Sustainable Development Goals Series

Connecting the Goals

Joel C. Gill
Martin Smith *Editors*

Geosciences and the Sustainable Development Goals

British Geological Survey

Geology for Global Development

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For Chloe, Leo, Aaron, and Eilidh

'Future generations will judge us not by what we say, but what we do.'

—Ellen Johnson Sirleaf (President of Liberia, 2006 to 2018)

Preface

In writing this book, we hope to catalyse greater engagement of the geological science (or geoscience) community in implementing the Sustainable Development Goals (SDGs), as set out in a Resolution adopted by the United Nations General Assembly on 25 September 2015: *Transforming our world: the 2030 Agenda for Sustainable Development*.[1] We set out to constructively engage with this agenda, and to illustrate how geoscientists can facilitate the ambitions of the SDGs, monitor progress, and ensure the ongoing translation and integration of geoscience to support sustainable growth, well-being, and environmental protection in the decades following 2030. Our desire is that this book will enhance teaching on the societal relevance of geoscience. Sustainability concepts are notably lacking from the traditional education of many geoscientists, and in their research communities, limiting their ability to engage in the SDGs and other global development frameworks. Each chapter includes educational resources to help those with teaching responsibilities to support students to contextualise and apply the substance of this book.

While seeking to focus on the role of geoscientists in delivering the SDGs, we are acutely aware that complex, multifaceted development problems require interdisciplinary solutions, inclusive engagement, and participation by diverse groups from across different sectors and disciplines. Setting out how geoscientists can support these efforts requires an understanding of the political, economic, social, cultural, technological, and environmental contexts in which we seek to engage. Balancing the tension between delving into aspects of geology and the economic and social drivers underlying the SDGs has not been easy. We have not attempted to capture every aspect of social, economic, and environmental science relevant to addressing any given SDG in this one volume. We hope that our approach helps readers to understand how geoscience sits within the bigger picture of sustainable development, and that the suggested further reading in each chapter enables them to continue exploring relevant themes and build new partnerships. We also hope that this book enhances understanding outside the geoscience community of how geoscientists can support sustainable growth and decent jobs, resilient cities and infrastructure, access to basic services, food and water security, and effective environmental management.

[1] www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf.

Our philosophy in editing this volume has been that ensuring lasting and positive change not only depends on *what* we as geoscientists do, but also *how* we do this work and engage in sustainable development. For example, geoscientists' actions can advance the inclusion of vulnerable and marginalised groups, or could exacerbate existing inequalities; geoscientists can recognise and build on existing expertise when working internationally, or undermine local leadership and science institutions. This book is, therefore, about both science and the professional practice of science. We cover themes linked to ethics, equity, conduct, and partnerships, as well as water, minerals, engineering geology, and geological hazards. Where possible we have used examples and images from the Global South to illustrate the themes in this book, but we recognise that actions towards the SDGs require engagement from all countries and regions.

What This Book Includes

Following an introduction, this book explores each of the 17 SDGs in 17 corresponding chapters (i.e., **SDG 1** is explored in Chap. 1; **SDG 2** is explored in Chap. 2, etc.). We bring together learning, emerging themes, and recommendations in the conclusions (Chap. 18).

Through each of Chaps. 1–17, we refer to links with other chapters in order to demonstrate the SDG interlinkages and how progress in one goal can drive progress in another. We use the SDG number (e.g., **SDG 6**, **SDG 10**) rather than stating Chap. 6 or Chap. 10 to make things easier for the reader.

In the chapters relating to **SDGs 1–17**, we include a visual abstract that sums up the key content of the chapter and illustrates how geoscience can help deliver its ambitions. In addition to the main text, we also include (i) key learning concepts, a series of bullet points summarising the chapter, (ii) educational resources, to support contextualisation of the information in this book in the classroom (aimed at undergraduates/taught postgraduates), (iii) further reading, directing you to resources that complement the chapter theme, and (iv) a full reference list at the end of each chapter.

Forty-two authors have contributed to this book, collectively coming from every inhabited continent of the world. We started this project desiring that the final book would have a 'global voice'. While we recognise that we can always do more to improve representation, we are delighted to present a book with authors from diverse countries and sectors. We have diverse gender representation, and include early career scientists, experienced professionals, and voices from diverse sectors.

Introduction to Supporting Organisations

The **British Geological Survey** (BGS), part of UK Research and Innovation (UKRI) and a research centre under the Natural Environment Research Council (NERC), is the UK's principal supplier of objective, impartial, and up-to-date geological expertise and information for decision-making for governmental, commercial, and individual users. The BGS maintains and develops the nation's understanding of its geology to improve policymaking, enhance national wealth and reduce risk. It also collaborates with the national and international scientific community in carrying out research in strategic areas, including decarbonisation and resource management; environmental change, adaptation, and resilience; and multi-hazards and resilience. You can read more about the BGS at www.bgs.ac.uk.

Geology for Global Development (GfGD) is a registered charity, based in the UK, existing to champion the role of geology in sustainable development, mobilising and reshaping the geology community to help deliver the SDGs. GfGD organise conferences and training, support international projects working to achieve the SDGs, and advocate for the importance of Earth science at local, national, and international forums. GfGD is an affiliated organisation of the International Union of Geological Sciences and a contributing organisation to the UNESCO/IUGS International Geoscience Programme Project 685 (Geoscience for Sustainable Futures). You can read more about GfGD at www.gfgd.org.

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We have had great support from Henry Holbrook, Ian Longhurst, and Craig Woodward (all at or formerly at BGS) in the preparation of figures for this book. The visual abstracts at the start of each chapter—coordinated by Ian and Henry—provide an excellent way to explore how geoscience relates to each SDG. Support was also provided to the Editors by Bryony Chambers-Towers (BGS Intellectual Property Rights), and a review completed by John Rees (BGS Chief Scientist, Multi-Hazards and Resilience).

Photographs and graphics have kindly been provided by Sarah Boulton (University of Plymouth/Girls into Geoscience); Stafford McKnight (Federation University Australia); Solmaz Mohadjer (Parsquake); The Villuercas Ibores Jara UNESCO Global Geopark; the American Geosciences Institute (AGI); Chris Rochelle (BGS); the Mixteca Alta, Oaxaca UNESCO Global Geopark; the Qeshm Island UNESCO Global Geopark; the Observatory of Rural Change, OCARU, Ecuador; and Andrew Bloodworth (BGS). We also acknowledge our gratitude to the Our World in Data resource (https://ourworldindata.org/) for generating useful content and making this freely available to use. The analysis and images on this site have informed many of the chapters in this book.

We are grateful to all those who have provided information and ideas to enrich this book. Keely Mills (BGS) and Laura Hunt (University of Nottingham, BGS) provided information and images for a case study in SDG 15. Tom Bide and Teresa Brown (both of the BGS) helped inform the Hanoi Material Flow Analysis in SDG 12. Bob Macintosh and Brighid Ó Dochartaigh (both at BGS) kindly shared their experiences and insights to inform SDG 17. Laura Hunt (University of Nottingham/BGS) also skilfully assisted with some final editorial tasks.

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Preparing a book of this size and scope unsurprisingly requires work to spill into many evenings, weekends, and holidays. Our deep thanks go to Stephanie and Jan for their patience, understanding, and constant support as we completed this work.

Introduction: Geoscience for Sustainable Futures

Science and the 2030 Agenda for Sustainable Development

In September 2015, UN member states formally adopted the 2030 Agenda for Sustainable Development, also known as the Sustainable Development Goals (SDGs). This set of 17 goals (Fig. 1) and 169 targets aim to eradicate global poverty, end unsustainable consumption patterns, and facilitate sustained and inclusive economic growth, social development, and environmental protection by 2030 (United Nations, 2015). The SDGs are complemented by a suite of associated development strategies relating to disaster risk reduction (Sendai Framework for Disaster Risk Reduction), climate change (COP21 Paris Climate Change Agreement), and sustainable urban development (New Urban Agenda). Achieving the SDGs by 2030 will require a concerted and sustained effort from many communities and sectors across the globe.

Fig. 1 The 17 Sustainable Development Goals. Each goal has an associated set of targets, means of implementation, and indicators (United Nations, 2015)

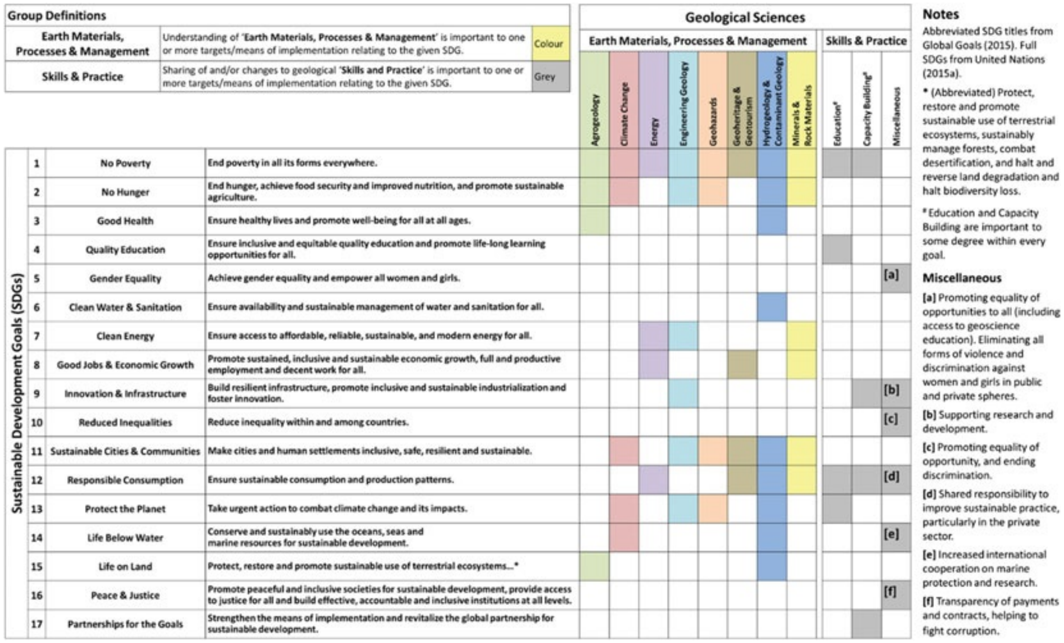

Fig. 2 Geology and the Sustainable Development Goals. From Gill (2017), used with permission

At the time of publication, the COVID-19 pandemic has had a devastating impact on families and communities around the world. This includes major loss of live, but also threats to livelihoods, education, and efforts to ensure gender equality in all contexts. Alongside conflict and other humanitarian disasters, COVID-19 is a serious threat to the development gains made in recent years and our ability to deliver the SDGs by 2030. This pandemic also highlights the need for delivery of the SDGs if we are to reduce the impact of future global health emergencies. Tackling poverty (**SDG 1**) and inequalities (**SDG 10**), improving health and wellbeing (**SDG 3**), increasing access to clean water (**SDG 6**), building safer communities (**SDG 11**), and protecting and restoring natural capital (**SDG 15**) all contribute to risk reduction and more resilient societies.

The SDGs are science intensive, emphasising the need for research, innovation, capacity building, and technology transfer. Meeting the SDG targets requires contributions by those scientists focused on understanding, monitoring, protecting, managing, and restoring the natural environment, including geoscientists. Geoscience is the study of the Earth's structure, processes and resources, and how life (including humans), interacts with Earth (American Geosciences Institute, 2019). Humans are extending their three-dimensional footprint on Earth (for example, through agriculture, infrastructure development, and urban expansion), inducing environmental change, and consuming greater volumes of natural resources.

In its broadest definition, demonstrated by the range of scientific divisions of organisation such as the European Geoscience Union, geoscience includes the study of the oceans, atmosphere, rivers and lakes, ice sheets and glaciers, soils, complex and dynamic surface, rocky interior, and metallic core

(American Geosciences Institute, 2019). Geological processes, including plate tectonics, basin development, and surface geomorphology, control the formation and distribution of resources, the generation of geological hazards and the flow of sediment across our landscapes through rivers and erosion, 'feeding' our oceans and supporting diverse ecosystems. Geoscience is, therefore, an essential part of the integrated research needed for development, and delivery of the SDGs as illustrated in Fig. 2 and expanded on through this book.

Geoscience engagement in the SDGs will be needed across academia, industry, government, and civil society, working in close partnership with other disciplines (e.g., engineering, ecology, social sciences, anthropology, psychology, health), and ensuring effective translation of knowledge into tools to inform policy and practice. A challenge for geoscientists is to demonstrate and communicate the relevance of our studies to policy and decision-makers now and into the future. For example, this includes ensuring the subsurface is considered in development discourses on urbanisation (see **SDG 11**), considering the availability of critical metal resources when developing energy, climate, and decarbonisation policies (see **SDGs 7**, **12**, and **13**), and improving public health by understanding links to the natural environment (see **SDG 3**). Embedding *public relations* as a theme in geoscience education, has long been advocated for (Stow and Laming, 1991) to strengthen connections between geoscientists and policymakers, but it is still largely missing in the core training provided to geoscientists around the world.

Case Study 1: Sustainable Development in Eastern Africa

One region that exemplifies the challenges of and multiple impacts from climate change, human activities, and development faced by the Global South is eastern Africa. Kenya, Tanzania, and Ethiopia are all striving for economic stability and growth, vying to be the regional hub for business and research and development, each with an ambitious development strategy (i.e., Kenya Vision 2030[2], Tanzania Vision 2025[3], Ethiopia Growth and Transformation Plan[4]).

Development in eastern Africa is envisaged to occur along geographical corridors, where infrastructure is developed that facilitates the movement of goods between sites of production (e.g., a copper mine, a gas field), processing zones, and national and international economic hubs (Enns, 2018). In northern Kenya (Fig. 3), a combination of recent discoveries of hydrocarbons in buried rift structures (Tullow Oil, 2019) and the construction of new wind farms (Dahir, 2019), together with existing knowledge of major aquifers and geothermal power, is driving infrastructure development and

[2]http://vision2030.go.ke/.

[3]http://www.mof.go.tz/mofdocs/overarch/vision2025.htm.

[4]https://www.greengrowthknowledge.org/national-documents/ethiopia-growth-and-transformation-plan-ii-gtp-ii.

Fig. 3 The Gilgel Gibe III Dam on the Omo River in Ethiopia *Credit* Mimi Abebayehu (CC-BY-SA 4.0, https://creativecommons.org/licenses/by-sa/4.0/)

presents significant potential for economic growth. This development corridor will extend northwards into Ethiopia, and connect Uganda to the Indian Ocean with new roads, railways, and projected pipelines to carry oil and gas to Lamu, on the Kenyan coast.

Much of this region is a semi-desert environment, inhabited by nomadic pastoralists, with Lake Turkana to the north, the world's largest permanent desert lake. Lake Turkana provides a source of much needed protein, and increased income from tourism. It is a UNESCO World Heritage Site, and important anthropological and archaeological sites, with the discovery of Hominin fossils of some of the earliest human ancestors (e.g., Feibel et al., 1991; Wood and Leakey, 2011). Lake Turkana is a closed basin and its sole water supply comes from the Omo River in Ethiopia. Plans for hydropower schemes and increased use of water from the Omo River for irrigation will affect the long-term water supply to Lake Turkana. The Gilgel Gibe III Dam in Ethiopia (Fig. 3), for example, is predicted to have a significant impact upon the sustainability of the lake (Avery 2012; Ojwang et al., 2017) and increase trans-boundary tensions.

The collective and diverse impacts of corridor development will bring significant change to this region of Kenya. It can be regarded as a microcosm, one of many around the world, exemplifying the challenges of sustainable development. In seeking to implement the SDGs, it is fundamental to understand their impact on each other at the local level (i.e., the ways actions to support one goal could catalyse or hinder progress in another goal), and both planned and unintended consequences on people, wildlife, and the wider natural environment (Fig. 4).

Geoscience research into the evolution of the East African Rift, an active continental rift zone where tectonic plates are gradually diverging, can support a wide array of development ambitions. It can inform our understanding and the development of groundwater resources (**SDG 6**), with the cascading impacts of improved health through reductions in diarrhoeal diseases (**SDG 3**), improved agriculture through greater means of

Fig. 4 Braided river in the Suguta Valley, Northern Kenya Rift, draining into Lake Logipi. *Credit* Martin Trauth (distributed via imaggeo.egu.eu), CC-BY 3.0 (https://creativecommons.org/licenses/by/3.0/)

irrigation (**SDG 2**), and improved economic growth through reducing the time spent collecting water (**SDG 8**). The geology of the East African Rift also determines the availability of energy resource in the region, including both geothermal and hydrocarbon discoveries (**SDG 7**). The management of both water and energy resource, together with the metals and minerals required for construction, manufacturing, and infrastructure development requires careful planning to ensure responsible consumption and production (**SDG 12**), action on climate change (**SDG 13**), and strengthened diplomatic relations between neighbouring countries with trans-boundary resources (**SDG 16**). The hazards associated with the East African Rift include volcanic eruptions, earthquakes, and landslides on steep topographical features. Characterising this multi-hazard landscape, integrating seismology, volcanology, and engineering geology, can inform the actions required to reduce risk, helping to develop resilient infrastructure (**SDG 9**), sustainable communities (**SDG 11**), and reduce poverty (**SDG 1**). Geoscience communities of eastern Africa, spanning all countries and specialisms, should therefore be integrated into the groups and processes shaping development planning and implementation, but also equipped to contribute to supporting and facilitating sustainability in a full and effective way.

Resourcing Geoscientists to Support Sustainable Futures

This book is not the first publication to make claim that geoscientists should be a major partner in the endeavour to transition to a sustainable way of inhabiting Earth. Since the birth of geoscience as a scientific discipline, sustainable development has been part of its DNA, with James Hutton noting in the 1788 volume 'Theory of the Earth' that '*this globe of the earth is a habitable world, and on its fitness for this purpose, our sense of wisdom in its formation must depend'* (Stewart and Gill, 2017). Geoscientists possess skills and understanding that make us well-suited to support development initiatives, with geology being fundamentally important to improving lives and supporting sustainability (Stow and Laming, 1991; Cordani, 2000; Mora, 2013).

After UN member states agreed to the SDGs in 2015, Gill (2017) completed an initial mapping of their dependence on geoscience, Gill and Bullough (2017) provided a broader discussion of *how* geoscientists can engage in the SDGs and other global development frameworks, and Schrodt et al. (2019) have mapped the SDGs to eight *essential geodiversity variables.* The UN Development Programme, World Economic Forum, and Columbia Center on Sustainable Investment have set out the links between mining and the SDGs (Sonesson et al., 2016). IPIECA, the global oil and gas industry association for advancing environmental and social performance, the International Finance Corporation and UN Development Programme have done the same for the oil and gas industry (2017). The International Association of Hydrogeologists (IAH) have published a note showing how groundwater links to the SDGs (IAH, 2017).

These analyses all show significant linkages between the targets of the SDGs and geoscience. In this book, we have collated perspectives from the authors who live and have worked around the world to expand on these works and set out why achieving all of the SDGs requires the study and practice of geoscience, and what steps the geoscience sector can take to accelerate progress towards these goals. While structured around the 17 interdependent SDGs, we recognise that their ambitions not only require concerted action in the months and years to 2030, but an ongoing commitment to pursue knowledge and adhere to frameworks that enable humankind to live sustainably well beyond 2030. We, therefore, aim to

1. *Raise awareness among both geoscientists and the development community of the role of geoscience in realising sustainable development, framed in the context of the 17 SDG priorities*. We do this by describing direct contributions geoscientists can make to the SDGs (e.g., in **SDG 6** we describe how the characterisation of groundwater resources helps to ensure universal access to safe and reliable water supplies), and links between development challenges and the wider natural environment, which geoscience helps to characterise (e.g., in **SDG 10** we outline how environmental degradation can exacerbate inequalities).
2. *Explore how the geoscience community needs to reform to help deliver the SDGs.* We recognise that issues of quality education (**SDG 4**), gender equality (**SDG 5**), equitable access to knowledge (**SDG 10**), safe and secure work environments (**SDG 8**), and effective science partnerships (**SDG 17**) require individual disciplines and sectors to take responsibility, identify weaknesses, and put into place the measures required to deliver these aspects of sustainable development. While government policies (local, regional, or national) are necessary to drive these agendas forward, disciplines and sectors (through professional bodies, scientific unions, and individual organisational policies) also have an ability to influence and contribute to their delivery.
3. *Set out critical aspects of socio-economic context that help broaden geoscientists' understanding of development challenges, the actions needed to address these, and how geoscience sits in that bigger picture.* We do not set out every aspect of economics or social reform relevant to each SDG, but we do introduce concepts that help to contextualise the input of geoscientists. For example, **SDG 1** (end poverty) describes the causes and catalysts of poverty relating to conflict, governance, economics, history, and the environment. The latter is set out in much more detail (covering spatial poverty traps, natural resources, environmental change, pollution, and natural hazards), but we believe it aids the reader to see how these sit alongside other themes.

In helping to deliver on these three ambitions (awareness, reform, context), we hope to accelerate engagement of geoscientists in implementing Agenda 2030, and encourage the embedding of geoscientists into sustainable development initiatives. Throughout this book, we highlight three key themes (equity, knowledge exchange, and interdisciplinarity), which the Agenda 2030 and SDGs also emphasise.

Equity. *Leaving no one behind* is emphasised throughout the SDGs, acknowledging the importance of supporting the least developed and low-income countries, landlocked developing countries, and small island developing states. We have integrated perspectives from scientists in many of these settings into this book, and selected case studies that demonstrate challenges and opportunities associated with sustainable development. For example, **SDG 14** (life below water) has a focus on small-island developing states in the Pacific Ocean, **SDG 9** (industry, innovation and infrastructure) includes an example from Nepal, a landlocked developing country, and **SDG 17** (partnerships) includes a science-for-development programme in Afghanistan, one of the world's least developed countries. Equity is also needed *within* countries. There are individuals, groups, and communities that do not currently have equitable access to services, infrastructure, or resources. Across many chapters, we highlight initiatives that are widening access to geoscience. **SDG5** (gender equality) includes details of inspiring engagement and mentorship activities such as the African Association of Women Geoscientists and Girls into Geoscience (Fig. 5), **SDG 8** (decent work and economic growth) outlines how 'geoparks' are increasing public understanding of geoscience and creating livelihood opportunities for marginalised groups. **SDG 16** (peace, justice, and strong institutions)

Fig. 5 Girls into Geoscience Fieldtrip to Dartmoor, UK. © Sarah Boulton (University of Plymouth/Girls into Geoscience), used with permission

describes the role of scientific unions and professional societies in tackling harassment and discrimination.

Knowledge Exchange. The creation and exchange of knowledge, skills, and technologies can accelerate progress towards the SDGs. We have previously highlighted the emphasis on research, capacity building, and technology transfer within the 2030 Agenda. This book includes examples of knowledge exchange across countries. **SDG 4** (quality education) profiles projects to strengthen understanding of seismic hazards in Central Asia, and **SDG 9** (industry, innovation and infrastructure) describes how geoscientists in the United States collaborates with scientists around the world to improve understanding of and response to volcanic hazards. **SDG 17** (partnerships) includes examples of how geoscientists can engage in the UN Technology Facilitation Mechanism, with the specific objective of increasing access to and understanding of science, technology and innovation.

Interdisciplinary and Multisectoral Partnerships. While this book demonstrates why geoscience matters when addressing sustainable development challenges, it also recognises that we will increasingly be working in partnership with other disciplines and across sectors. Many geoscientists already work with engineers, ecologists, and chemists, but we will increasingly need to collaborate with economists, human geographers, anthropologists, psychologists, and public affairs professionals. These partnerships take time to develop, but are necessary to develop responses to the complex challenges that communities around the world are facing. We highlight in this book how networks and organisations fostering collaborations between geoscientists and other disciplines can help deliver improved health and well-being (**SDG 3**), restoration of biodiversity (**SDG 15**), and strengthened ocean management (**SDG 14**).

Stewart (2016) notes that *geologists possess a valuable synoptic and temporal conceptual framework for evaluating Earth's sustained viability for life*. This, together with thematic knowledge of Earth systems, natural resources, Earth hazards, and environmental management places geoscientists in a strong position to be key partners in sustainable development and champions of change. To leverage this opportunity, geoscientists should evaluate our contribution, our systems, and our role. As you read the following 17 chapters, one for each of the SDGs, we invite you to reflect on your own contribution to sustainable development, and how you can influence other geoscientists to fulfil our shared responsibility to support society in achieving a sustainable future.

Joel C. Gill
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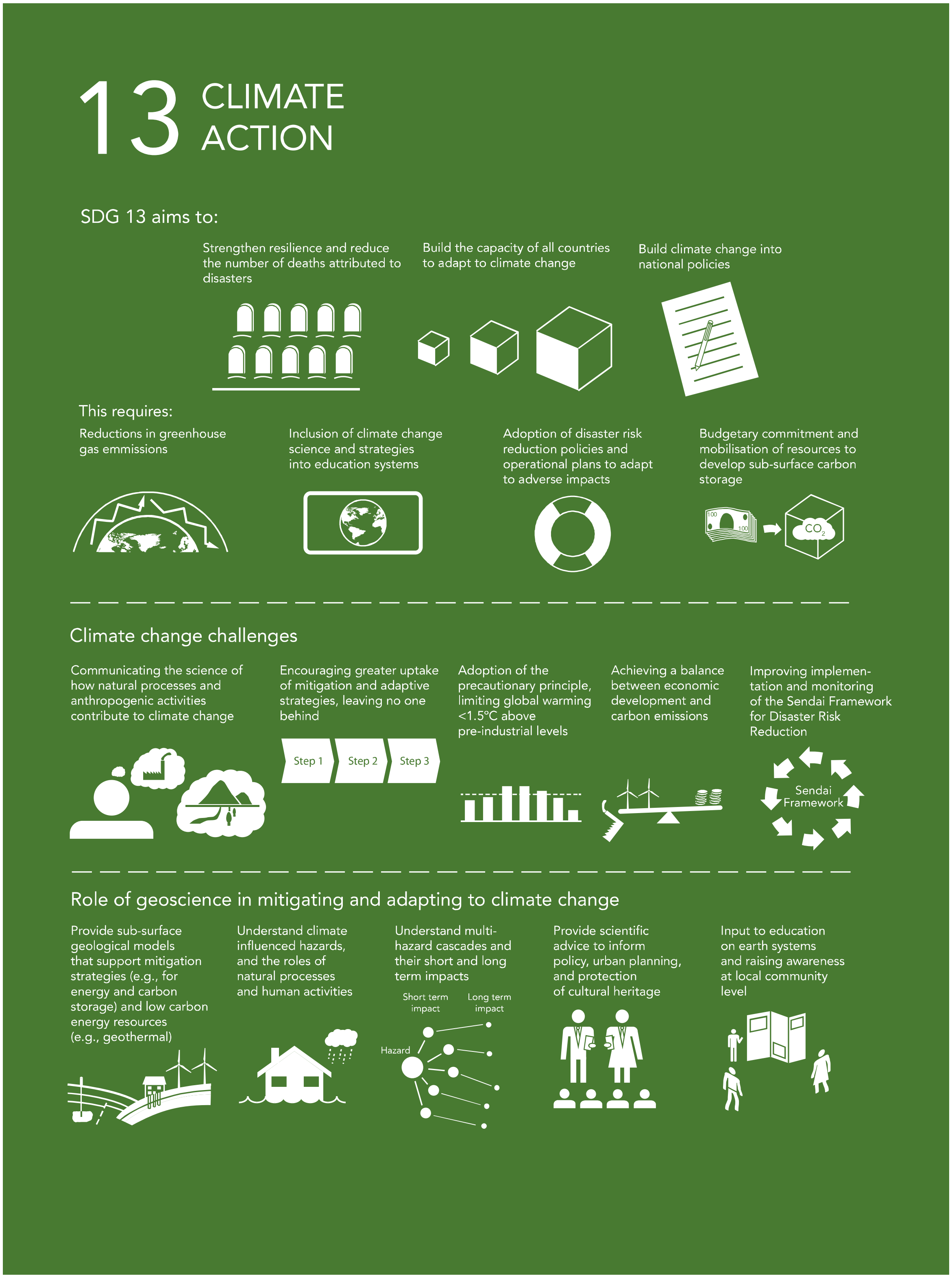
Abstract


13 CLIMATE ACTION
SDG 13 aims to:
Strengthen resilience and reduce the number of deaths attributed to disasters
Build the capacity of all countries to adapt to climate change
Build climate change into national policies
This requires:
Reductions in greenhouse gas emmissions
Inclusion of climate change science and strategies into education systems
Adoption of disaster risk reduction policies and operational plans to adapt to adverse impacts
Budgetary commitment and mobilisation of resources to develop sub-surface carbon storage
CO2
Climate change challenges
Communicating the science of how natural processes and anthropogenic activities contribute to climate change
Encouraging greater uptake of mitigation and adaptive strategies, leaving no one behind
Step 1
Step 2
Step 3
Adoption of the precautionary principle, limiting global warming <1.5°C above pre-industrial levels
Achieving a balance between economic development and carbon emissions
Improving implementation and monitoring of the Sendai Framework for Disaster Risk Reduction
Sendai Framework
Role of geoscience in mitigating and adapting to climate change
Provide sub-surface geological models that support mitigation strategies (e.g., for energy and carbon storage) and low carbon energy resources (e.g., geothermal)
Understand climate influenced hazards, and the roles of natural processes and human activities
Understand multi-hazard cascades and their short and long term impacts
Short term impact
Long term impact
Hazard
Provide scientific advice to inform policy, urban planning, and protection of cultural heritage
Input to education on earth systems and raising awareness at local community level

13.1 Introduction

Climate in a narrow sense refers to weather, in a wider sense it refers to the state of the climate system that is statistically described over a period ranging from months to thousands or millions of years. The World Meteorological Organization (WMO) generally averages the mean and variability of climate parameters such as temperature, precipitation, and wind over 30 years. The Intergovernmental Panel on Climate Change (IPCC) defines climate variability as differences in the mean and other statistics of climate parameters on all spatial and temporal scales beyond that of individual weather events. Climate change refers to changes in the state of the climate that is depicted by differences in the mean and other statistics of climate parameters that persist over an extended period, typically decades or longer (IPCC 2014).

An extreme weather event is a rare event at a particular place and time of year where the value of the weather variable is above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. The characteristics of extreme weather vary from place to place. A persistent pattern of extreme weather over a season can be classified as an extreme climate event (e.g., drought or intense rainfall). Both extreme weather events and extreme climate events could be collectively referred to as 'climate extremes'.

Natural processes and human activity cause climate change. Changes in solar cycles and volcanic eruptions are examples of natural phenomena that affect the global climate. However, since the industrial revolution economic development, population growth and land-use change have augmented natural change by contributing unprecedented levels of greenhouse gases (GHGs) including carbon dioxide, methane, and nitrous oxide. There is growing evidence that human influence has contributed substantially to surface warming of continents (Bindoff et al. 2013), affected the global water cycle, caused glaciers to retreat as well as increased surface melting of the Greenland ice cap, loss of Arctic sea ice, and raised the upper oceanic heat content and global mean sea levels (IPCC 2014). Recent findings indicate that human activities have caused around 1 °C of global warming since pre-industrial times (IPCC 2018).

The impacts of climate change have been observed on natural and human systems on all continents and oceans. These include alteration of hydrological systems that affect the availability and quality of water resources, variations in geographic ranges of seasonal activities, animal and bird migration patterns, abundances and interactions of terrestrial, freshwater, and marine species, fluctuations in crop yield as well as ocean acidification.

The prognosis for climate change over the twenty-first century is not very favourable under all assessed emission scenarios (Fig. 13.1), even without the addition of GHGs due to natural sources. Surface temperature is expected to rise, more frequent and longer lasting heatwaves are anticipated, extreme precipitation events will be more intense and frequent, and the ocean will continue to warm and acidify while global mean sea level is projected to rise albeit unevenly across regions. Past emissions have already committed the forthcoming climate to warming conditions. The gravity of the situation is worse at 2 °C compared to 1.5 °C. Compared to 1.5 °C, global warming of 2 °C is projected to result in more extreme weather, higher impact on biodiversity and species, lesser productivity of maize, rice, and wheat, 50% more of the global population exposed to water shortages and several hundred million more people exposed to climate-related risk and susceptible to poverty by 2050.

Climate change will amplify existing climate-related risks and create new risks for natural and human systems in all stages of development. There are two complementary approaches to reducing and managing the risks of climate change. These are climate change mitigation and adaptation. Mitigation refers to human actions to reduce the source or enhance the sinks of GHGs in order to restrict future climate change. Substantial emission reduction is required over the next decade including the removal of carbon

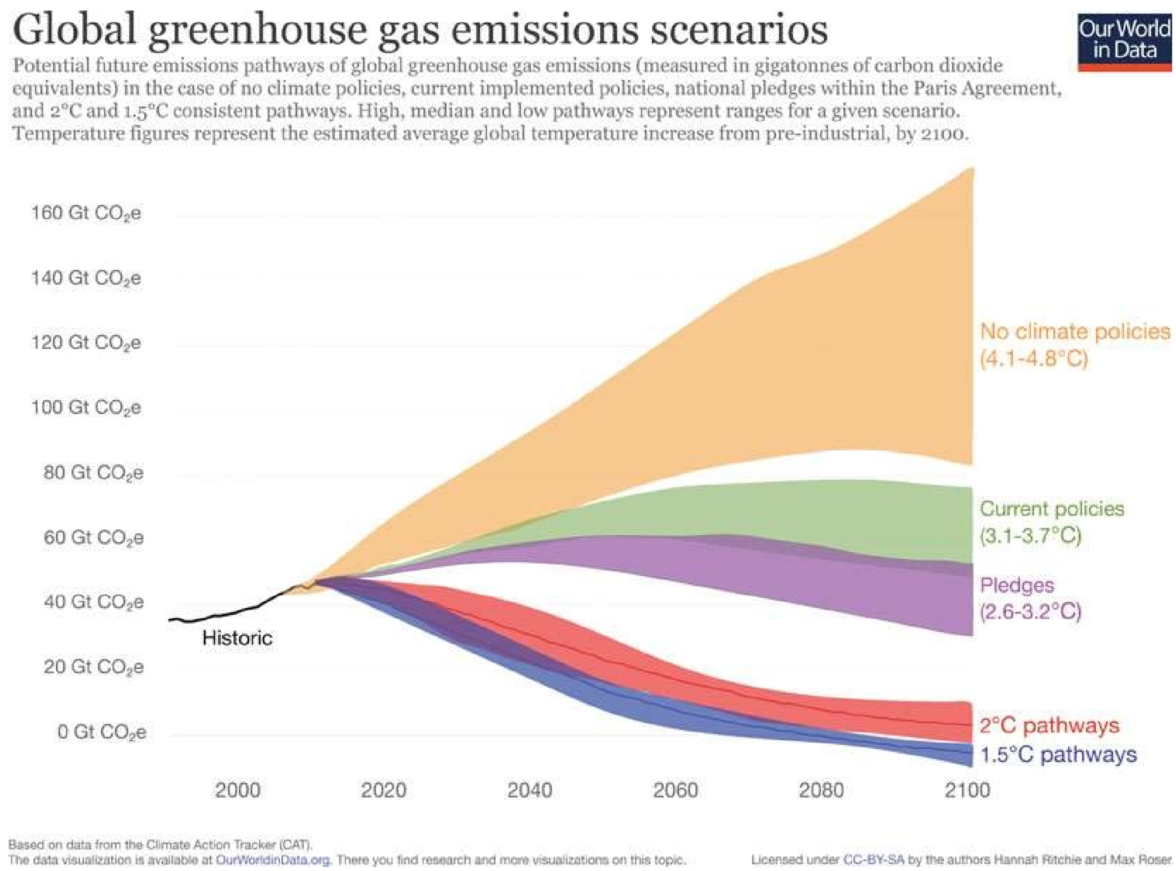


Fig. 13.1 Global greenhouse gas emission scenarios. All scenarios result in some degree of warming. Current policies are likely to result in warming of more than 3 °C, double the warming desired in the Paris Agreement. Credit: Ritchie and Roser (2019). Reproduced under a CC-BY-SA licence (https://creativecommons.org/licenses/by-sa/2.0/)

dioxide from the atmosphere, to limit global warming to 1.5 °C and reduce climate risks (IPCC 2018). Adaptation is the process of adjustment to actual or expected climate and its effects. Adaption is required to respond to committed warming due to past emissions. However, the increased extent of climate change limits the potential for adaptation. With increased mitigation, there is a better opportunity for effective adaption and reduced costs.

Sustainable Development Goal (SDG) 13, Climate Action, is therefore a key global challenge for managing climate change with effective policies, investment, and technologies as well as behavioural and lifestyle choices. The goal is to '***Take urgent action to combat climate change and its impacts'*** with three targets (13.1–13.3) and two means of implementation (13.A and 13.B), as listed in Table 13.1.

The collective ambition of **SDG 13** is to strengthen resilience and adaptive capacity to climate-related hazards and disasters, integrate climate change measures into policies, strategies, and planning, as well as improve education, awareness-raising and capacity building by meeting the commitments of the United Nations Framework Convention on Climate Change (UNFCCC), the primary platform for negotiating global action on climate change.

Climate actions are linked to numerous SDGs including **SDG 1** (end poverty), **SDG 2** (zero hunger), **SDG 3** (good health and well-being),

Table 13.1 SDG 13 targets and means of implementation

Target	Description of target *(13.1 to 13.3)* or means of implementation *(13.A to 13.B)*
13.1	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.2	Integrate climate change measures into national policies, strategies and planning
13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
13.A	Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible
13.B	Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities

SDG 7 (energy), **SDG 11** (sustainable cities), **SDG 14** (life below water), and **SDG 15** (life on land). Using the SDGs as an analytical framework, the IPCC underscored that the potential synergies for climate mitigation actions that limit global warming to 1.5 °C far outweigh the negative outcomes in various sustainable development dimensions (IPCC 2018).

Science is closely connected to the implementation of climate actions in building the resilience of the poor, ensuring sustainable practices in the agriculture, health, and energy sectors as well as conserving oceans and coastal ecosystems (ICSU 2017; IPCC 2018; Pereira et al. 2019). The contribution of geoscience towards these objectives is set out in Table 13.2, which also shows the indicators used to monitor progress towards **SDG 13**. Examples of geoscience being relevant to **SDG 13** include modelling the susceptibility of multiple hazards to inform disaster risk reduction and understanding where ground conditions are appropriate for carbon and energy storage. Climate extremes are expected to be unprecedented as the climate changes. The risk of disasters will be determined by the exposure of assets and the vulnerability of society. For example, the impact of a tropical cyclone depends on where it makes landfall. Likewise, the impact of a heatwave will depend on the vulnerability of the population. The cumulative impacts of disasters can affect the livelihood options and resources of a society as well as their capacity to prepare for and respond to future climate extremes. This situation calls for enhanced synergies between climate change adaptation (CCA) and disaster risk reduction (DRR).

This chapter explores these contributions, setting out how geoscientists can contribute to the targets of **SDG 13**. We emphasise the importance of common framing for climate and disaster risks over different time frames and spatial settings as well as knowledge of the subsurface to contribute to the multidisciplinary solution space of climate action. We begin with an overview of global progress in tackling climate change (Sect. 13.2). We then illustrate the role of geoscience in climate change adaptation and mitigation (Sect. 13.3) as well as examples of actions on resource mobilisation and capacity building (Sect. 13.4). In the conclusion (Sect. 13.5), we highlight the important ways in which geoscience knowledge plays a critical role in limiting global warming to 1.5 °C and addressing future climate risks, to achieve **SDG 13** for the global community.

13.2 Progress in Tackling Climate Change

Scientific work on climate change goes back as early as the fifteenth century and the industrial revolution served as an impetus for investigating atmospheric carbon dioxide and surface

Table 13.2 SDG 13 indicators by 2030 and geoscience relevance

SDG 13 indicator	Relevance to geoscience
13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015-2030 13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	Susceptibility modelling of multiple hazards such as landslides, flash floods, coastal hazards, etc. for developing local disaster risk reduction strategies
13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other)	Enhance forecasting of climate-related hazards through susceptibility modelling and improve knowledge of ground conditions for storage of carbon and energy
13.3.1 Number of countries that have integrated mitigation, adaptation, impact reduction and early warning into primary, secondary and tertiary curricula 13.3.2 Number of countries that have communicated the strengthening of institutional, systemic and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions	Improve communication on relevance of geoscience for integrating climate change mitigation, adaptation and disaster risk reduction as well as better geoscience curricula for water supply and sanitation, ground conditions, land use planning, subsurface development, siting of critical infrastructure, multi-hazard early warning; heat island effect, etc.
13.a.1 Mobilized amount of United States dollars per year between 2020 and 2025 accountable towards the $100 billion commitment	Mobilisation of resources on a bilateral basis from the Global North to the Global South through national geological organisations for subsurface evaluation, carbon capture and storage, etc.
13.b.1 Number of least developed countries and small island developing States that are receiving specialized support, and amount of support, including finance, technology and capacity-building, for mechanisms for raising capacities for effective climate change-related planning and management, including focusing on women, youth and local and marginalized communities	Reinforcing existing regional geoscience networks such as the CCOP in East Asia and SPC in the Pacific Islands for raising capacity in least developed countries and small island developing States, covering aspects of geoscience for integrated adaptation, disaster risk reduction and mitigation

temperature (Koh et al. 2013). Progress in the science domain gained traction in the 1970s and culminated in the establishment of the Intergovernmental Panel on Climate Change[1] in 1988 by the World Meteorological Organization (WMO[2]) and the United Nations Environment Programme (UNEP[3]). The initial task for the IPCC as outlined in UN General Assembly Resolution 43/53 of 6 December 1988 was to prepare a comprehensive review and recommendations with respect to the state of knowledge of the science of climate change, the social and economic impact of climate change, and possible response strategies and elements for inclusion in a possible future international convention on climate (IPCC 2018).

The First Assessment Report of the IPCC in 1990 led to the creation of the United Nations Framework Convention on Climate Change

[1]https://www.ipcc.ch/.

[2]https://public.wmo.int/en.

[3]https://www.unenvironment.org/.

(UNFCCC[4]), the key international treaty to reduce global warming and cope with the consequences of climate change. Since then, the IPCC has been conducting periodic assessments on the scientific basis of of risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation. The IPCC plays a critical role in linking the science and policy domains for climate change, where findings from this platform serve as the basis for climate change negotiations at the UNFCCC (Gao et al. 2017). The risk framing approach to climate change introduced by the IPCC provides a conceptual basis for the integration of climate change and disaster risk reduction over a range of time frames and spatial settings (Fig. 13.2).

Notwithstanding this, there is a fundamental difference in the use of the term 'climate change' in the science and policy domains with respect to its attribution. The science perspective as represented by the IPCC ascribes climate change to natural variability or external forcings that are both natural and due to human activity. In the policy domain, the UNFCCC restricts the definition of climate change to changes that are directly or indirectly attributed to human activity and that is in addition to natural climate variability over comparable time periods. Further clarification has been provided to improve the science policy discourse by mainstreaming terms such as detection and attribution (IPCC 2014).

Detection is the process of demonstrating a statistical change in climate or a system without providing a reason for that change. *Attribution* is the process of evaluating the range of causes for a change or event to ascertain relative contributions, with the provision of statistical confidence. Scientific communication on climate change is expected to be more nuanced with an increase in studies on the impacts of climate change that take into account aspects of detection and attribution.

The UNFCCC was ratified in 1994 and serves as the primary platform for enacting mechanisms to stabilise greenhouse gas concentrations to prevent dangerous human interference with the climate system. The stabilisation is to be achieved within a duration to allow ecosystems to adapt naturally, maintain food production, and enable sustainable development. Industrialised nations spearhead emission reduction taking into account values of 'equity' , 'common but differentiated responsibilities and respective capacities', and the 'precautionary principle'. Figures 13.2 and 13.3 show the annual and cumulative total CO_2 emissions (by world region), respectively, from 1751 to 2017. It is evidence from these that while China is currently the largest emitter of CO_2, European Union states and the USA have made by far the largest contributions to CO_2 emissions over time. The UNFCCC has sought to enhance global engagement in climate actions through various means including the Kyoto Protocol (1997), Cancún Agreements (2010), Durban Platform for Enhanced Action (2011), and most recently the Paris Agreement (2015) (Ha and Teng 2013; Gallo et al. 2018; Kuriyama and Abe 2018).

Progress in tackling climate change has accelerated in the policy domain through the Paris Agreement[5]. The Paris Agreement is a legal framework of the UNFCCC in which the Global North and Global South share the burden of reducing the emission of GHGs to manage the risks of climate change. A political target has been set to hold the increase in the global average temperature well below 2 °C compared to pre-industrial levels, and if possible pursue a warming limit of 1.5 °C. It is economically feasible to achieve this target through stringent mitigation efforts whilst enabling effective adaptation measures to cope with the climate impacts despite the political challenges (Yu and Zhu 2015; Leemans and Vellinga 2017; Cooper 2018; Travis et al. 2018).

The robust review of the global literature by the IPCC has confirmed that many impacts will be less potent by limiting the global warming to 1.5 °C compared to 2 °C. Limiting the global limit to 1.5 °C is possible but requires deep emission cuts, deployment of a range of

[4]https://unfccc.int/.

[5]https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

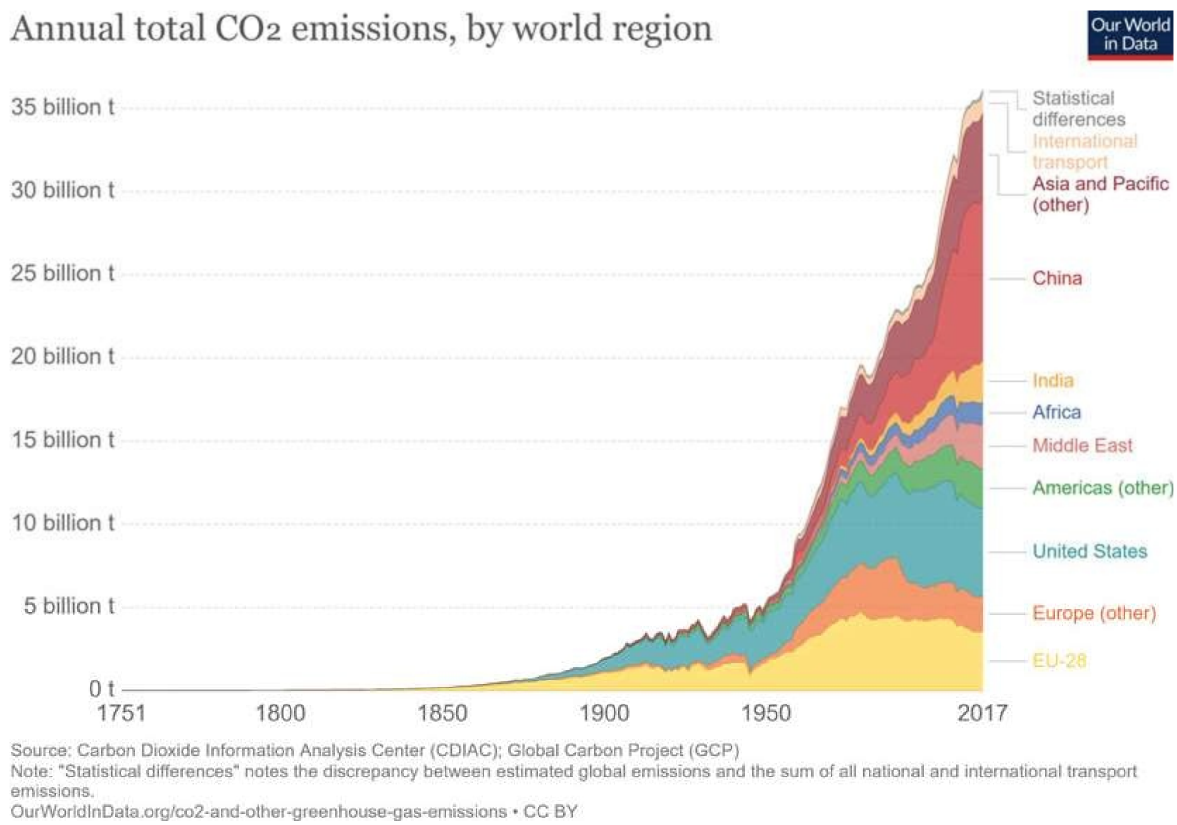


Fig. 13.2 Annual total CO_2 emissions, by world region. Credit: Ritchie and Roser (2019). Reproduced under a CC-BY licence (https://creativecommons.org/licenses/by/4.0/)

technologies, behavioural changes, and increased investment in low carbon options, at an unprecedented scale (IPCC 2018). Four plausible pathways with no or limited overshoot of 1.5 °C have been proposed, including a scenario with lesser use of technology through afforestation to one where emission reduction is mainly achieved through technological means such as carbon capture and storage. Early action is expected to be cheaper and would lead to better outcomes as well as reduce the need for adaptation.

Global progress on **SDG 13** and implementation of the Sendai Framework is tracked using the Sendai Monitor,[6] released in March 2018. The Sendai Monitor is an online tool where official information is uploaded by Governments based on a set of indicators that were negotiated in 2016 (United Nations 2016). Only nine of the 195 countries have validated their data while 108 have not started the process as of June 2019. Reports from the remaining countries are still in progress. Nearly half of the nations in the world have adopted and implemented national disaster risk reduction strategies in line with the Sendai Framework while data is not available for the remaining countries. Information is lacking for all other indicators where some have not been identified. The situation is expected to improve after the means for implementing the Paris Agreement, currently being negotiated by Governments, are established.

13.3 The Contribution of Geoscience to Climate Action

Geoscientists have made major contributions in multidisciplinary settings to enhance understanding of climate change in the science domain. Geoscience knowledge drives models

[6]https://sendaimonitor.unisdr.org/.

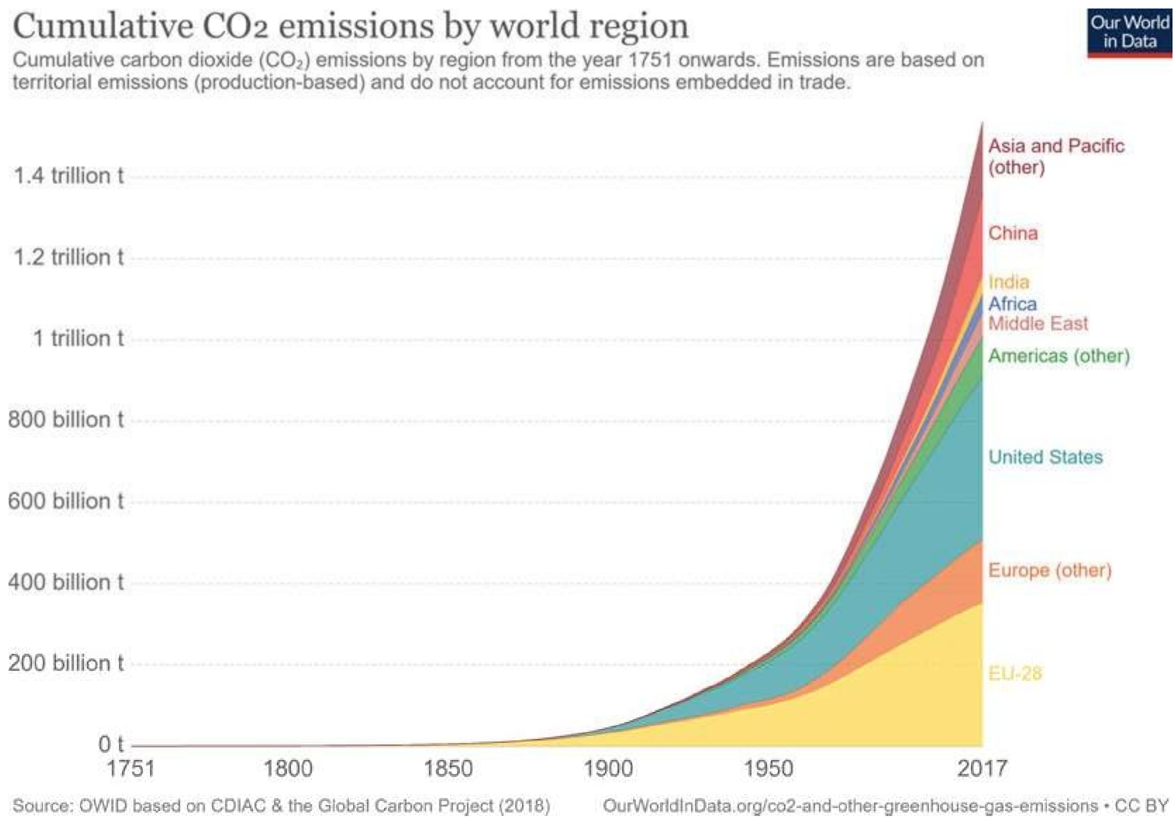


Fig. 13.3 Cumulative CO_2 emissions, by world region. Credit: Ritchie and Roser (2019). Reproduced under a CC-BY licence (https://creativecommons.org/licenses/by/4.0/)

that provide basic information for climate change adaptation. Subsurface geoscience information is also critical for key technologies that support climate change mitigation. There is significant potential for geoscientists to contribute further in the scientific discourse, for example, on the attribution of climate change to determine the causes of climate-driven geohazards. Geoscience inputs in this aspect could provide insights to delineate the contribution of natural and anthropogenic causes and serve as the basis for developing climate change policies that are equitable.

The geoscience community has also played a significant role in the policy domain, specifically in advancing progress in climate change mitigation. For example, geologists in the UK, Norway, and Canada played a critical role in the adoption of carbon capture and storage (CCS) as a climate change mitigation option under the Clean Development Mechanism, a cooperative instrument of the Kyoto Protocol (Lovell 2009) and in developing sound regulatory advice to underpin safe storage and enhance public confidence in CCS. The potential deployment of CCS technology to the Global South will help to balance energy resource development with emission reduction.

13.3.1 Climate Change Adaptation (Target 13.1)

The 2015 Paris Agreement calls for measures to strengthen climate change adaptation and this is important to address impacts due to historical emissions, which have already committed the future climate to warming conditions. Even if the climate eventually equilibrates at 1.5 °C or less above pre-industrial levels, anticipatory adaptation planning is required to eliminate the risk of large damages and adaptation costs in exposed and vulnerable areas (Travis et al. 2018).

In line with **Target 13.1** of **SDG 13**, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction mutually support development goals by strengthening resilience and adaptive capacity to climate-related hazards and disasters, particularly within national systems. The Sendai Framework on Disaster Risk Reduction emphasises climate change as a driver of hazards (**Box 13.1**). The transformation of scientific knowledge on climate, systematic observation, and early warning into tools, products, and services that support decision-making at the local level is critical for this purpose (Dolman et al. 2016; Giuliani et al. 2017; Forino et al. 2017). Greater involvement of local governments in implementing disaster risk reduction measures is expected to bring positive outcomes in reducing the number of deaths and injuries due to climate extremes and change.

Box 13.1. The Sendai Framework and Climate Change

The UNISDR (now UNDRR) Sendai Framework on Disaster Risk Reduction has seven global targets covering mortality, affected people, economic loss, damage to critical infrastructure, national and local disaster risk reduction strategies, international cooperation, and early warning including risk information and assessments. Four priority areas have been identified covering

- Understanding disaster risk.
- Strengthening disaster risk governance to manage disaster risk.
- Investing in disaster risk reduction for resilience.
- Enhancing disaster preparedness for effective response, and to 'Build Back Better' in recovery, rehabilitation, and reconstruction.

For more information see the relevant sections of ***SDG 1****, ending poverty.*

The Sendai Framework considers climate change and variability as a significant impediment to sustainable development. Climate is recognised as an underlying driver of increasing disaster risk both in terms of severity and increased frequency and intensity. In addition to large catastrophic disasters, the Sendai Framework equally applies to the risk of small- to large-scale, frequent and infrequent, sudden and slow-onset events, caused by natural or anthropogenic hazards. New risks and a steady rise in disaster losses are expected in the short, medium, and long terms, especially at the local level.

The Sendai Framework promotes partnerships and multi-hazard management of disaster risk in development, at all levels and across all sectors. There is a wide range of complementary approaches to deal with current disaster risks and future risks due to climate change within national systems, which constitute 'no-regrets' options (IPCC 2012; Forino et al. 2017). The use of science is advocated, for example, in comprehensive surveys on multi-hazard disaster risks, development of regional disaster risk assessments and climate change scenarios. Geoscientists should foster partnerships with climate scientists and other specialists to advance knowledge on multi-hazard risks.

Geological hazards have been widely investigated and significant contributions have been made to reduce the risk of catastrophic disasters (Marriner et al. 2010). Notwithstanding this, national-level investigation on the susceptibility of climate-influenced hazards using the wealth of information available from national geoscience agencies is not widespread (Cigna et al. 2018). Geoscience information has also not been mainstreamed into the policy domain with respect to climate change adaptation, to benefit society through cross-sectoral planning. This is reflected by the limited geoscience inputs and participation of national geoscience agencies in preparing progress reports such as the National Communications and Biennial Update Reports to the UNFCCC. National Adaptation Programmes are conducting climate risk assessments in designated conservation sites, which draw on geoscience information (Wignall et al. 2018). However, this is not a common practice, particularly in the Global South.

Earth processes and society are connected in multiple ways and geoscience inputs provide invaluable insights to understanding risk, exposure, and vulnerability. Whilst knowledge and technology is progressing in many areas, the geoscience community has to enhance the effort to contribute to the multidisciplinary solution space to meet the challenges expressed in the Paris Agreement and the Sendai Framework (Rogelj and Knutti 2016; Pereira 2018). In this context, a key challenge is to forecast and lessen the impact of natural hazards as the climate changes, particularly in the Global South. In Asia and Africa, lack of data, poor understanding of interactions between geology, climate change, and land-use change coupled with weak institutions and capacity have caused much damage and destruction to infrastructure (Hearn 2016; Broeckx et al. 2018; Maes et al. 2018).

Susceptibility modelling is advancing in the evaluation of climate-related hazards such as landslides, floods, erosion, and subsidence (e.g., Cigna et al. 2018; Reichenbach et al. 2018; González-Arquerosa et al. 2018; Hosseinalizadeh et al. 2019). Susceptibility modelling enables spatial demarcation of areas where a hazard event could occur, depending on contributing surficial features, geological conditions, and processes that vary depending on the hazard. Modelling of hazards at the global, regional, and national scale is not sufficient to provide specific adaptation measures at the local level, as indicated by the experience of landslides (Fig. 13.4), glacial lake outburst flooding, and coastal hazard assessments (Radosavljevic et al. 2016; Allen et al. 2018; Broeckx et al. 2018).

Local-level studies offer the best options for monitoring and early warning adaptation measures. The British Geological Survey (BGS) has

Fig. 13.4 Landslide (Cusco, Peru). Credit: Galeria del Ministerio de Defensa del Perú. Reproduced under a CC-BY 2.0 licence (https://creativecommons.org/licenses/by/2.0/)

assessed the entire range of nationally available datasets to delineate areas of the United Kingdom that are susceptible to hazards including landslides, flooding, and subsidence, targeting World Heritage Sites in the UK (Cigna et al. 2018). This approach can be applied to target other areas where there may be a risk to infrastructure such as dams, transport routes, and coastal power stations, among others. Areas at risk can be subject to further detailed investigation using conventional engineering geology methods (see **SDG 9**, covering resilient infrastructure).

Landslide susceptibility modelling is progressing to incorporate the effects of climate and environmental changes at different spatial and temporal scales (Gariano and Guzzetti 2016; Reichenbach et al. 2018). Machine learning algorithms are advancing to use a small number of samples for landslide susceptibility modelling with periodic updates to take into account climate change (Huang and Zhao 2018). Susceptibility modelling based on terrain morphology, geology, soils, and land cover has been found to be cost effective, applicable at large or small scales, complementary to hydrological models and suitable for land-use decision-making (van Westen et al. 2008; Perucca and Angilieri 2011). For example, high-resolution terrain mapping is taking into account the identification of and linkage of landslides and erosional processes as a response to tectonic activity and climate change (Geach et al. 2017).

Machine learning models have also been found to be effective in delineating areas susceptible to internal erosion or piping processes, which contribute to loss of agricultural productive capacity, land degradation, and increased sediment yields (Hosseinalizadeh et al. 2019). The monitoring of areas susceptible to landslides prior to the occurrence of wildfire has been identified as an adaptation option to help reduce the effects of erosion (Peterson and Halofsky 2018). Similarly, the monitoring of periglacial degradation of bedrock and moraine has been identified as a key option for early warning of debris flow in high mountain regions as the temperature increases (Wei et al. 2018).

Flood and flash flood risk assessment and solutions to flood and flash flooding have also benefitted from the susceptibility approach. Intensive data requirements and access to expert knowledge for standard engineering flood models are a challenge to governments of the Global South (Cunha et al. 2017; Teng et al. 2017; Komi et al. 2017). Flash floods and water shortages have also been reported to occur in the same areas at different seasons. Geoscience knowledge is significant in this respect, particularly to promote sustainable urban drainage systems, for storage for excess water in underground reservoirs and engineered structures to ensure consistent water supply (Stephenson 2018; Nguyen et al. 2019).

Coastal hazards such as storms and floods as well as slow-onset sea-level rise, inundation, and erosion are expected to impact communities that live in susceptible coastlines with high exposure. Recent geoscience findings indicate that a small rise of 0.5 m in sea level is expected to double the frequency and the intensity of tsunami-induced flooding of the coasts of Macau due to earthquakes along the Manila Trench (Li et al. 2018). Sea-level rise also threatens coastal aquifers and exposes infrastructure such as waste disposal sites that could emerge as future pollution sources (Jamaludin et al. 2016; Yahaya et al. 2016; Stephenson 2018). Geomorphological features are an important factor in the development of decision-support tools that deal with coastal disaster risk reduction and multi-hazard risk of social–ecological systems (Fischer 2018; Ferreira et al. 2018; Hagenlocher et al. 2018). Geoscientists have the capacity to advance disaster preparedness in a variety of sea-level scenarios, to build the resilience of coastal communities.

There is great potential for geosciences to progress susceptibility modelling for multi-hazards at the local level under a variety of climate settings, in collaboration with experts from diverse disciplines.

Box 13.2. Disaster Resilience in Kuala Lumpur, Malaysia

The Asian Network on Climate Science and Technology (ANCST[7]) facilitates the advancement of science, technology, and innovation through multi-sector and multidisciplinary partnerships, to support the implementation of the Sendai Framework on Disaster Risk Reduction and the Paris Agreement.

ANCST has been instrumental in bringing together geoscience, climate, and atmospheric experts from Malaysia and the UK, to jointly develop the project on '*Disaster Resilient Kuala Lumpur*', summarised in Fig. 13.5. In this project, selected meteorological and hazard models including susceptibility approaches are being adapted for tropical circumstances and integrated onto a common multi-hazard platform for the City Hall of Kuala Lumpur (DBKL) to improve forecasting.

Improved forecasting capacity for flash floods, landslides (Fig. 13.6), sinkholes, strong winds, urban heat, and air pollution at the city and neighbourhood scales is expected to contribute greatly to enhance disaster resilience as the climate changes in tropical terrain.

13.3.2 Climate Change Mitigation (Target 13.2)

The Paris Agreement set the global goal of limiting warming to below 2 °C above pre-industrial levels while '*pursuing efforts to limit the increase to 1.5* °C' (UNFCCC 2016). Geoscience contributes to this goal by supporting the transition to a low-carbon energy regime to mitigate greenhouse gas emissions and address future energy security. Renewable energy resources and technologies such as geothermal, wind, solar power, hydropower, tidal wave, and biomass as well as their applications and services to buildings, industry, electricity, and transport utilise geoscience information. Geoscience knowledge, integrated into policies, strategies, and planning at various levels, has great potential to support integrated tools to facilitate the transition to a low-carbon energy regime, adapt to the adverse climate change impacts and foster disaster resilience, and achieve **Target 13.2** of **SDG 13** (Lovell 2009; Barrie and Conway 2014; Martens and Kühn 2015; Kühn et al. 2016).

Wind, solar power, hydropower, tidal wave, biomass, and other renewable forms of energy generation are dependent on weather and climate. Modelling and measurement for resource assessment and site selection for these energy sources draw on geoscience information. For example, the placement of renewable energy facilities may extend to complex terrain and offshore regions that are difficult to model. More effort is required to combine geoscience information with climate and other data sources to enable a multidisciplinary and dynamic analysis of the suitability of renewable energy facilities (see also the chapter exploring **SDG 7**, affordable and clean energy).

Carbon capture and storage (CCS) is increasingly accepted as a viable, feasible, and safe technology for climate change mitigation. However, CCS alone cannot be expected to support the goal of maintaining global temperatures below 2 °C, particularly in the absence of effective policy drivers. The CCS technology essentially involves the separation of carbon dioxide from a source and subsequently storing the carbon for long-term isolation from the atmosphere (Metz et al. 2005). The process involves three stages: capture, transport, and storage. The CO_2 is collected from a static emitter such as a power plant, compressed and then routed to a storage site through pipelines. Storage sites are essentially geological formations with suitable porosity and permeability including oil and gas reservoirs, deep coal seams, saline aquifers, and salt caverns (Fig. 13.7).

The deployment of CCS has been shown to be geologically viable, safe, effective and its costs are expected to decrease (Szulczewski et al. 2012; Cook 2017). However, there are concerns regarding pressure increase and saltwater

[7]http://ancst.org.

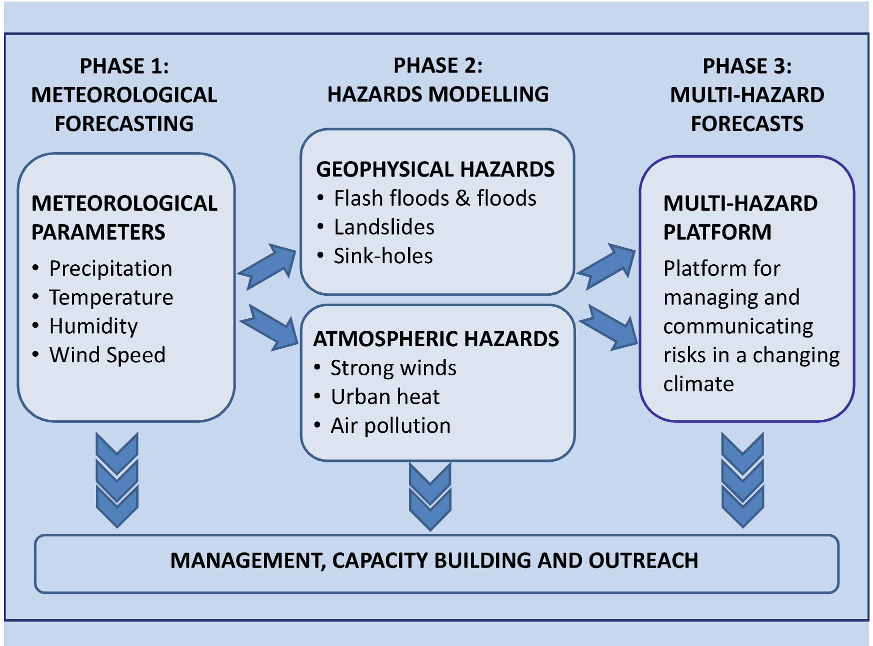


Fig. 13.5 Established in 2013 with seed-funding from the Cambridge Malaysia Education Development Trust Fund and Malaysia Commonwealth Studies Centre, ANCST under the coordination of Universiti Kebangsaan Malaysia's Southeast Asia Disaster Prevention Research Initiative (SEADPRI-UKM) was instrumental in bringing together a multidisciplinary team of scientists from meteorological, geological and atmospheric backgrounds for the Disaster Resilient Kuala Lumpur project supported by the Newton Ungku Omar Fund, a joint initiative of the Governments of UK and Malaysia. Credit: Authors' Own

displacement in deep aquifers. Pressure increase could lead to the disintegration of cap rocks or reactivation of faults and subsequently cause leakage of carbon dioxide. Saltwater displacement may contaminate drinking water reservoirs in shallow groundwater systems above the storage complex, if they are connected. The effort to increase the understanding of sequestration mechanisms and technology is continuously ongoing (Charalampidou et al. 2017; Kühn et al. 2017; Renforth and Henderson 2017).

Geoscientists can contribute to limiting negative emissions by providing safe storage capacity to meet the temperature target of the Paris Agreement. Advances in integrating CCS technology with other types of energy production (e.g., biomass) and energy storage require significant geoscience knowledge (Martens and Kühn 2015). Another emerging geoscience sequestration technology is coupled carbonate weathering (CCW), from carbonate mineral weathering in combination with aquatic photosynthesis on the continents, which may help to offset atmospheric CO_2 at a global scale (Liu et al. 2018).

Geothermal energy is increasing in use for both heating and cooling (Lund and Boyd 2016), requiring more enhanced knowledge on subsurface conditions. This includes information on natural and induced fractures as well as permeability characteristics to better predict mechanical and flow response of heat and ensure safe and economical energy supply from shallow and deep geothermal resources (Kühn et al. 2016). A range of modelling is applied in all phases of geothermal exploitation, from the prediction of geothermal potentials to the optimisation of borehole locations as well as in improving the efficiency of existing geothermal facilities (Bocka et al. 2013; Hong et al. 2017). A thorough understanding of the subsurface is critical for managing geothermal systems effectively, particularly in urban areas, to avoid overexploitation and conflicts with other subsurface use.

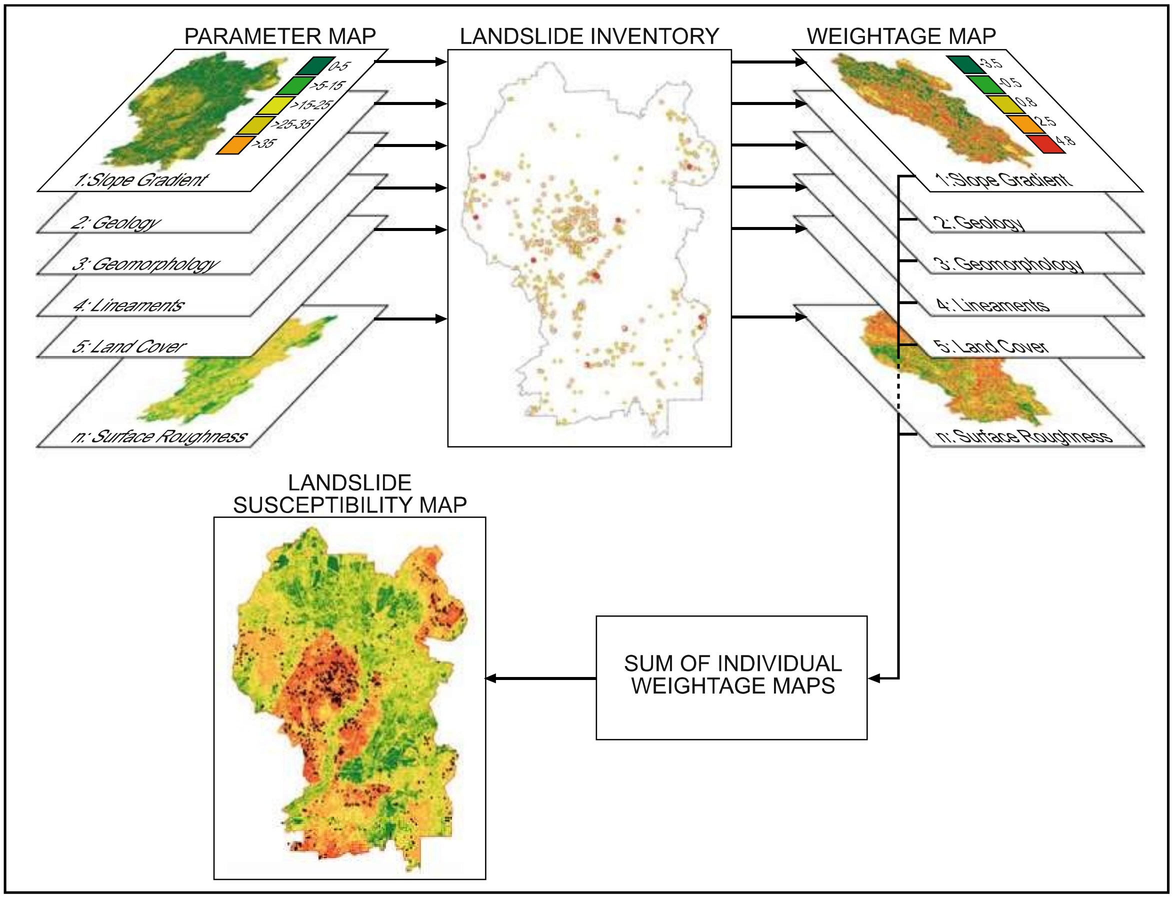


Fig. 13.6 *Landslide susceptibility modelling* in the Disaster Resilient Kuala Lumpur project *used the statistical approach, where* parameters that influence the hazard were correlated with the inventory to obtain the weightage that is used to derive the level of susceptibility at the city scale, which is subsequently validated. Credit: Authors' Own

Long-term utilisation of geothermal systems requires numerical simulation and three-dimensional models. These research fields should be further expanded in the geosciences.

Wind and solar are becoming increasingly important energy sources. However, energy production from these facilities is intermittent and alternate sources are required to compensate for fluctuating power generation.

Geological formations offer a great potential to store energy over various timescales in the form of subsurface storage of heat, subsurface hydrogen storage, and compressed air energy storage (Kabuth et al. 2017). Storage of energy is primarily in salt caverns (Ozarslan 2012; Bauer et al. 2013; Bauer 2016). Compressed air energy storage is most promising in wind farms, converting electricity into mechanical energy in the form of highly pressurised air, which is then stored in the subsurface. The pressurised air is then used to generate electricity through wind turbines, which is integrated into the grid during peak loads. The use of porous geological formations is currently under investigation to expand the deployment of compressed air energy storage (Wang and Bauer 2017). This is expected to advance the expansion of wind and solar energy as porous geological formations are more widely available and can offer even larger storage capacities. The use of geological formations to integrate energy storage and carbon storage is also being explored to close the entire carbon cycle (Martens and Kühn 2015).

Offshore, the marine environment offers much potential for renewable energy and carbon storage (see also **SDG 14**). The development of renewable energy is most advanced for wind while wave and tide energy sources are expanding

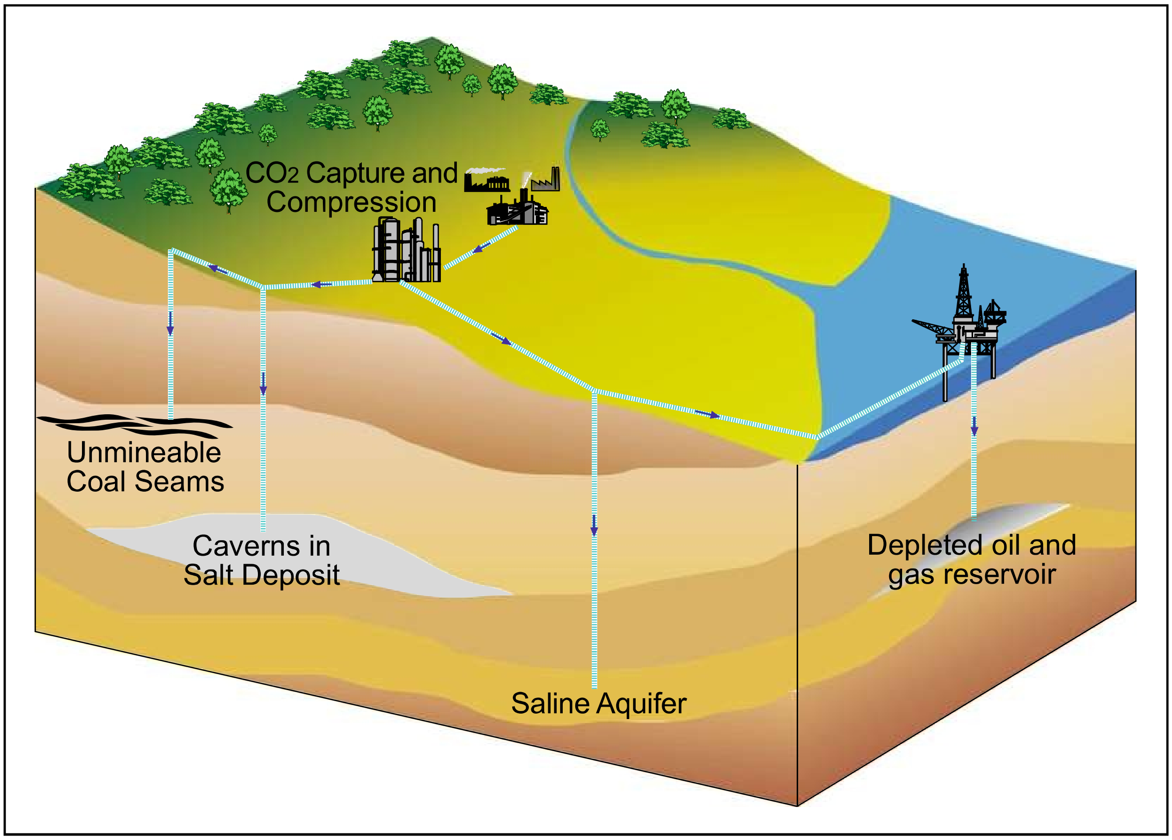


Fig. 13.7 There are various ways in which geological formations can sequester and store carbon dioxide as well as stockpile energy, and this requires substantial geoscience knowledge of subsurface conditions and processes. Credit: Authors' Own

rapidly (Barrie and Conway 2014). Much of the advancement in the marine sector is challenged by a range of geoscience issues (Barrie et al. 2014). Geological characteristics and physical environment parameters need to be properly assessed to facilitate the safe deployment of marine renewable energy and support offshore carbon storage. Geological information is critical for understanding geotechnical conditions on which the energy system will be anchored. The routing of cables is also dependent upon the geological and physical conditions of the seabed, where the understanding of ocean phenomena such as subaqueous landslides needs to be improved (Mengerink et al. 2014; Reichenbach et al. 2018). The assessment criteria for site suitability and potential assessment for carbon storage is under development, drawing on geological characteristics and their potential for leakage. This new feature of continental shelf research is expected to advance strategies for carbon storage in offshore sedimentary basins.

13.3.3 Education and Awareness Raising (Target 13.3)

Education, awareness raising, and strengthening of institutional capacity are key to achieve **Target 13.3** of **SDG 13** (Fig. 13.8). However, educational curriculum reforms in institutions of higher learning have had limited success in ensuring that all students are exposed to climate science, climate change, disaster risk reduction, and sustainability issues (Hess and Collins 2018; Brundiers 2018; Nakano and Shaw 2018). Scientists tend to converse with their peers and require new skill sets to communicate with the media, policymakers, and other stakeholders to influence public discussion about climate change.

Fig. 13.8 Students in Ladakh express their perspectives on climate change through paintings and artwork © Geology for Global Development (used with permission)

This contributes to a poor understanding of the role of geoscience in climate change and disaster risk in many policy and planning institutions. There is also the need to develop a good narrative for the geoscience story of climate change (Filho et al. 2018; Harris 2017; Reis and Ballinger 2018).

A wide range of education, awareness-raising, capacity building, and policy engagement orientations is required, including more inclusive and transformative social learning approaches, to effectively support the Paris Agreement (Macintyre et al. 2018). The geoscience community needs to strengthen linkages with multiple disciplines including the social sciences, forge strategic partnerships, and participate actively in science-policy platforms. The rich tradition of geo-conservation and emerging capacity for providing web-based 'smart geo-services' can be leveraged upon for this purpose. Enhanced communication on the relevance of geoscience knowledge in integrating climate change adaptation and disaster risk reduction will also support sustainable development. These aspects should be explicitly integrated into geoscience education, training, and continued professional development (Stewart and Gill 2017; Bolden et al. 2018; Zhang et al. 2018).

Geoscience institutions have played a leading role to support education, awareness raising, and capacity building to mitigate greenhouse gas emission and meet future demands for renewable energy supply. The Sleipner storage site in the North Sea is the world's first and longest operating CCS demonstration project, which is being successfully monitored by using geoscience knowledge to raise awareness and provide assurance to policymakers, investors, and the public on the safety of the technology. Awareness raising of CCS is also emphasised in Canada, where geoscience expertise was utilised at the Weyburn CO_2-Enhanced Oil Recovery project to refute claims of leakage (Jones et al. 2011; Sacuta et al. 2017). Another major CCS demonstration project is in Australia. The demonstration site is the result of two decades of work focused solely on carbon capture and geological formations, initially drawing on the expertise of geologists, geophysicists, geochemists, and hydrogeologists (Cook 2017).

The number of specialised courses on geothermal energy is limited worldwide (Zarrouk 2017). Raising awareness of geothermal energy in Germany uses a geoethical approach where a generic underground laboratory has been established (Meller et al. 2017), and transparent communication is encouraged. This is tangible science that can serve to enhance mutual understanding of stakeholder groups and increase public awareness to facilitate responsible exploitation of geothermal energy. Capacity building of geoscientists in climate mitigation technology is advanced by the European Geosciences Union, which periodically brings together geoscientists from all over Europe and the rest of the world to discuss future challenges during the General Assembly. The issue of renewable energy and carbon storage is of explicit concern at this platform where advances in multidisciplinary approaches and future research needs are highlighted, providing insights on the role of geoscience (Kühn et al. 2016).

13.3.4 Resource Mobilisation and Capacity Building (Targets 13.A and 13.B)

Resource mobilisation in the context of meaningful mitigation actions (**Target 13.A**) as well as capacity building in the least developed countries and small island developing States (**Target 13.B**) are important means of implementation for **SDG 13**. The Global South faces many challenges in maintaining economic growth while increasing energy efficiency and shifting from carbon to renewable energy to reduce GHG emissions (Liobikienė and Butkus 2018), with links to many other SDGs. Such challenges include capacity limitations and the availability of and access to technology and financial resources. Economic development is a necessity for the Least Developed Countries (LDCs) as they manage the risks of climate change. Issues such as extensive poverty (**SDG 1**), widespread unemployment (**SDG 8**), poor access to clean water (**SDG 6**), rural electrification (**SDG 7**), deforestation as well as dryland and desert expansion (**SDG 15**) are critical for LDCs (Teklu 2018). Small island developing states (SIDS) are already experiencing the impacts of climate change (see **SDG 14**), particularly in the tourism and fisheries sectors (Nurse et al. 2014). Existing vulnerabilities and weak adaptive capacities need to be urgently addressed to ensure the sustainability of SIDS in a changing climate (Robinson 2018).

Resource mobilisation and capacity building related to geoscience have had a long history of creating enabling conditions for contributing to economic development and poverty eradication in the mineral, energy, and construction sectors of the Global South. Enhanced capacity in geoscience knowledge has also played an important role in ensuring the well-being of society by the provision of information on groundwater resources, disaster risks, and environmental pollution as well as food security and human health. The practice of resource mobilisation for enhancing geoscience capacity is now supporting climate change mitigation actions in the Global South. Climate change adaptation is of particular focus in LDCs and SIDs. In both these cases, the importance of ensuring that the recipient country has the capacity to absorb and sustain the technology being deployed by the donor cannot be overemphasised.

Resources have been mobilised for enhancing geoscience capacity in carbon capture and storage (CCS) from the British Geological Survey and Geoscience Australia to emerging economies such as China and India (Feitz et al. 2017; BGS 2018). Regional bodies such as the Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP) and the Geosciences Division of the Pacific Community (SPC) serve as important one-stop-networks for strengthening geoscience knowledge in CCS and renewable energy in the Global South. The CCOP convenes training and capacity building in CCS on a routine basis for national geoscience organisations in the region (CCOP 2018). The SPC facilitates opportunities for exploration of geothermal energy and ocean thermal energy conversion to advance sustainable development in the region (Petterson and Tawake 2016).

Groundwater has a significant relationship with the water, health, food, and energy nexus in the context of climate change (Jakeman et al. 2016). Countries in the Pacific islands are frequently exposed to climate extremes, and sea-level rise is an imminent threat to groundwater resources, as characterised in the chapter exploring **SDG 14**. Many LDCs and SIDs need enhanced geoscience capacity for groundwater resource management and climate extremes. National geoscience institutions are addressing this need through the mobilisation of resources. For example, rural Africa has benefited from work conducted by BGS to support adaptation and build resilience to climate change (BGS 2011). Among the products of this project is the aquifer resilience map for Africa, which draws on existing information on geology and hydrogeology (see **SDG 6**). Geoscience Australia is developing tools that encompass desktop software designed for local governments and communities to provide insights into the likely impacts of future risks, so that appropriate responses can be taken for planning, preparing, and responding to disasters.

13.4 Summary and Conclusions

All countries are exposed to increased risks due to climate change. Climate change adaptation and mitigation are two complementary approaches for reducing and managing the risks of climate change. Adaption is required to respond to committed warming due to past emissions but its potential is limited for high levels of warming. Climate change mitigation by substantially reduced emissions over the next few decades is critical to reduce future climate risks. The Paris Agreement sets an ambitious target to maintain global average temperatures well below 2 °C and if possible, limit warming to 1.5 °C above pre-industrial levels, whilst supporting adaption efforts in the least developed countries and small island developing states. The complementary goals of the Paris Agreement and Sendai Framework on Disaster Risk Reduction have strengthened policy coherence under **SDG 13** on urgent actions for combating climate change and its impacts (Djalante 2019; Mizutori 2019).

Geoscience is steadily increasing its contribution to the multidisciplinary solution space that addresses the challenge of climate change. Susceptibility modelling of hazards such as landslides, floods, erosion, and subsidence offers invaluable insights for understanding risk, exposure, and vulnerability to predict and lessen the impact of natural hazards as the climate changes. Nationally available geoscience datasets must be leveraged to develop local-level monitoring and early warning adaptation measures, under a variety of climate settings. Geoscience also fundamentally supports emission reduction and the transition to a low-carbon energy regime. This is done primarily through carbon capture and storage (CCS) and the development of geothermal energy which are viable, feasible, and safe options to mitigate carbon emissions.

Geoscience knowledge has been integrated into policies, strategies, and planning at various levels. At the global level, carbon capture and storage has been successfully promoted at the UNFCCC (Lovell 2009). But increasingly geoscience data and understanding need to be mainstreamed into the policy domain with respect to climate change adaptation, to benefit society through cross-sectoral planning. This calls for a major transformation in the geoscience community with respect to education, awareness raising, capacity building, and policy engagement. The geoscience community needs to strengthen linkages with multiple disciplines including the social sciences, forge strategic partnerships, and participate actively in science-policy platforms. Such aspects should be explicitly integrated into geoscience education, training, and continued professional development. The long-term benefits would include enhanced resource mobilisation and strengthening of geoscience capacity for climate change mitigation actions in the Global South, particularly for the least developed countries and small island developing states.

13.5 Key Learning Concepts

- Climate change refers to changes in the state of the climate that persists over an extended period, typically decades or longer, which is caused by natural processes and human activity. Natural processes that affect the global climate are solar cycles and volcanic eruptions. Human activities have contributed to natural change by contributing unprecedented levels of greenhouse gases (GHGs) including carbon dioxide, methane, and nitrous oxide.

- Human activities have caused around 1 °C of global warming since pre-industrial times, contributing to surface warming of continents, affecting the global water cycle, causing glaciers to retreat as well as increasing surface melting of the Greenland ice cap, loss of Arctic sea ice, raising upper oceanic heat content and global mean sea levels.
- Past emissions have already committed the future climate to warming conditions. The gravity of the situation is worse at 2 °C compared to 1.5 °C. More extreme weather, higher impact on biodiversity and species, lesser productivity of maize, rice, and wheat, 50% more of the global population exposed to water shortages and several hundred million more people will be exposed to climate-related risk and susceptible to poverty by 2050 should global warming increase to 2 °C compared to 1.5 °C.
- All countries are exposed to increased risks due to climate change. Climate change mitigation and adaptation are two complementary approaches for reducing and managing the risks of climate change. Climate change mitigation is critical for substantially reducing emissions over the next few decades and reduce future climate risks. Climate change adaption is required to respond to committed warming due to past emissions but its potential is limited for high levels of warming.
- Geoscientists support emission reduction and the transition to a low-carbon energy regime. This is done primarily through carbon capture and storage (CCS), development of geothermal energy, and subsurface energy storage by providing options that are viable, feasible, and safe. Geoscience knowledge is recognised at the global policy level for carbon capture and storage.
- The risk of disasters is determined by the extent of a hazard, exposure of assets, and vulnerability of society. Susceptibility modelling of hazards such as landslides, floods, erosion, and subsidence offers invaluable insights for understanding risk, exposure, and vulnerability to predict and lessen the impact of natural hazards as the climate changes. Nationally available geoscience datasets can be leveraged to develop local-level monitoring and early warning measures under a variety of climate settings, requiring enhanced synergies between climate change adaptation (CCA) and disaster risk reduction (DRR).
- Geoscience knowledge needs to be mainstreamed into the policy domain with respect to climate change solutions that benefit society. A major transformation is required in geoscience education, training, and continued professional development with respect to awareness, capacity building, policy engagement, strategic linkages, and transdisciplinary networking for climate change actions.

13.6 Educational Ideas

In this section, we provide examples of educational activities that connect geoscience, the material discussed in this chapter, and scenarios that may arise when applying geoscience (e.g., in policy, government, private sector international organisations, and NGOs). Consider using these as the basis for presentations, group discussions, essays, or to encourage further reading.

- How may climate changes affect the frequency and magnitude of natural and environmental hazards? Prepare a matrix with characteristics of climate change (e.g., rising temperatures andsea-level rise) on one axis, and diverse natural hazards relevant to your region (e.g., landslides, flooding, and subsidence) on the other axis. For each cell, consider if there is an effect of the climate change characteristic on the natural hazard, and if so, describe it. How can the contents of your matrix inform steps taken to reduce disaster risk?

- What are the geological characteristics associated with good locations for carbon capture and storage? Review a geological map of your region (use the OneGeology Portal[8] or any available paper/digital maps) to determine if there are potential geological units that may be suitable.
- Communicating geoscience to public audiences is a valuable skill. Reflecting on the theme 'what does geological history teach us about climate change today', design a public engagement activity that helps *children* understand key lessons from the geological record for climate action.
- Research the four plausible pathways proposed with no or limited overshoot of 1.5 °C warming (mentioned in Sect. 13.2). What are the geoscience contributions to each? Divide into four groups, with each giving a summary of different pathways, the role of geoscientists, and any assumptions made when assuming this pathway would have no or limited overshoot of 1.5 °C warming. Debate the merits of each pathway as a class, and vote on which you would choose to pursue.

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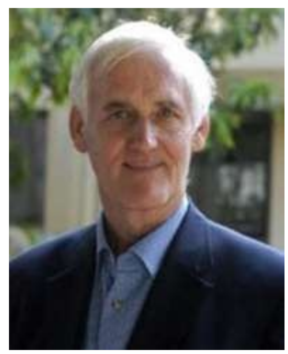

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