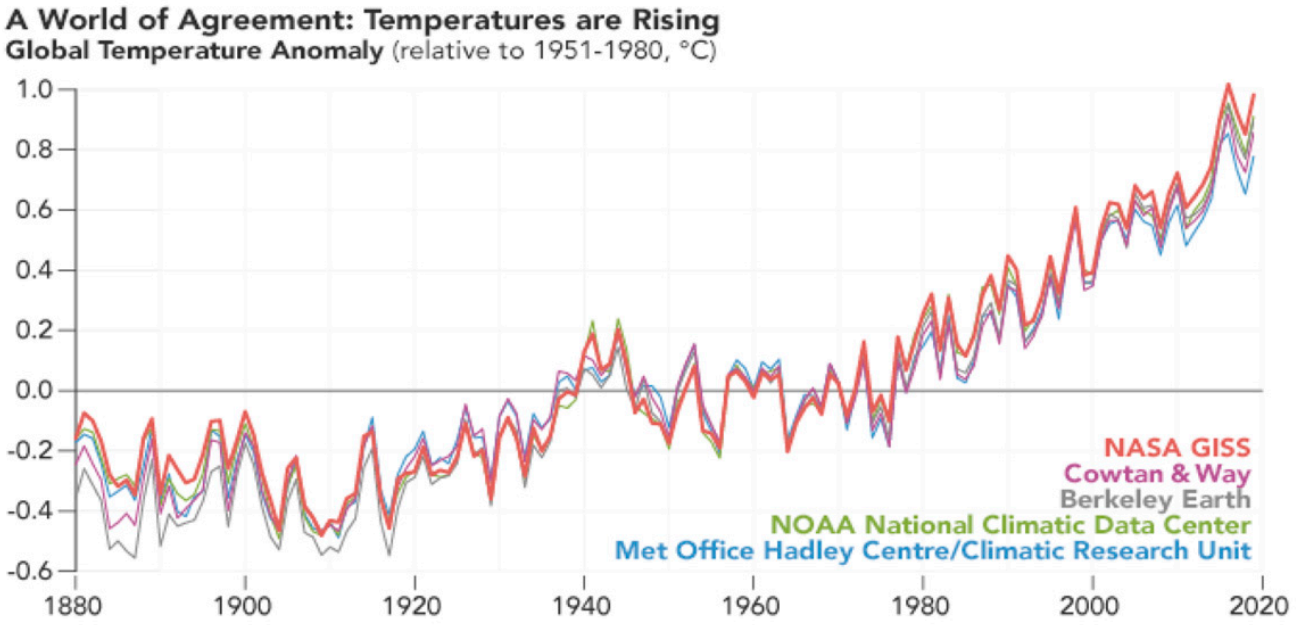


Figure 1. World temperature anomalies from 1880 to 2019 as recorded by NASA, NOAA, the Berkeley Earth research group, the Met Office Hadley Centre (United Kingdom), and the Cowtan and Way analysis (Credits: NASA's Earth Observatory, obtained from: https://earthobservatory.nasa.gov/world-of-change/global-temperatures, accessed on 1 September 2022).

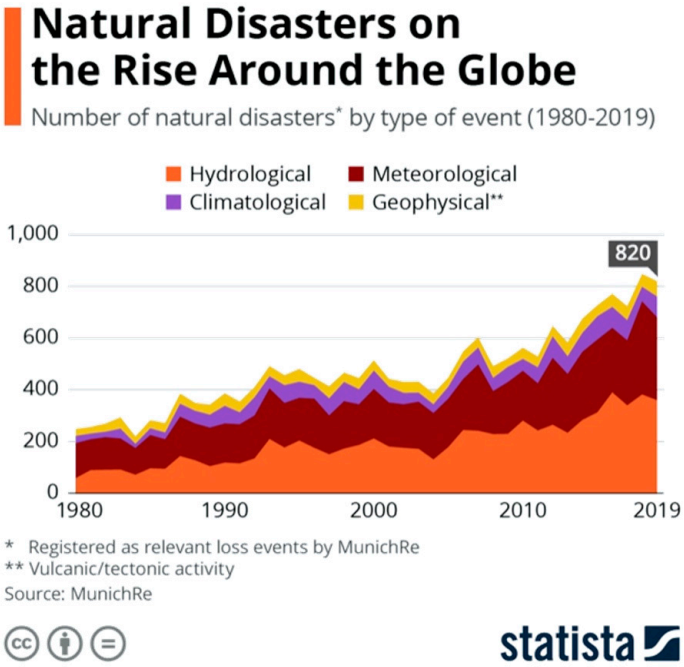


Figure 2. Trends in the world number of events causing major insured relevant loss events by peril 1980–2019 (obtained from: https://www.statista.com/chart/22686/number-of-natural-disasters-globally/, accessed on: 1 November 2022).

The pandemic scenario due to the SARS-CoV-2 raises questions about how extreme events might affect the achievement of SDGs in a post-pandemic world. COVID-19 is a contagious pandemic caused by SARS-CoV-2, a coronavirus variant [5]. The World Health Organization (WHO) declared it as a global pandemic in early 2020. The pandemic has resulted in significant environmental, economic, and social consequences [6], including 626 million cases, with 6.56 million deaths globally by 29 October 2022 [5]. This article highlights these social and environmental risks with cross-cutting impacts, towards a holistic view.

1.2. Cascading Risks from Extreme Weather Events and the COVID-19 Pandemic

Cascading risks from environmental and biological hazards have amplified the vulnerabilities of people most at risk from these threats [7,8]. These risks have also highlighted the realities and challenges faced by the various groups, individuals, and institutions working on disaster and risk management. Multiple weather-related and environmental hazards devastate many parts of the world contemporaneously with the health threats posed by the pandemic [9,10]. Table A2 provides the number of hazard incidents prior to, and intersecting with, the COVID-19 pandemic per region (Asia, Africa, Americas, Europe, and Oceania). For example, heavy rains over parts of Southern and Western India in October 2020 caused flooding in Telangana, Andhra Pradesh, Karnataka, and Mahar. Over 61 people died during those floods, while another 80,000 faced evacuation to relief camps [11]. Other cases include the 2020 fires on the Pantanal Biome in Brazil with 893 occurrences [12,13]. The severe cyclone "Yaas" made landfall in West Bengal and Odisha coast in India during the pandemic on 26 May 2021, coinciding with spring tides. The cyclone caused a 6–8 feet storm surge across nine coastal districts [14].

Another example is the impact of Hurricanes Eta and Iota in November 2020, which affected more than 7.5 million people in Central America. The nations of Guatemala, Honduras, and Nicaragua declared states of emergency and requested humanitarian aid, which occurred during peak SARS-CoV-2 transmission in the region [15]. Similar events have also been recorded in other parts of the world [16], including flooding in Western Germany and Belgium [17], or wildfires in Greece and Turkey [18]. The flames destroyed

farms, homes, wild animals and delicate ecosystems. The United States' Interagency Fire Centre [19] recorded 46,148 fire incidents in 2020, with another 48,333 recorded by October 2021. Yet, these are substantially small compared to the pre-pandemic years, indicating that human activity contributes to fires.

Concurrent hazards interacting with the ongoing COVID-19 pandemic pose new challenges to disaster and emergency management worldwide. These hazards have ultimately exacerbated vulnerable and marginalized populations' already precarious conditions, and have complicated disaster response and evacuation management. Moreover, compound events such as the successive or near-simultaneous occurrence of two or more extreme events exacerbate social vulnerabilities [2]. Their amplified effects contribute to greater societal and environmental risks, with cross-cutting impacts across spatial and temporal scales in communities' economic, social, and political landscapes. Conversely, Ahlerup [20] argues that disasters resulting from extreme events may not be entirely negative in their impacts. For instance, there may be a noticeable increase in collaborative efforts towards overcoming communal/common challenges, which can enhance social cohesion and unity. In addition, disaster experiences may influence the improvement of DRR policies and programs to build back better.

1.3. Drawing on Lessons Learned from Past Historical Extreme Events and Their Management

Crises present uniquely rich lessons to improve resilience and sustainability. Historically, societies have dealt with past disasters and used their learned lessons to progress. Pfister and Brázdil [21] showed how authorities dealt with adverse weather patterns in Central Europe during the Little Ice Age (from around 1300 to 1850). Ballesteros-Canovas et al. [22] highlight societal changes and the implementation of adaptation measures against extreme flood events in Kashmir over the past millennium. The recent volcanic eruption in La Palma (Canarias Island) during the COVID-19 pandemic has also shown how knowledge from past eruptive events can be employed in crisis management to mitigate impacts on the population. Adequate preparation for repetitive events necessitates implementing response measures and planning to address complex and completely random disasters [23]. In addition, healthy ecosystems and nature-based infrastructures are resources for effectively mitigating weather extremes. For example, land covered with vegetation intercepts and absorbs water, serving as a buffer against flooding and stabilizing slopes against landslides. However, this effect could be conditioned by the intensity of the precipitation [24]. Without the defenses that natural resources and ecosystems offer, the negative impacts of extreme events may be more disastrous.

According to the International Panel on Climate Change (IPCC), extreme weather or climate events refer to the initial and consequent physical phenomena, including some (e.g., flooding) that may have human (anthropogenic) components of causation other than those related to climate, e.g., changes in land use change or land cover, or changes in water management [2]. Extreme weather and climate-related events compromise the steady and sustainable development of society. They can result in significant infrastructure damage, economic crises, and population displacements, among other undesired consequences [25]. Extreme weather and climate-related events impact many socio-economic aspects with diverse consequences [26,27]. They impact communities through the loss of lives and livelihoods, injuries, and illnesses, coupled with significant socio-economic implications [28]. The substantial impact of these highlighted problems on human development has prompted increased attention to the connections between disasters, socio-economic development, and poverty outcomes, especially in light of the "Leave No One Behind" agenda. This consideration is crucial, as losses related to extreme events are estimated to cost the global economy around US $520 billion annually and are projected to force 26 million individuals into poverty [29]. Mainstreaming risk management into development planning can mitigate the negative impacts of disasters. This is especially urgent and even critical now, given the multidimensional effects of the COVID-19 pandemic on the global community.

Considering the illustrated background, this study seeks to answer the following research question: "How does the compounding impact of cascading risks from extreme events and the COVID-19 pandemic affect the achievement of the UN SDGs?". Ultimately, this study aims to highlight some core lessons and contribute to the debate on post-pandemic recovery pathways to build resilient and sustainable communities.

2. Methods and Data

To identify the nexus of extreme events and SDGs, an evaluation of relevant case studies published in the literature was conducted by reviewing journals and scientific publications that dealt with this topic since the onset of the COVID-19 pandemic. Articles addressing the nexus of extreme events and SDGs were analyzed systematically using bibliometrics techniques and meta-analysis approaches. We carried out the bibliography search at the end of 2021 and the beginning of 2022 using the Web of Science database. We initially scanned 260 articles, of which 18 were finally selected for in-depth assessment. The inclusion criteria were: (i) the article's publication date was between 2020 and 2022; and (ii) the article had to deal with the impact of extreme events or the coronavirus pandemic on the SDGs. The study is based on the collective opinions of the 16 authors of this article, who have diverse expertise and good geographical distribution. We used the Emergency Events Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED) to collate all disasters that have occurred since the outbreak of the COVID-19 pandemic. The EM-DAT hosts data on the occurrence and effects of more than 22,000 mass hazard events from 1900 to date. The data is provided by different national and international organizations across the globe. EM-DAT is the global reference database on disaster auspices by the World Health Organization (WHO), aiming to enhance humanitarian actions and inform disaster management policies.

3. Results and Discussion

Study results (Tables A1 and A2) indicate meteorological (27%) and hydrological (49%) disasters registered the most incidence in 2019, as well as during the pandemic (2020), with 33% and 55% occurrence, respectively. A similar pattern can be observed in preliminary records for 2021. Moreover, meteorological disasters increased in the year of the pandemic, whilst there was a relative reduction in the occurrence of other disasters (see Appendix A). This discussion focused on learning lessons from the coronavirus pandemic for risk resilience and sustainability in the post-COVID-19 era, and is described in the following sections.

3.1. Disaster Management in Pandemic Times

The human element in disaster management is essential, including health caregiving or trauma management [30]. Physical distancing measures introduced as part of the COVID-19 pandemic containment upended disaster management protocols, especially involving close human contact. Moreover, the high death rates amongst first responders foregrounded the debate on using technology in disaster recovery and caregiving, such as using robots and drones [31]. The human element such as caregiving was ever present and more appreciated, as reflected in measures to acknowledge the sacrifices of first responders worldwide such as through songs, salutes, and others. Additionally, the working conditions of caregivers received attention on issues such as zero hours and exploitative contracts in the sector, especially amongst minority groups [32]. The debate on technology also highlighted the global technology divide. Advanced technology was rolled out in wealthy nations to catalyze vaccine production and facilitate containment measures such as contact tracing [33]. In poorer parts of the globe this was largely absent, with the promotion of indigenous medicine and spirituality to cope with the pandemic [34,35]. This dynamic underlines the need to revitalize global cooperation to address the world's pressing issues as espoused in SDG 17. This issue includes cooperation in dealing with extreme events and their cross-cutting impacts.

3.2. Harnessing the World's Collective Intelligence to Address Compound Events

The coronavirus pandemic has underscored the essence of pooling the global community's collective intelligence, and has created novel forms of rapidly sharing this combined knowledge [36]. Collective intelligence is the enhanced capacity that is fostered when several groups collaborate to assemble the most information, ideas, and knowledge to address a problem. Digital technologies have redefined the nature of contemporary collective intelligence, linking more people in real-time, augmenting human intelligence with artificial intelligence (AI), and facilitating the generation of new data sources [37]. Collective intelligence can aid in responding to crises with greater confidence, clarity and cooperation. Hence, the WHO is championing a Global Pandemic Radar, which will assemble a worldwide network of surveillance hubs to spot novel COVID-19 variants and other emerging diseases [38]. This will facilitate monitoring patterns of vaccine resistance, disease tracking and the identification of emerging issues. Enhancing sentinel systems to improve surveillance and effective responses to future risk challenges is critical. Involving the public through citizen science-harnessed collective intelligence, drawing on public participation and collaboration, are also required. More inclusive and participatory approaches should be followed that integrate the voices of women and minorities. Harnessing the possibilities of data, technology, and people will be vital in the final decade of action to build resilience towards the world's next big crisis.

3.3. Health and Wellbeing in the Context of Compound Events

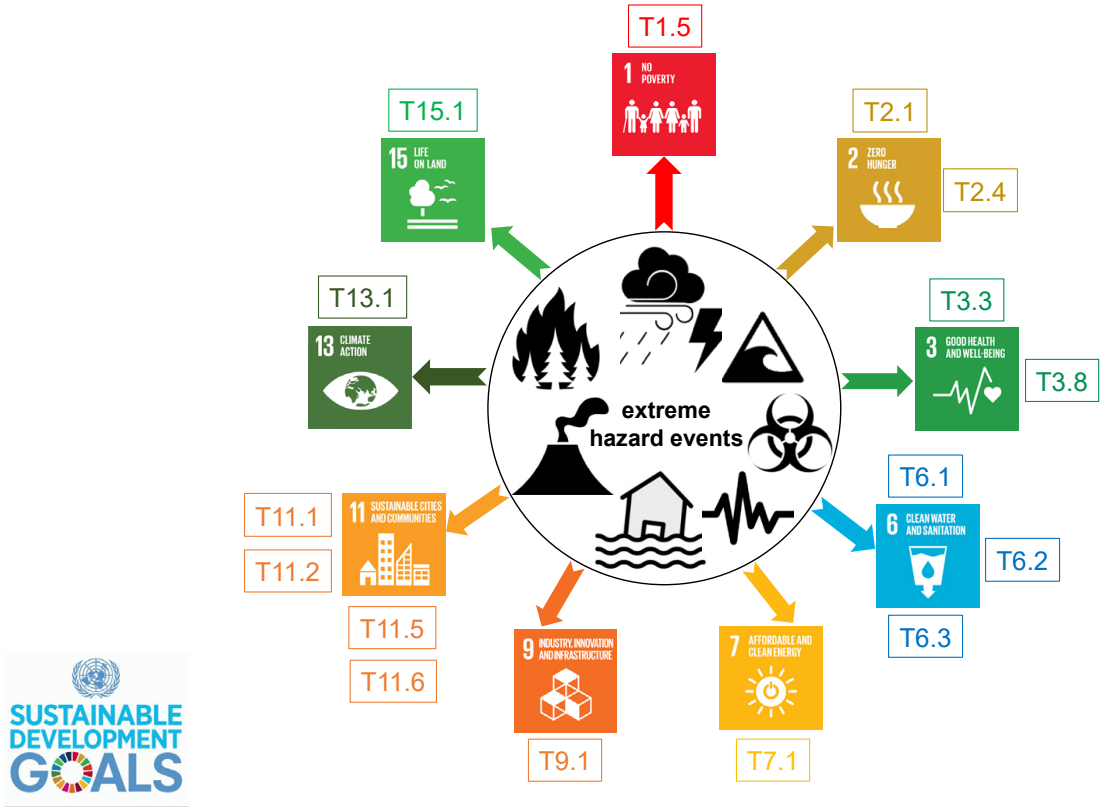
The pandemic has forced people to spend a significant part of their day indoors. This makes it necessary to consider the design and operation of buildings with Indoor Environmental Quality (IEQ). Poor IEQ predisposes vulnerable people to several diseases aggravated by socio-economic factors [39]. Understanding the core factors behind IEQ can help secure society's health and wellbeing during extreme events. This will limit health risks in housing, especially amongst vulnerable groups who are often in precarious conditions.

Moreover, COVID-19 has negatively affected many people's mental health due to isolation and increased stress and anxiety [40]. Furthermore, the coronavirus pandemic has had a dire impact on the global economy and endangers the livelihoods and food security of the worldwide populace. Estimates indicate that disruptions in agricultural production could result in a loss of 451 million (or ~30%) jobs worldwide [41]. Weather-induced supply-side shocks cause food prices to escalate, with detrimental effects on consumers globally. Climatic shocks compromise food access through effects on production; they also influence food access and demand via low revenues that negatively impact agricultural workers [42]. The economic downturn due to the coronavirus crisis has dissipated individuals' incomes and savings. This significantly affects people's purchasing power, so measures to secure health and wellbeing are compromised. For example, eating nutritious food is important for strengthening individuals' immune systems and overall health in such a precarious time. However, the increased costs of highly nutritious foods cause them to be unaffordable to regular citizens. They are substituted with lower-value foods, which undermine the health and wellbeing of vulnerable people [42]. The coincidence of climatic shocks and the pandemic has amplified food insecurity with implications for health and wellbeing. The peculiar challenges of coronavirus containment measures are also worth considering, such as social/physical distancing regulations and limitations on mobility. This can be very severe in countries that are net importers of food. In building back better, novel measures that address the combined threat of pandemic and weather shocks are essential, including scaling up access to virtual platforms that enable uninterrupted extension services. Interventions that promote adequate food storage and limit food wastage and loss, deserve consideration.

Furthermore, climate-adaptive agriculture policies should integrate risk management measures. Ultimately, resilience is knowledge-intensive, necessitating investments in research. This is vital to overcoming the effect of widespread misinformation that undermines resilience efforts [43].

3.4. Direct Impact of Extreme Events on SDGs and Associated Targets

Extreme and LPHI events potentially affect all UN SDGs, either directly or indirectly. Figure 3 shows the UN SDGs that are directly affected by extreme (i) hydro-meteorological events (extratropical cyclones, windstorms, storm surges, river floods, pluvial floods, avalanches, debris flows, coastal erosion), (ii) climatological hazard events (heat waves, frost, wildfires, droughts), (iii) geophysical hazard events (earthquakes, tsunami, landslides, rockfalls, volcanic eruptions, volcanic ashfall) and/or (iv) biological hazards (e.g., the COVID-19 pandemic). The relevant targets (T) that are directly affected are included in the figure for each SDG. The impact of extreme events may differ depending on the hazard's characteristics. For example, T15.1 (forest areas) and T15.4 (mountain ecosystems) are mainly affected by wildfires, e.g., see the August 2021 fires in Greece and Turkey, while T15.3 (degraded land and soil) is influenced by droughts and floods, e.g., see the 2021 floods in Germany.



T1.5: population exposure and vulnerability to climate-related extreme events
T2.1: access to safe, nutritious and sufficient food, **T2.4:** agricultural productivity and production, land and soil quality
T3.3: communicable diseases, **T3.8:** access to quality essential health-care services and to safe, effective, quality and affordable essential medicines and vaccines
T6.1: access to drinking water, **T6.2**: access to adequate and equitable sanitation and hygiene, **T6.3**: water quality
T7.1: access to electricity
T9.1: access to quality, reliable, sustainable and resilient infrastructure
T11.1: access to adequate, safe and affordable housing and basic services, **T11.2**: access to safe, affordable, accessible and sustainable transport systems, **T11.5**: number of deaths and number of people affected, and direct economic losses caused by disasters, **T11.6**: environmental impact and air quality
T13.1: resilience and adaptive capacity to climate-related hazards and natural disasters
T15.1: conservation, restoration and sustainable use of forest areas, **T15.3:** combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, **T15.4**: conservation of mountain ecosystems

Figure 3. The direct impact of extreme events on UN SDGs and relevant Targets (T). Source: Elaborated by the authors based on Argyroudis et al. [37].

Another example is the case of hydro-meteorological and climatological hazards which directly affect T2.4 (agricultural productivity, land, and soil quality). In contrast, the direct impact of geophysical hazard events on this target is limited, and is most likely indirect and/or localized. Similarly, wildfires and volcanic eruptions followed by ashfall are expected to have more significant impact on T11.6 (air quality), e.g., see the 2018 volcano eruption in Hawaii [44] or the wildfire seasons in the US [45], as opposed to other hazards. From the selected SDGs and targets shown in Figure 2, most are affected directly by all types of identified extreme events, for example target T1.5 (population exposure and vulnerability) and T11.5 (number of deaths and people affected and direct economic losses). Another observation is that compound hazards may have a cumulative impact on SDG targets. For example, disastrous earthquakes and wildfires in Greece and Croatia during the COVID-19 pandemic added strain to the already overloaded healthcare system and affected T1.5 or T3.8 [46].

The extent and duration of the direct impact varies depending on the type and scale of the extreme event. For example, landslides, rockfalls, avalanches or earthquakes affect smaller areas. However, the impact of cyclones, floods, or heat waves can be extended to regions or countries. For example, a volcanic eruption or a pandemic may influence a continent or have a global impact, e.g., the 2010 Eyjafjallajokull volcano eruption in Iceland disrupted aviation in Europe and North America (target T11.2), whilst the COVID-19 pandemic affected the entire world (target T3.3). The duration of the impact of the first example (volcano) was relatively short (6 to 10 days), while the pandemic started in early 2020 and is still ongoing almost three years later. The duration of direct impact was found to vary from country to country, depending on the available resources. For instance, the post-disaster recovery of critical infrastructure (T7.1, T11.1, T11.2) after the 2010–2011 Canterbury earthquakes in New Zealand or the 2011 Tohoku earthquake in Japan was shorter compared to the 2010 earthquake in Haiti [47]. Apart from direct impacts, extreme events indirectly impact SDGs and associated targets. For example, an indirect impact is the mobilization of additional financial resources for developing countries (T17.3) or the enhancement of regional and international cooperation and access to science, technology, and innovation (T17.6) in the wake of extreme disasters. An indirect effect of the COVID-19 pandemic is the increase in deaths due to other diseases, as the hospitalizations for other illnesses have declined (T3.8: access to quality essential healthcare services) [48].

3.5. Exacerbation of Extreme Event Impacts by the COVID-19 Pandemic

Concurrent hazards resulting from the intersection of the ongoing COVID-19 pandemic with extreme weather and climate events shape the latter's multidimensional impacts. For example, baseline infrastructure like the health system, educational system, transport, and logistics have been under strain worldwide, and their functions have been compromised during the pandemic. This degradation in performance and reliability constrains efforts to plan for and cope with extreme events, while simultaneously hampering the pandemic response [49]. Together, such interactions add to the potential for cascading impacts across multiple areas of society, particularly in locations where these systems are fragile to begin with. This issue represents a challenge encompassing all aspects of the disaster and resilience suite of actions: planning, management, and recovery. Evacuations and relief distribution measures are among the activities most directly affected by COVID-19, particularly for acute extreme events that require evacuation or shelter such as tropical cyclones or heat waves. The associated displacements have likely also contributed to the virus's spread [50,51]. Indoor crowding also increased as people sheltered from long periods of heavy smoke due to wildfires in the Western US. This poor air quality likely enhanced susceptibility to severe cases of COVID-19 through preconditioning effects on respiratory function [52,53]. Mobility and supply chain issues also disrupted the normal apportioning of resources for extreme events. In general, the pandemic triggered a greater awareness of the value of national supply banks, flexible and fast emergency management policies, and strategic structural redundancies that reduce the risk of extreme events, caus-

ing catastrophic system failures in both the public and private sectors [54,55]. COVID-19 has likely had a major, if indirect, effect on extreme events by catalyzing structural changes in emissions due to work-from-home policies, new infrastructure investments, and other demand-based shifts [56,57]. Whilst the incidences of disasters reduced in 2020 (Table A2), developing world regions such as Asia and Africa generally recorded relatively higher incidences, similar to 2019. This incidence can further worsen global inequality, which compromises SDG10.

4. Conclusions

Challenges in contemporary society have been characterized by an escalation of extreme and LPHI events exacerbated by climate change, posing a global threat to sustainable development. Addressing novel and emergent risks requires new inclusive approaches to collecting data, analyzing impacts and determining, and implementing feasible, equitable, and sustainable solutions whilst overcoming gaps in evidence. The COVID-19 pandemic has disrupted the "business as usual" mindset about global political and economic trajectories, and exposed significant vulnerabilities concerning the challenges of anticipating and managing multiple intersecting crises. Given the multidimensional impacts of the COVID-19 pandemic on the global community [58,59], Building Back Better principles are especially relevant for post-pandemic resilience. Nevertheless, the COVID-19 pandemic's direct and indirect effects have emphasized the need to maintain and enhance goals directed toward enhanced sustainability. It has also highlighted the importance of resilience and established the value of digital transformation.

Furthermore, the COVID-19 pandemic has exposed vulnerabilities in making possible a full implementation of the United Nations' 2030 Agenda for Sustainable Development, as we have witnessed a rise in poverty and clear evidence of inequalities and injustices worldwide. The "human rights" core of the 2030 Agenda must be central to our future collective efforts, emphasizing that the needs of those most vulnerable are attended to and that any identified patterns of inequality and discrimination are addressed [60–62]. This study is mainly based on a selection of 18 works published before 2022. Future studies could explore in a more quantitative manner the impact of COVID-19 on reactive processes toward recovery and restoration after extreme events. This study focused on the immediate effects of concurrent natural hazard events with the pandemic. Future studies could consider human-induced hazards, and analyze more systematically the temporal and spatial impact at national, regional, and continental scales, as well as the resilience of societies to low-probability high-impact concurrent events.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of articles addressing the impact of extreme events and/or the COVID-19 pandemic on the SDGs (compiled from the Web of Science database).

Article	Related SDG	Outcome
Al Dhaheri et al. [63]	3	The coronavirus pandemic has compromised mental health and quality of life. This manifests in increased reports of apprehension, helplessness, and stress over work and finances. It has increased mental health awareness and mutual family support.
Argyroudis et al. [37]	9, 11, 13	Emerging digital technologies such as AI, digital twins, satellite images, agent-based modelling, and data analytics enhance climate infrastructure resilience and reduce aleatory and epistemic uncertainty in all phases (plan/prepare, absorb/respond to, recover from, adapt to a threat), thus increasing resilience
Arora et al. [64]	3	AI can facilitate the management of the COVID-19 pandemic and the creation of early warning systems.
Barua et al. [43]	All	The proliferation of misinformation during the pandemic has grave implications for safeguarding health amidst disasters like coronavirus.
Berchin et al. [57]	All	In recent times, epidemics of global significance have increased. The COVID-19 pandemic is considered the fastest unprecedented crisis in history, resulting in one of the worst socio-economic crises ever. This poses a grave challenge to livelihoods and wellbeing globally, and jeopardizes the attainment of the SDGs. Lifestyle modifications may facilitate new enlightenment premised on the desire for global solidarity and an imperative for applying sustainable development pathways, thus forming a common agenda for the future of humanity as part of the ecosystem.
Cowls et al. [65]	13	AI can help address climate change and its impacts. However, AI presents several social and ethical challenges and has a high carbon footprint.
De Wit et al. [7]	All	The coronavirus has resulted in grave socio-economic challenges. To safeguard public health and employment, governments introduced sizeable fiscal stimulus packages. Though social security measures are vital, there is the fear that sustainable and resilient development will be side-lined in the bid to protect livelihoods. Safeguarding public health and essential services is feasible whilst championing resilience and sustainability. Japan's integrated solutions show that the pandemic response can include accelerated decarbonization and resilient, sustainable development. Failing to take action on long-term sustainability threats increases inequality, escalates opportunity costs, cascades hazards, and affects planetary thinking and globalism.
Esses et al. [66]	1, 2, 3, 4, 8, 13	Digital transformation can enhance sustainability goals; in particular, the impact on specific SDGs was higher during COVID-19, measured through connectivity, human capital, internet use, integration of digital technology and digital public services.
Fenner & Cernev [67]	All	The coronavirus pandemic affects the attainment of the 17 SDGs, coming when efforts need to be doubled in the final decade of action. There are avenues to redouble efforts towards achieving the SDGs, but the competing interests of new geopolitics could impede them.
Knolle et al. [40]	3	The COVID-19 pandemic has aggravated general mental health, evidenced by escalated anxiety, stress and depression.
Loomba et al. [68]	All	Misinformation about the COVID-19 pandemic undermines public confidence and responsible behavior for successful recovery.

Table A1. *Cont.*

Article	Related SDG	Outcome
Raza et al. [69]	13, 11	Climate-related extreme weather events present sustainable development challenges. Mainstreaming climate change adaptation in the initial stages of development planning promotes the SDGs through sustainable and climate-resilient societies.
Sarker et al. [31]	3	Robotics and AI-based technologies have become a vital component of the healthcare value chain in combating the COVID-19 pandemic.
Schröter et al. [70]	3, 11, 15	Nature-based Solutions (NbS) can contribute to achieving many SDGs; however, cooperation is necessary across different sectors and governance levels.
Udmale et al. [71]	2	The study sheds light on the core actors in the global food chain, the possible consequences of COVID-19 on worldwide food security, and SDG-2 (zero hunger). Developing countries are the most prone to fluctuations in cereal supply. The prevailing pandemic can result in transitory food insecurity amongst vulnerable nations. Moreover, the consequence of the pandemic on food security (SDG-2) could persist as a compound effect of economic meltdown and rise in poverty, reducing food supply and accessibility beyond 2020.
Wang & Huang [72]	All	It has exposed global inequality between rich and developing countries and territories in managing the pandemic, and poses a severe risk to attaining the SDGs.
Wilby [73]	6	The riverine resources of the globe are endangered by several stresses including climate change, undermining resilience and increasing vulnerability to extreme events. Resilience policy needs to acknowledge both the rate of change related to these shocks and the capacity of extreme events to transgress sustainability thresholds.
Woźniak & Tyczewska [74]	All	The coronavirus pandemic has come with severe effects on human lives globally. However, it can catalyze a global integration regarding the bioeconomy, particularly in realizing the SDGs, creating national and regional bioeconomy frameworks, promoting the circular economy, facilitating food security coupled with sustainable food production, and conserving biodiversity. Nevertheless, the pandemic has interrupted the attainment of economic, environmental, and social objectives globally.

Table A2. Hazard incidents before and during the COVID-19 pandemic (2019–2021).

Year	Hazard Group	Hazard Sub-Group	Region					Total
			Asia	Africa	Americas	Europe	Oceania	
2019	Natural	Meteorological	43	12	27	34	2	118
		Hydrological	87	69	38	17	3	214
		Climatological	12	6	9	1	2	30
		Geophysical	21	0	7	4	3	35
		Biological	8	25	7	0	4	44
		Total	171	112	88	56	14	441
2020		Meteorological	52	5	45	21	9	132
		Hydrological	99	66	32	16	8	221
		Climatological	4	8	3	2	1	18
		Geophysical	12	1	4	3	0	20
		Biological	3	3	2	0	0	8
		Total	170	83	86	42	18	399
2021		Meteorological	25	8	31	8	6	78
		Hydrological	59	24	48	20	4	155
		Climatological	8	6	6	5	2	27
		Geophysical	15	2	6	1	0	24
		Biological	0	2	0	0	0	2
		Total	107	42	91	34	12	286

Note: This table was compiled in September 2021. Source: compiled from the EM-DAT database.

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