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Business and Policy Solutions to Climate Change

From Mitigation to Adaptation

Edited by
Thomas Walker · Stefan Wendt
Sherif Goubran · Tyler Schwartz

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Preface

Our planet's climate is changing, and we are heading to a world that is at least 2 °C warmer than it was prior to the world's industrialisation. Predictions for this future suggest that freshwater will be scarce, extreme weather events will become a frequent reality, global sea levels may rise up to 2.4 m above today's levels, and flooding and wildfires will no longer be discrete events. In light of these consequences, this collection aims to ignite an academic discussion regarding the necessary and potentially urgent adaptation actions required.

The book does not intend to cause panic for its readers. Instead, it explores how we can adapt to this "new" world and assesses the readiness of our businesses and policies to a future where climate change is a reality. The book stresses the importance of transformational strategies to adaptation, in contrast to incremental approaches that may be misaligned with the possibly extreme consequences of climate change.

The editors invited researchers, practitioners, and entrepreneurs who are at the intersection of business, policy and climate research to share their solutions and adaptation strategies to our climate-induced economic, technical, urban, and societal challenges. The editors accepted contributions that shed new light on our understanding of vulnerabilities and risks, present new and emerging processes for internalizing adaptation in existing business and policy approaches, and identify new barriers to large-scale and/or local climate change adaptation. The editors encouraged the contributors to move beyond the current disciplinary divides and present novel interdisciplinary approaches. In addition, they encouraged contributions that employ scenario analyses in their investigations and study the social, economic, environmental, and cultural dimensions of this complex future world.

The resulting collection reviews and critically analyses new business and policy approaches regarding solutions to climate change mitigation and adaptation across different locations and economic sectors and presents new ways to overcome conflicts in business and policy adaptation trajectories. In these contributions, the authors make connections to the business and policy aspects of the book by applying ethical and behavioural frameworks, studying the role of financial tools and instruments, and exploring the role of civil engineering in the adaptation of cities. In many instances, the accepted chapters focus on emerging challenges and themes regarding adaptation, including health, well-being, air quality, urban planning, production and consumption, waste, threats to indigenous communities, and biodiversity.

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Part I

Introduction

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Climate Change Adaptation: An Overview

Thomas Walker, Stefan Wendt, Sherif Goubran, and Tyler Schwartz

1 Introduction

Climate change mitigation, understood as an approach to reduce human-induced emissions, has taken center stage in climate action debates and efforts in the last decades. Numerous publications, reports, books, and conventions have presented, analyzed, and compared the actions and strategies

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taken by governments, non-governmental organizations, and the private sector to curb emissions and other forms of anthropogenic pollution.

Published reports and studies present scenarios under which we can limit the global temperature rise to 2 °C above the pre-industrial level threshold. To achieve the representative concentration pathway (RCP) needed to stay within the 2 °C threshold, we need to move toward net-negative global emissions, which despite various efforts could not be accomplished so far (Carton et al., 2020). Moreover, for such a scenario to be possible, mobilization on a global scale is required, and improvements are needed in the mitigation approaches to managing global warming. Although there is global political aspiration to stay within 2 °C above the pre-industrial level threshold, researchers have already explored the consequences of more realistic warming scenarios that consider the Copenhagen pledges and other international agreements, which could place us close to or even beyond 4 °C of warming by 2070 (Beits et al., 2011). After passing the symbolic 400 parts per million (ppm) threshold of carbon dioxide equivalents (CO_2-eq) in the atmosphere, climate studies have highlighted that the current emission trajectory can easily lead to concentrations of up to 1000 PPM of CO_2-eq (Collins et al., 2013, p. 1096). This status-quo-based RCP is expected to result in average global warming of up to 5.4 °C by the end of this century (Krinner et al., 2013, p. 1056).

Moreover, even a 2 °C global warming level is expected to have catastrophic outcomes on both the ecosystem and on human activities—including substantial increases in heatwaves and associated droughts/wildfires, a reduction in freshwater availability, an increase in the frequency and severity of natural disasters, reductions in various crop yields and associated malnourishment in many developing countries, and an endangerment of the world's coral reefs (Karmalkar & Bradley, 2017).

Even though climate research continues to report upon and warn us about such updated warming scenarios and their biophysical and social effects (Gemenne, 2011; Karmalkar & Bradley, 2017; Nicholls et al., 2011; Thornton et al., 2011), recent publications have paid little

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attention to the concrete business and policy changes that are required to adapt to this new warmer world (Anderson & Bows, 2011; Minx et al., 2017). Moreover, while there has been a growing interest in direct carbon removal technologies (Carton et al., 2020), it is increasingly evident that adapting business models, policies, and human activities and settlements to the changing climate is essential to ensure their continuity.

Practitioners and policymakers are increasingly shifting their attention away from the almost exclusive focus on climate change mitigation to consider adaptation plans and find the optimum combination of both (Al-Ghussain, 2019; VijayaVenkataRaman et al., 2012). The Intergovernmental Panel on Climate Change (IPCC, 2014, p. 1758) defines the process of climate change adaptation as the "adjustment to actual or expected climate and its effects." In more general terms, the IPCC describes adaptation as an approach whereby a living being seeks to moderate or avoid harm or exploit beneficial opportunities in the face of a change in its surroundings (IPCC, 2014). This approach considers both mitigation and adaptation, and calls for designing and implementing concrete strategies for a world beyond the climate tipping point—one in which we will have to adapt to more pessimistic climate change scenarios (Al-Ghussain, 2019). It would also require seeking innovations that can help us synchronously adapt to committed change and shift our planning processes and behaviors (Kahn, 2016). Within these definitions, actors are expected to not only reduce the negative impact of existing hazards but also act and adjust their activities based on the expected threats that climate change poses.

This growing challenge creates uncertainties, which put pressure on businesses, governments, and even individuals. Stakeholders are expected to consider scenarios that have not yet materialized or that may never fully materialize depending on the actual emissions pathway (Kahn, 2016). Some have criticized this shift to adaptation, highlighting that adaptation might create trade-offs with the current mitigation efforts. This tension highlights the interwoven cycle of adaptation-mitigation that requires a delicate and knowledgeable balance and underscores the current knowledge gaps that need to be addressed to move in this sensible direction (Jorgenson et al., 2019)

2 Overview of Content

This edited book addresses these complex problems and the knowledge gaps identified by investigating the business and policy adaptation trajectories beyond what is currently understood to be the major tipping point in the climate system. It reviews and critically analyzes new and innovative business and policy approaches to climate change adaptation across different economic sectors and locations. It also aims to assess strategies that move beyond the current incremental approaches to consider systemic changes—what the IPCC classifies as transformational adaptation (IPCC, 2014, 1758). Through this approach, the book evaluates the readiness of our businesses and policies to adapting to this "new" world and presents novel interdisciplinary approaches, which use scenario-building methodologies in their investigations and study the social, economic, environmental, and cultural dimensions of the complex adaptation trajectories.

Following this introduction, the book continues with Chap. 2, "Defining Net-Zero and Climate Recommendations for Carbon Offsetting," which presents a series of robust metrics to better account for the climate impacts of different GHGs. The authors, Rayer, Jenkins, and Walton, examine the appropriate use of offsetting and how it can be used to stabilize the climate. The book is then divided into four parts: 1. "Ecology and the Natural Environment," 2. "Finance and the Economy," 3. "Cities and Urban Areas," and 4. "Global Perspectives." The content of each of these parts is summarized below.

2.1 Part I: Ecology and the Natural Environment

The first part looks at ecological adaptation solutions to climate change in different natural environments, where special adaptation measures are needed depending on the geographical location.

The part begins with Chap. 3, "Green Infrastructure Mapping for Adaptation, Biodiversity, and Health and Wellbeing: A Tool Development Case Study in Edinburgh," a case study of a green mapping tool used at the University of Edinburgh. Vander Meer explores the value of green and blue infrastructure in climate mitigation by reviewing existing digital tools that attempt to integrate nature-based solutions (NBSs) into urban planning. The potential of these tools in climate adaptation is examined through examples from Europe and a specific case study at the University of Edinburgh in Scotland.

Chapter 4, "Agroecological Approaches for Climatic Change Mitigation and Adaptation: Experiences from the South to Encourage Direct Producer-Consumer Relationships," examines the history of agricultural ecology, including the Green Revolution (GR), a science-based technology aimed to increase agricultural yields. Using a Bolivian and Colombian case study, Rosse contrasts third-party certification schemes (e.g., organic, fair-trade) and explicitly investigates Participatory Guarantee Systems (PGS), providing conclusions and recommendations for all actors involved in PGS and organic agriculture.

Following this, Chap. 5, "Sustainable Renaturation in Desertification Control: Expediting the Natural Succession of Large-Scale Vegetation in Drylands," evaluates a mitigation and adaptation strategy for desertification and the related loss of arable land resulting from drought and extreme heat. In their chapter, Huebner, Fadhil Al-Quraishi, Branch, and Gaznayee propose a way of accelerating natural succession, which is how vegetation naturally adapts and evolves to be better protected to current conditions. Furthermore, they use lessons learned from China to optimize their "hydrologic networking" methodology.

2.2 Part II: Finance and the Economy

The second part, "Finance and the Economy," looks at climate change adaptation through the lens of the financial and economic sectors. It examines how these sectors can provide solutions and tools to help adapt to the changing climate. In addition, the part explores cultural and ethical factors that should be considered in the climate adaptation debate.

The part begins with Chap. 6, "Weaknesses in Corporate Commitments to Climate Change Adaptation and How to Fix Them: A Systemic Scenario Assessment Approach," which employs scenario-based analysis to explore how different business priorities affect specific Sustainability

Development Goals (SDGs), Climate Change Adaptation (CCA), and thus the global system. Lazurko, Kearney, Siddhantakar, Kurniawan, and Schweizer highlight gaps in current business efforts and provide recommendations on how the corporate sector can better adapt to climate change.

Chapter 7, "Climate Finance: A Business-Ethical Analysis," evaluates the moral and ethical responsibility of financial institutions in climate adaptation and mitigation. Woersdoerfer does so by analyzing the current relationship between banks and the fossil fuel industry while also looking into the divesting movement and the relatively new climate bond market.

Chapter 8, "Risk-Rating GHG Emissions Offsets Based on Climate Requirements," transcends traditional offset rating frameworks by incorporating climate risk into their model. Rayer and Walton use a case study approach on schemes proposed by major oil companies and the PAS 2060 carbon-neutrality standard to apply their new framework to demonstrate its effectiveness by grading offsets from most to least beneficial.

Chapter 9, "An Investigation of Climate Change Within the Framework of a Schumpeterian Economic Growth Model," examines the connection between entrepreneurship and emissions. Using a literature review and case study-guided approach across countries all over the globe, Sahin and Ayyildiz show how promoting entrepreneurship and innovation is a critical factor in adapting to the changing climate.

Chapter 10, "Culture, Economics, and Climate Change Adaptation," provides a cultural viewpoint to economics and climate change and looks at the interconnectedness of these themes. As adaptation ultimately requires a change in the behavior of humans across the globe, Venkatesan considers in detail how grassroots movements and stakeholder involvement can support mitigation strategies as long as the proper communication and alignment of goals are met.

The concluding chapter in the part, Chap. 11, "Investors' Adaptation to Climate Change: A Temporal Portfolio Choice Model with Diminishing Climate Duration Hazard," focuses on adapting investor behaviors to the challenges faced with climate change. To do so, Fahmy proposes an asset pricing model, which describes uncertainty in financial and climate risks as a temporal process. Lastly, he makes recommendations on how to change investors' mindsets and behaviors.

2.3 Part III: Cities and Urban Areas

The volume's third part, "Cities and Urban Areas," looks at climate change adaptation from an urban and architectural point of view. It evaluates how these areas can be improved to better adapt to climate change.

The first chapter in the part, Chap. 12, "Mainstreaming Adaptation into Urban Planning: Projects and Changes in Regulatory Frameworks for Resilient Cities," defines the climate risks that cities endure and evaluates current mitigation and urban planning solutions in adapting to the changing climate. Moreover, García Sánchez dives deeper into the development of new regional and urban management tools, providing more insight on how to properly build urban resilience with the aid of global case studies.

In Chap. 13, "Path-Dependency as a Potential Cause for the Disjunction Between Theory and Tools in the Modelled Reality of Sustainable Architecture," Leblanc and Castros focus on the architectural aspects of our city building by examining the viewpoints of building experts and scholars, as well as the tools being used to model buildings. The chapter evaluates how the green building industry's failures can be explained through the concept of path dependency. Moreover, the chapter examines why certification standards and green awards have hardly any positive environmental impact.

2.4 Part IV: Global Perspectives

The final part of the book, "Global Perspectives," takes a case study approach to examine climate change adaptation from different local perspectives and how these local perspectives could serve as an example for the global landscape.

The first chapter in the part, Chap. 14, "Addressing Climate Change and Waste Management Problems Through the Development of the

Waste-to-Energy Value Chain for Trinidad and Tobago," looks at how to address waste management to adapt to climate change through a value chain and stakeholder analysis approach. By looking at the case of Trinidad and Tobago, Charles details how a waste-to-energy approach under which waste is destroyed and converted to electricity can serve as a solution to waste management issues.

Following this, Chap. 15, "The Role of Businesses in Climate Change Adaptation in the Arctic," examines how businesses can play a role in adapting to the changing climate in the Arctic. Arruda, Johannsdottir, Wendt, and Sigurjonsson further investigate how risk can be assessed to produce adequate adaptation mechanisms and improve existing adaptation methods in the region from a business point of view. Lastly, the chapter presents a conceptual framework detailing how different economies in the Arctic are intertwined within the institutional, environmental, social, and cultural context, which has many implications for how governmental institutions should develop policies in the region.

In Chap. 16, "Climate Risk on the Rise: Canada's Approach to Limiting Future Climate Impacts," Filippi and Bakos compare Canada's climate adaptation efforts to those of other innovative countries, including the United States and the Netherlands. These countries have implemented novel and forward-looking initiatives such as cost-sharing programs for high-risk properties, tri-governmental partnerships on proper flood management, and mandated risk disclosure for private businesses. The authors explain how these initiatives could inform Canada's adaptation strategies to climate change.

In Chap. 17, "Unlocking Climate Finance to Compensate Caribbean Small-Island Developing States for Damages and Losses from Climate Change," Charles asks how financial resources should be used to compensate areas where climate change and extreme weather are more prevalent. The chapter uses a case study approach by looking at the Bahamas, which experienced significant damages due to Hurricane Dorian in 2019. The chapter then studies how different insurance mechanisms and financial instruments can compensate small-island developing states (SIDS) in the Caribbean as more extreme weather events continue to increase in this vulnerable region.

The book concludes with Chap. 18, "Integrating Local and Indigenous Knowledge for Climate Change Adaptation in Africa," where Pratap uses a literature review method to evaluate whether indigenous knowledge is affected by local experimentation, connection with an external system, or both. Based on the literature review and analysis conducted, the chapter provides recommendations to better integrate the knowledge of indigenous communities to help governments in Africa adapt to climate change. The chapter makes recommendations for enhancing the current structure of indigenous knowledge integration, which could prove crucial in climate change adaptation efforts.

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2

Defining Net-Zero and Climate Recommendations for Carbon Offsetting

Quintin Rayer, Stuart Jenkins, and Pete Walton

1 Introduction

Accumulated atmospheric greenhouse gas (GHG) emissions, primarily carbon dioxide, cause anthropogenic global warming (AGW) (Allen, 2016). Net-zero anthropogenic CO_2 emissions, and the stabilization of contributions by non-CO_2 pollutants, are required for AGW to stabilize within, or above, the 1.5–2.0 °C Paris Agreement goal (Matthews & Caldeira, 2008; Millar et al., 2018; Rayer, 2018; UN FCCC, 2015). Currently, warming is around 1.2 °C above preindustrial levels and is increasing (Haustein et al., 2017; University of Oxford Environmental Change Institute and University of Leeds Priestley International Centre

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for Climate, n.d.). To achieve the Paris Agreement's goal, the IPCC suggests rapid emissions reductions and ultimately large-scale CO_2 removal (Masson-Delmotte et al., 2018). This is necessary to address historical warming and a potential temperature overshoot, and to offset ongoing emissions from hard-to-abate sectors, such as agriculture and aviation (Pozo et al., 2020). Dramatic GHG emissions reductions are needed, to reduce the quantity of CO_2 removal required to offset unavoidable emissions. For residual emissions, offsetting can be used to achieve net-zero (emissions minus offsets) in the mid-century (Jenkins et al., 2021; Leach et al., 2018).

Individually and collectively countries are introducing climate change targets and legislation (e.g., China, EU, New Zealand, UK) (EEAS, 2020; European Commission, n.d.; Parliamentary Counsel Office, 2019; HM Government, 2019). Simultaneously, companies need to become carbon-neutral, both by reducing their emissions and, ultimately, by recapturing atmospheric CO_2 (Rayer et al., 2019).

Many policymakers and academics may not appreciate the massive deployment of negative-emission technologies assumed in global mitigation scenarios (Anderson & Peters, 2016). While there are risks from poor strategies, if used responsibly "carbon offsets" are one tool that can accelerate the action necessary to avert dangerous climate change (Broekhoff et al., 2019). We require urgent discussion and clarification around what defines a credible net-zero offsetting strategy.

Currently, emissions can be "neutralized" by "deemed offsets." Deemed offsets may be verified and audited; they can include atmospheric CO_2 sinks, emissions reductions, prevention of climate-malign activities, or the purchase of units from carbon allowance schemes. Crucially, the offset "quality" must be verified in terms of physical climate benefit. Carbon, once removed, must be robustly stored for geological timescales (Broekhoff et al., 2019; Joos et al., 2013).

We begin by defining carbon-neutral, net-zero, carbon-positive, and net-negative. Next, we address the challenges of defining a suitable metric for converting between different GHGs. For clarity, we explore atmospheric sources and sinks and introduce "deemed offsets." We illustrate these concepts using the PAS 2060 carbon-neutrality standard (BSI, 2014).

We consider offsetting from a climate science perspective, summarizing existing standards and considering the role of emissions reductions (McLaren et al., 2019; Rayer, 2018, 2020). We conclude with recommendations for how offsetting should be used based exclusively on physical climate benefit. Our focus is not on other offsetting aspects, such as the social or biodiversity benefits of nature-based-solutions (NbS). We recognize their value, but here dedicate our attention solely to halting AGW.

In summary, offsetting will be required for climate stabilization. Offsetting schemes differ in their capacity to halt AGW. Ultimately, we argue, high-quality offsets meeting the recommendations made in this chapter will be necessary to stabilize AGW.

2 Carbon-Neutral and Net-Zero

2.1 Terminology

The terms "carbon-neutral" and "net-zero" (emissions) are widely, and often interchangeably, used. These terms generally refer to a GHG emitting organization using offsetting as a "negative emission" to bring their total (or net) emissions to zero. As AGW is primarily caused by carbon dioxide emissions (Allen, 2016), it makes sense to use "carbon-neutral" when only CO_2 emissions have been offset to zero (Masson-Delmotte et al., 2018). However, this is not always followed by common practice. For example, the British Standards Institution's (BSI) PAS 2060 standard is titled a "specification for the demonstration of carbon-neutrality" but covers all GHGs (BSI, 2014).

The distinction between carbon-neutral and net-zero emissions matters. Although CO_2 accounts for between 58 and 76% of AGW (Joos et al., 2013), warming is caused by many GHGs, including methane, nitrous oxide, ozone, chlorofluorocarbons, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, and nitrogen trifluoride. The term "carbon-neutral" is misleading if interpreted as covering all GHGs or implying that only CO_2 emissions matter. We recommend, in line with

IPCC Special Report on 1.5 °C (Masson-Delmotte et al., 2018), reserving the term "net-zero" to indicate when emissions from all anthropogenic GHGs (not just CO_2) have been offset to zero such that no pollutants contribute to future AGW, while using carbon-neutrality to refer to the offsetting of CO_2 emissions to zero in isolation.

Often, the distinction between carbon-neutrality and net-zero will be insignificant. However, a firm with high emissions of non-CO_2 GHGs (e.g., chlorofluorocarbons) may be carbon-neutral but far from achieving net-zero. In this case, a claim to be carbon-neutral, if interpreted as applying to all GHGs, could be misleading.

Carbon-neutrality is achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period. It is particularly relevant to high-CO_2-emitting fossil fuel–related industries.

Net-zero emissions are achieved when anthropogenic emissions of GHGs are balanced by anthropogenic removals over a specified period. Where multiple GHGs are involved, net-zero calculations depend on the climate metric chosen to compare different gases. These metrics include global warming potential (GWP) and global temperature change potential (GTP) (Masson-Delmotte et al., 2018).

Organizations may wish to target either carbon-neutrality or net-zero emissions. Both terms apply to emissions caused by anthropogenic activities, either directly or indirectly.

2.2 Different GHGs

For the range of GHGs in a net-zero framework, it is often useful to convert individual GHG emissions into equivalent contributions from a single pollutant. This requires a GHG metric: a methodology for converting the emissions of one pollutant into the emissions of another.

One widely recognized GHG metric is the Global Warming Potential (GWP) (Shine et al., 2005). The GWP is the heat absorbed by a pulse emission of any GHG in the atmosphere over a time interval, as a multiple of the heat that would be absorbed by the same mass pulse emission of CO_2 over the same interval. Thus, the GWP of CO_2 is 1. For other GHGs, the GWP depends on the gas considered as well as the time interval, as different pollutants have different atmospheric lifetimes and radiative effects on the climate system. For example, methane, a powerful GHG, has a GWP of 86 over 20 years, but a GWP of 34 over 100 years (denoted GWP20 and GWP100 respectively) (Myhre et al., 2013). IPCC reports tend to focus on 20- and 100-year GWPs (for example see Stocker et al., 2013).

Offsetting calculations often use GWPs. Consider the GWP100 of methane; to offset 1 tonne of methane emissions, an organization might call this 34 tonnes of CO_2 "equivalent" (tCO_2e) and purchase 34 tonnes of CO_2 offsets (Myhre et al., 2013). Such conversions to CO_2 using GWP are the most familiar for policy and business settings. However, issues concerning GWP are well documented (Allen et al., 2018; Pierrehumbert, 2014). It significantly misrepresents short-lived climate pollutants (SLCPs). GWP's use of a single factor to convert to "equivalent" CO_2 values results in SLCP contributions to future warming being overstated, especially for ambitious mitigation pathways.

This questions GWP's use in multi-gas net-zero calculations. If a GHG metric is to equate the impact of one GHG's emissions with a CO_2 emissions timeseries over all policy-relevant timescales, the metric must convert GHGs according to their warming impact. This is non-trivial for SLCPs using offsetting by CO_2, as the lifetimes of the SLCP and CO_2 significantly differ. GWP conversion will not achieve equivalent warming outcomes (Allen et al., 2018).

There are alternative GHG metrics available, such as GTP (Collins et al., 2013), GWP* (Cain et al., 2019), and CO_2-forcing-equivalent (CO_2-fe; Jenkins et al., 2018), which take different approaches to addressing GWP's shortcomings. We discuss these in Sect. 2.3. As converting between different GHGs is difficult, we recommend that raw emissions of individual GHGs should be stated alongside their converted "equivalent CO_2" values and the metric chosen for the conversion.

2.3 GHG Matching

GWP has weaknesses for offsetting calculations. Consider offsetting methane emissions with CO_2. Methane is a more potent GHG than CO_2, causing an initial climate perturbation much larger than the equivalent mass CO_2 emission. Over short timescales a large CO_2 offset would balance the methane emission's impact (methane's GWP20 is 86). However, a few decades later, natural processes have largely removed this methane from the atmosphere, and its radiative perturbation largely disappears. Over these timescales a much smaller CO_2 offset would balance the methane's warming.

Allen et al. (2021) consider the implications of using GWP100 when offsetting 1 tCH_4 emissions, with 34 tCO_2e. Analysis shows net-warming over the first 45 years, with net cooling thereafter. If the opposite occurred (emitting 34 tCO_2 and reducing methane emissions by 1 tCH_4) it would cause warming on all timescales beyond 45 years. Both scenarios have the same CO_2-equivalent emissions offset. Hence using GWP does not align with the concept of net-zero "halting the warming contribution from all GHGs."

Offsetting emissions of methane with CO_2 is not a one-to-one exchange, where X tonnes of CO_2 can be removed to account for Y tonnes of methane. To mimic methane emissions over all policy-relevant timescales, a *timeseries* of CO_2 emissions is required. Figure 2.1 shows the theoretical shape of such a timeseries, if the radiative imbalance of a 1 tonne methane emission is balanced by CO_2 over all time. This timeseries is called the CO_2-forcing-equivalent (CO_2-fe) emissions since they mimic the radiative forcing of the methane emission in perpetuity. For a pulse methane emission CO_2-fe emissions require a large positive initial emission followed by negative emissions a couple of decades later. The large initial CO_2 emission mimics the initial methane perturbation, and the later negative CO_2 emissions account for the atmospheric removal of the methane over the following two decades. For further detail on CO_2-fe, see Jenkins et al. (2018).

Using CO_2-fe to convert GHG emissions into CO_2 for offsetting calculations is physically accurate. However, practical implementation will

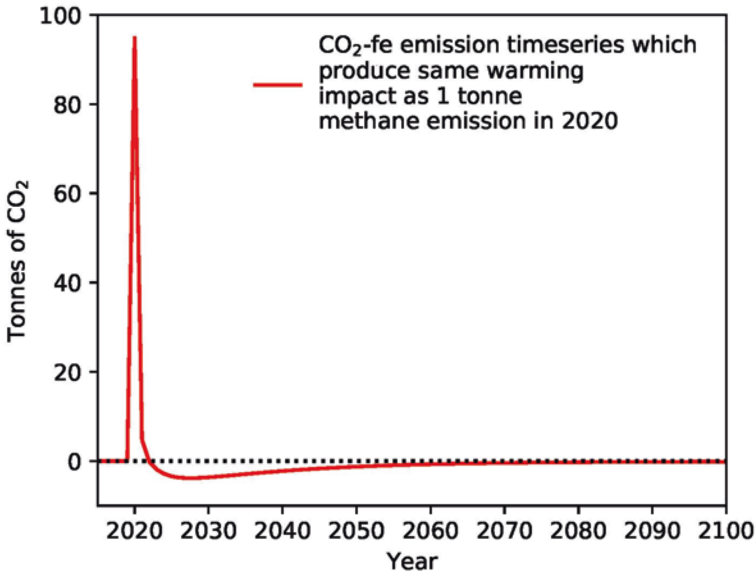

Fig. 2.1 Profile over time of carbon dioxide emissions needed to mimic the radiative climate impact of a 1 tonne emission of methane in 2020

prove difficult for many organizations targeting net-zero. Below we discuss other options, including simplifications of the CO_2-fe calculation.

2.3.1 Global Temperature Potential

The Global Temperature Potential (GTP) is calculated similarly to GWP but considers the impact of a GHG emission on the temperature anomaly over the time-period (Myhre et al., 2013). For example, GTP20 considers the relative temperature anomaly 20 years after a 1 tonne emission of a pollutant compared to a 1 tonne CO_2 emission. Although better than GWP in some conversions, GTP suffers from similar problems comparing SLCPs against long-lived climate pollutants (LLCPs) (Allen et al., 2018). Here we recommend GTP within a dual accounting approach, as Sect. 2.3.3 explains.

2.3.2 GWP*

Another metric is GWP* (Allen et al., 2018; Cain et al., 2019; Lynch et al., 2020). GWP* separates methane (the principal SLCP) and LLCPs into two separate calculations. For LLCPs, the conversion to CO_2e uses GWP100 values. For SLCPs (e.g., methane) the GWP* metric conversion uses:

$$E_{CO_2e*}(t) = 128 \times E_{CH_4}(t) - 120 \times E_{CH_4}(t-20).$$

Annual methane emissions in year t and in year t - 20 are used to calculate the CO_2e emission rate. For 1 tCH_4 emission, the equivalent CO_2 emission (in terms of warming response) is a 128 tonne CO_2 emission, followed by a 120 tonne CO_2 removal 20 years later. GWP* captures important behaviour from Fig. 2.1: methane's large initial warming is replicated by a large CO_2 emission. The methane emission then decays from the atmosphere over around a decade, so much of this CO_2 must be removed from the atmosphere to equate the behaviour of the short-lived methane and the long-lived CO_2.

Offsetting pulse methane emissions with a large removal of CO_2 and then emitting CO_2 20 years later is a significant departure from standard practice. Of course, the later emissions can be foregone, thereby contributing to net cooling over all timescales longer than the lifetime of methane, but this would be unusual. This problem is not specific to GWP*, using GWP or GTP, for these calculations will ultimately cause net-warming or net cooling when offsetting an SLCP with CO_2 (Allen et al., 2021).

Accounting for continued variable methane emissions over several years is more relevant than a one-off methane pulse. For continued methane emissions, if an organization's annual emissions increase by 1tCH_4/year, GWP* suggests the CO_2 offset required to mitigate the warming impact is 128 tCO_2/year CO_2 removal over the first 20 years, followed by 8tCO_2/year CO_2 removal for every year thereafter. Inversely, offsetting continued CO_2 emissions with methane reductions is harder. While GWP or GTP metrics suggests this is acceptable, GWP* shows that it is impractical in the long term since continual methane emissions reductions would be required year after year to offset the accumulating CO_2 warming.

2.3.3 Do No Harm

The "do no harm" principle (see Sect. 2.3.6) uses an extension of the concept of dual accounting for SLCPs and LLCPs in the UNFCCC (Ocko et al., 2017). Allen et al. (2021) argue that where no other conversion is practical (when conversion using GWP* is not possible), it is best to offset continued methane emissions by converting them into CO_2e using methane's GWP20 value. In reverse, to offset continued CO_2 emissions with methane reductions, the required methane reduction should be calculated using the GTP100 value for methane. This "do no harm" approach ensures that no net-warming occurs over any timescale, although net cooling will result over some timescales.

2.3.4 Isolated Balancing of Emissions

Finally, GHGs can be offset in isolation, that is offset CO_2 emissions with CO_2 offsets, methane emissions with methane offsets, N_2O emissions with N_2O offsets. Doing so balances the warming contribution of individual pollutants. Although, at a national level, governments and large organizations may wish to trade offsets between pollutants to maintain specialized industries or income streams. However, this is a valid approach.

2.3.5 Final Thoughts on GHG Metrics

A physically representative GHG metric for offsetting ensures accuracy when predicting the climate impact of complex multi-gas emissions. Since most offsets act to reduce or remove CO_2 emissions, having a physically representative method to estimate the required CO_2 offset for another GHG emission is important. We recommend that carbon-neutrality and net-zero calculations use the most physically representative approach to calculate the impact of GHGs in carbon-equivalent terms. This represents a significant departure from the methods commonly used, such as in PAS 2060 (BSI, 2014), which are based solely on GWP.

2.3.6 A Framework for GHG Conversions When Offsetting

Physically, a credible offset must remove a quantity of GHG from the atmosphere that accounts for the impact of the emission it counters. When converting the emissions of one GHG into another, there is no simple answer satisfying both ease of implementation and physical accuracy. To allow organizations of all sizes to adopt the best practices for offsetting, in order of preference, our recommendations are as follows:

1. Offset each GHG emitted by the organization separately by balancing CO_2 emissions with CO_2 offsets, methane emissions with methane offsets, and so on. As methane is an SLCP, methane offsets are subject to slightly different considerations (see Sects. 2.3, 2.3.1, 2.3.2, 2.3.3). For most organizations, the difficulty of offsetting GHGs separately means that the approaches below will be required. Solely where necessary, employ the methods below to convert into CO_2-equivalent emissions.
2. Employ a GHG metric which represents the physical properties of each pollutant. The most physically representative approach is CO_2-fe.
3. If CO_2-fe is impractical, consider using a two-basket approach: splitting GHGs into two groups: SLCPs and LLCPs. For LLCPs (CO_2, N_2O, many HCFCs, etc.) use the GWP100 metric to convert to CO_2-equivalent emissions. For SLCPs, use a more representative metric (e.g., GWP* for methane offsetting).
4. If (3) is impractical, use the "do no harm" principle for methane (Allen et al., 2021). Calculate CO_2 offsets for ongoing methane emissions using methane's GWP20 value of 86 (to guarantee no short-term warming) and calculate methane offsets for ongoing CO_2 emissions using methane's GTP100 value of 11, guaranteeing no long-term warming results (Myhre et al., 2013). We have used the "do no harm" principle both in the selection of the time-period (20 versus 100 years) and in the choice of metric used (GWP or GTP)—see Table 2.1. Calculate all other pollutants' offsets using GWP100.

For most organizations, the novel step is to consider converting methane emissions into CO_2-equivalent emissions using the GWP* metric

Table 2.1 Example of "do no harm" principle applied to methane emissions (using CO_2 offsets) and to CO_2 emissions (using methane offsets)

Scenario	Equivalency based on GWP	Equivalency based on GTP	"Do no harm" recommendation
Emission of 100*t* methane (offset using CO_2)	20 years: CO_2 offsets of 100 × 86 = 8600*t* 100 years: CO_2 offsets of 100 × 34 = 3400*t*	20 years: CO_2 offsets of 100 × 70 = 7000*t* 100 years: CO_2 offsets of 100 × 11 = 1100*t*	Select largest offset. Offset 100*t* CH_4 emissions with 8600 tCO_2 removals.
Emission of 100*t* CO_2 (offset using methane)	20 years: CH_4 offsets of 100/86 = 1.16*t* 100 years: CH_4 offsets of 100/34 = 2.94*t*	20 years: CH_4 offsets of 100/70 = 1.43*t* 100 years: CH_4 offsets of 100/11 = 9.09*t*	Select largest offset. Offset 100*t* CO_2 emissions with 9.09 tCH_4 removals.

Source: Myhre et al. (2013)

(recommendation 3). Even this alone would be extremely beneficial: the sum of GWP* methane emissions, N_2O emissions using GWP100, and CO_2 emissions together covers the vast bulk of present-day anthropogenic emissions.

For convenience, we refer to emissions quantities that are calculated following the recommendations above as CO_2-best-equivalent emissions or CO_2be emissions. We label them best-equivalent emissions because the quantities converted using these metrics incorporate a "do no harm" principle and should result in the same (or slightly less) global warming overall.

2.4 Sources, Sinks, and Deemed offsets

Organizations have different levels of GHG emissions, typically categorized into three "scopes" under the GHG Protocol.[1] Our focus is on how

[1] https://ghgprotocol.org/. Scope 1 emissions, or direct emissions, originate from sources that are owned and controlled by a company, including, for example, fuel used by company vehicles. Indirect emissions are covered by scopes 2 and 3; scope 2 emissions result from energy used by a company, including electricity, steam, heating, and cooling, while scope 3 emissions cover all other indirect emissions arising due to company activities. Scope 3 emissions also include upstream and downstream value chain emissions, including those of suppliers and customers using their products.

those emissions should be treated and all scopes of emissions should be included. We recommend that organizations state which scopes of emissions they address using offsets.

GHG emissions are typically stated in tonnes of CO_2 equivalent, tCO_2e. For the conversion of non-CO_2 GHGs into CO_2 equivalent terms, we recommend the use of alternative metrics (CO_2-fe, GWP*, "do no harm"). Following our recommendations in Sect. 2.3.6, GHG emissions should be stated in terms of tonnes of CO_2-best-equivalent, tCO_2be.

We define:

1. Physical emissions, as sourc*e*s of GHGs in terms of CO_2be to the atmosphere, E_{GHG}.
2. Physical removal of GHGs from the atmosphere in terms of CO_2be, which are atmospheric sin*k*s, denoted K_{GHG}. Anderson and Peters (2016) describe these as "negative emissions."
3. Deeme*d* removals of GHGs in terms of CO_2be, often by a mechanism based on allowed emissions, or reduced emissions rather than an atmospheric sink. Denoted D_{GHG}.
4. Carbon offse*t*s denoted T_{GHG} in terms of CO_2be, which could comprise either atmospheric GHG sinks or deemed removals. So, $T_{GHG} = K_{GHG} + D_{GHG}$.

Currently, net-zero refers to the state of net emissions at zero based on physical emissions minus offsets, or, GHG CO_2be sources minus offsets are zero: $E_{GHG} - T_{GHG} = 0$. The physical climate requirement is that $E_{GHG} - K_{GHG} = 0$. Thus, deemed offsets, D_{GHG}, must be of high quality. Unless they reduce global emissions or embody a significant "sink" component, reliance on deemed offsets could be catastrophic. We recommend E_{GHG}, K_{GHG}, D_{GHG}, T_{GHG} be defined in terms of tCO_2be (Sect. 2.3.6).

Distinguishing between carbon-neutral and net-zero, we similarly define carbon-neutral based solely on CO_2, E_{CO_2}, K_{CO_2}, D_{CO_2}, T_{CO_2}. Thus carbon-neutrality requires that $E_{CO_2} - T_{CO_2} = 0$, where $T_{CO_2} = K_{CO_2} + D_{CO_2}$.

The situation where offsets exceed emissions, so that $E_{CO_2} - T_{CO_2} < 0$, or $E_{GHG} - T_{GHG} < 0$ is denoted as "net-negative," with such entities also qualifying for "carbon-neutral" or "net-zero" status.

"Deemed" offsets may not result in the physical removal of CO_2 from the atmosphere. Generally, little or no distinction is made between entities that are net-zero due to sinks ($E_{GHG} - K_{GHG} = 0$) or net-zero due to deemed removals ($E_{GHG} - D_{GHG} = 0$). Ultimately, this presents a hazard. While some deemed removals, D_{GHG}, are reductions in emissions, others are economic tools to help promote change towards a lower carbon economy. In physical climate terms, these may have only an indirect impact. There is a risk that organizations may pay for deemed offsets rather than decarbonizing.

To illustrate, the PAS 2060 carbon-neutrality standard (BSI, 2014) considers all GHGs, making it a net-zero standard. In PAS 2060, all non-CO_2 GHG emissions are converted, using GWP100, to tCO_2e. It recognizes a range of deemed offsets including atmospheric sinks, reductions in emissions, and Kyoto-compliant schemes that include EU allowances, which are designed to create an economic stimulus by providing a price for carbon emissions (European Commission, 2015). Updating PAS 2060 to use more physically representative metrics for GHG conversion and to enforce the separation of deemed offsets from atmospheric removal offsets would improve its physical climate validity.

2.5 Atmospheric Lifetime of CO_2

Atmospheric CO_2 emitted from fossil fuel combustion is extremely long lived (15–40% of emitted CO_2 remains in the atmosphere longer than 1000 years, while turnover of geological reservoirs takes 10,000 years or longer (Stocker et al., 2013)). Atmospheric carbon removed by offsetting must be stored without re-emission for a longer period. Broekhoff et al. (2019) note a standard convention: carbon needs to be kept out of the atmosphere only for 100 years to be considered "permanent." Scientifically, this is inadequate; offsetting should be permanent over periods exceeding 10,000 years.

In fossil fuel reserves carbon has been stored in the lithosphere over the geological timescales associated with coal (around 300 million years), or oil or natural gas (generally over 65 million years) (McElroy, 2009). Extracting and burning this carbon releases CO_2 into the atmosphere.

Offsetting using forestry schemes results in conversion of stable lithospheric carbon into carbon stored in forests, which are vulnerable to fire, disease, and other natural disruptors. As a widespread strategy, this would massively increase climate risk. The first human civilizations developed around 3000 BCE (Roberts & Westad, 2013). Requiring forestry offsetting schemes to store carbon over 5000 years is akin to society uninterruptedly managing a forest scheme founded in the early dynastic period of ancient Egypt, predating the Giza pyramids (Shaw, 2003).

3 How Should Offsetting Be Used?

Although offsetting has a part to play in controlling net emissions, given the risks of uncontrolled climate change, it would be unwise to rely on unproven technologies (Steffen et al., 2018). Opportunities exist for immediate, rapid, and deep reductions at modest costs using existing, proven technologies (i.e., improving energy efficiency, encouraging low-carbon behaviours, and continued deployment of renewable energy technologies) (Anderson & Peters, 2016). The Oxford offsetting principles (Allen et al., 2020) prioritize cutting emissions.

The UNFCCC, article 3.3, states, "parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects" (United Nations, 1992). It would be far safer to focus on reducing emissions rather than CO_2 removal at present. There is also a moral responsibility to minimize harm by reducing emissions as rapidly as possible (Shue, 2017). As substantial emissions reductions take place, priorities change to offsets, which pursue the highest-quality CO_2 capture and storage opportunities instead (see Sect. 3.3).

One might ask: if a carbon-intensive business is sufficiently profitable, why not just offset in large volume today? This approach carries risks. If an extremely high volume of carbon offsetting were required, there may be insufficient capacity to meet demand, resulting in either a shortfall or the creation of substandard schemes that may not yield the promised benefits. Further, inaccurate estimation of carbon emissions and carbon stored by schemes, or future leakage, creates a danger that mitigation efforts may later prove insufficient.

A related risk is "moral hazard"; the availability of offsetting becomes an excuse to continue to use and expand reliance on fossil fuels and other GHG emitting technologies. McLaren et al. (2019) have identified the risk that offsets as negative emissions deter efforts at reductions (see also Pierrehumbert [2019] on technological climate interventions). Policies must be designed to ensure the delivery of negative emissions in addition to rapid emissions reduction, and not at their expense (McLaren et al., 2019).

CO_2 emissions produced by burning fossil fuels must cease. Although achieving zero net emissions is necessary, at present day the focus should be on reducing GHG emissions directly (and dramatically) in line with global mitigation goals. Once committed to substantial emissions reductions, offsetting can be employed. A precautionary principle advises that offsetting be used only after, or as a temporary measure, once all immediate reductions are implemented (Rayer, 2018; Broekhoff et al., 2019). Such approaches are only as good as the quality of the offsets acquired (Ceppi, 2006).

The difficulties of GHG matching represent another challenge, ensuring that the warming impact of GHGs emitted is appropriately matched by the cooling impact of offsets used. If GHG sinks are used, storage needs to be robust on geological timescales.

3.1 Existing Offset Standards

All offsets should meet minimum audit and verification standards. Following Ceppi (2006), Gillenwater (2012), Broekhoff et al. (2019), and Allen et al. (2020), we recommend that offsets meet the following standards:

- Avoid issuing credits before emission reductions have occurred.
- Be complete and accurate. Use conservative estimates and sound quantification methodologies.

- Factor emissions "leakage" into emission reductions calculations. Leakages are unintended increases in emissions caused by a project. A frequently cited example is a forest sequestration project that shifts deforestation activities elsewhere, reducing or eliminating the project's net sequestration.
- Verify and audit schemes with independent, third parties.
- Ensure reductions are permanent.
- Avoid double counting. At project level, a credit could be sold multiple times to different buyers, and voluntary reductions could be counted against national targets (Broekhoff et al., 2019).
- Ensure projects are genuinely additional to current emissions reduction or removal efforts.[2]

A number of offsetting standards are listed in Broekhoff et al. (2019), Ceppi (2006), Gillenwater (2012), and PAS 2060 (BSI, 2014).

3.2 Emissions Reduction Is Essential

Reduction is so important that we recommend all offsets should be associated with emissions reduction strategies (Allen et al., 2020; McLaren et al., 2019).

To meet the Paris Agreement objectives, net-zero emissions are required by around 2050 (Leach et al., 2018), meaning at the time of writing (2020) there are 30 years to 2050. If an organization's emissions are reduced annually by around 10%, then emissions approximately cease by 2050. Therefore, we recommend that over an annual offset accounting period, an organization should aim to reduce its absolute emissions by at least 10%, as well as offsetting emissions. Emissions calculations should include all scopes of emissions (Greenhouse Gas Protocol, n.d.) from the firm's activities. The exception to this rule would be for organizations which have already substantially cut absolute emissions, with minimal total emissions remaining.

[2] A European Union study found that 85% of the projects considered were unlikely to provide additional offsetting (Cames et al., 2016).

3.3 Carbon Storage: Hard Versus Soft

For offsets that remove CO_2 from the atmosphere or capture it, the robustness of the carbon storage is crucial. In a "hard" offset the carbon removed has a high degree of "permanence" (the expected duration of storage). For example, solid carbon stored deep underground in geologically stable formations has a high degree of "permanence." Since fossil fuel combustion is effectively irreversible except over geological timescales, reliable sinks to offset remaining fossil CO_2 emissions must be effectively irreversible and permanent on a geological timescale (1000–10,000 years or more). This requires atmospheric GHG removal followed by permanent storage or avoided emissions where industrially produced CO_2 is captured at source and the carbon is stored in a permanent form.

However, most commercially available offsets are "soft offsets," where emissions are netted against a natural carbon sink with a shorter or more uncertain degree of permanence. Examples include reforestation or afforestation. Over the decades while trees grow, they remove CO_2 from the air, but the CO_2 is permanently removed only if the mature forest remains in place. If the trees are felled and left to decay, or burnt without CO_2 capture, the carbon will be re-released. Although offset-providers typically hand 100% of the CO_2-removal credits to the purchaser of the offsets when the trees are planted, there is no guarantee that these offsets are permanent. Conversely, "hard" offsets store carbon with a high degree of permanence on a geological timescale (Allen et al., 2020).

3.4 Recommendations

We make the following recommendations based on a climate science perspective. First, offsetting should be used primarily in the following two circumstances (Rayer, 2020):

- After emissions have been reduced as much as possible. Offsetting is used to absorb residual GHG emissions.

- As a temporary measure to mitigate the worst effects of emissions while a strategy for transitioning to lower GHG emission technologies is developed and implemented.

Direct emissions should be reduced first, followed by indirect emissions. Only after this should offsetting be used (Ceppi, 2006). Our further recommendations for using offsetting are:

- Distinguish between schemes targeting carbon-neutral and net-zero (Sect. 2.1).
- State emissions from different GHGs, how these are being offset, and aggregate total emissions (Sect. 2.2). If quantities are obtained from external parties and only available in CO_2-equivalent terms, they should be stated as such, together with the metric used (if known).
- Follow the "do no harm" principle embodied in the framework of Sect. 2.3.6 for conversions between different GHGs and state them in "best-equivalent" terms.
- State the scopes of emissions included (Sect. 2.4).
- Identify whether offsets are "deemed offsets" or "sinks" (Sect. 2.4).
- Use existing proven technologies (Sect. 3).
- Meet existing standards, such as those summarized in Sect. 3.1.
- Tie use of offsetting explicitly to year-on-year emissions reductions (Sect. 3.2).
- Use "hard" storage that is robust on geological timescales for schemes that involve GHG sinks (Sects. 2.5 and 3.3).

Organizations must define strategies for credible, time-bound reductions in addition to how they intend to implement high-quality offsetting. Strategies should be realistic to minimize the risk of failure at later stages and regularly reviewed and, if necessary, updated, to reflect best knowledge and practices.

4 Conclusions

To stabilize the climate, offsetting approaches are needed. We recommend offsetting priorities based on their effectiveness in stabilizing anthropogenic global warming (AGW). This is not to say that other aspects of offset approaches, such as the social or biodiversity benefits of nature-based-solutions, are not of value; in this chapter we focus entirely on offsetting's physical attributes.

One existing carbon-neutrality standard that uses offsetting is PAS 2060 (BSI, 2014). Although considered a carbon-neutrality standard, PAS 2060 is a net-zero standard, as it covers all greenhouse gas (GHG) emissions. To convert between different GHGs, PAS 2060 uses Global Warming Potential, which is not best suited for offsetting calculations. Section 2.3.6 discusses alternative options, including a "do no harm" principle.

High-quality offsetting is required to stop AGW. By following the recommendations above, offsets can better protect the Earth from dangerous global warming.

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Part II

Ecology and the Natural Environment

3

Green Infrastructure Mapping for Adaptation, Biodiversity, and Health and Wellbeing: A Tool Development Case Study in Edinburgh

Elizabeth Vander Meer

1 Introduction

Recognition of the value of city green and blue infrastructure, or urban green infrastructure (UGI), has grown due to increased understandings of climate change adaptation and the importance of these spaces for human health and wellbeing. Tools have been developed to assist in planning for adaptation, in some cases, with digital components. For instance, the European project, GRaBS (green and blue space adaptation tool for urban areas and eco-towns) addressed the lack of adaptation planning in cities by creating green space factor (Kruuse, 2011) and STAR tools (surface temperature and run off) (GRaBS, n.d.). These tools improve understandings of green and blue spaces and integrate climate risks into

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planning processes, resulting in enhanced green infrastructure to address these risks. Cities across Europe are considering how to adapt to climate change using similar approaches to apply nature-based solutions (NBS). Such projects attempt to answer the question: how can nature-based solutions be effectively integrated into urban planning for adaptation and equally for biodiversity, human health, and wellbeing?

Scotland faces many of the same climate change impacts as other European countries, such as flooding, heat waves, and, most recently, drought conditions that could lead to water shortages (CREW, 2020). Edinburgh is already considered a "green" city filled with large parks; however, green and blue spaces may require alterations for adaptation. The implementation of improvements has been under threat due to local authority underfunding, a problem that could be heightened by the COVID-19 crisis. The University of Edinburgh tested a digital tool to capture biodiversity and ecosystem services value (e.g. flood regulation, cooling potential) of different types of vegetation and blue spaces. The University's digital application derives from the Natural Capital Standard (NCS) developed by the Scottish Wildlife Trust for use on existing sites to make improvements and in development planning (SWT, 2016; Keegan, 2018); NCS development was influenced by the GRaBS green space factor method. The initial pilot projects have involved the creation and use of a green infrastructure (GI) mapping application to map University campus sites as well as a selection of city parks. Vegetation types and blue space data from campus and park sites have been collected to generate a GI Factor score for each site.

This chapter sets out the value of UGI for climate change adaptation and biodiversity and reviews a selection of existing tool methodologies to consider the question of how to integrate green infrastructure into urban planning, with specific focus on GRaBS. The GI mapping application pilot in Edinburgh is then introduced as a case study of an approach with potential to meet adaptation and biodiversity needs in urban contexts. The case study will provide insight on tool development, its method, first use, and revision as a result of citizen science volunteering. Alongside GI mapping, the chapter also presents complementary emotional mapping research to capture Edinburgh residents' perceptions of different types of green and blue spaces in the city in order to begin to understand the relationship between spaces with high adaptation and biodiversity value, and perceptions of these spaces. The GI mapping digital tool in development at the University of Edinburgh is compared to existing tools to highlight their different approaches and what approach may be most appropriate in urban settings. The analysis can serve to inform decisions on the use of green space factor methods in urban contexts for both climate change adaptation and biodiversity.

2 The Value of Urban Green Infrastructure and Biodiversity

Maintaining and allowing a diversity of species in green and blue spaces ensures resilience (Lin et al., 2015; Schneiders et al., 2012). The recently published *Dasgupta Review* (HM Treasury, 2021) provides evidence of the underpinning importance of biodiversity to economic, social, and mental wellbeing. Biodiversity is defined by the Convention on Biological Diversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems" (CBD, n.d.). Protection of biodiversity also means protection of ecosystems, including the climate change mitigation and adaptation services they provide; climate change and biodiversity loss are twin and inextricably linked crises. The concept of "One Health" exemplifies a view that acknowledges the interconnectedness of ecosystems, biodiversity, and human health through interdisciplinarity. The importance of viewing cities as integrated socio-ecological systems cannot be understated (see Artmann et al., 2017), in order to confront the challenges of increasing populations and inequality in urban areas alongside climate change and biodiversity crises. Urban areas need to adapt, becoming "climate ready," thus addressing climate change risks such as flooding and heat in equitable ways.

Green infrastructure has been defined by the European Commission as: "a strategically planned network of high quality natural and semi-natural areas, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity" (URBES, 2014). Urban green infrastructure, or UGI, has gained attention in the research of nature-based solutions (NBS) to implement in cities to mitigate climate change impacts and biodiversity loss (Schewenius et al., 2014; Hansen et al., 2019; Lafortezza et al., 2013). Natural green and blue spaces in urban contexts assist in removing carbon (carbon sequestration), dampening the urban heat island (UHI) effect, contributing to flood prevention, and buffering against storm damage. UGI evaluated in Lugo, Spain, was shown to contribute to carbon emission reductions in the city through carbon sequestration, but not all GI actions were equal in terms of carbon uptake (de la Sota et al., 2019). Modelling in Glasgow, Scotland, predicted areas of warming and determined that increased green infrastructure would significantly tackle the problem (Emmanuel & Loconsole, 2015). A study in Melbourne, Australia, reviewed the effectiveness of different UGI which included public parks, trees, green roofs, and green walls to counter extreme heat events and UHI (Norton et al., 2015; see also Zölch et al., 2016 on effectiveness of UGI types). This research provided a framework for decision-making that started with prioritizing socially vulnerable neighbourhoods, heat mapping of these neighbourhoods, identifying existing UGI, improving that infrastructure for cooling, and identifying new areas for UGI. Urban waterways, or blue infrastructure, have an essential adaptation value for flood prevention. Longitudinal research of regeneration of a canal in Glasgow concluded that such regeneration could have multiple benefits in terms of climate change adaptation and health, especially for communities nearby, many of which represented the most deprived areas of Scotland (Tieges et al., 2020). Sustainable urban drainage (SUD) ponds and rain gardens (shallow, carefully planted basins) have been shown to be effective in city flood management, while also providing biodiversity, health, and amenity value (Wade & McLean, 2014; RBGE, 2019).

Additionally, green/blue infrastructure has been recognized as an important part of a green recovery post COVID-19. For instance, the Scottish government has sector plans to deliver a green recovery (Scottish Government, 2020). The Edinburgh Climate Commission has also laid out key principles for Edinburgh's green recovery, which include judging success in terms of improvements for biodiversity, health, and wellbeing (Edinburgh Climate Commission, 2020). However, biodiversity may pose problems for urban residents, such as increases in allergic responses or increases in the number of species such as rats and ticks that may carry pathogens (Lõhmus & Balbus, 2015). These potential problems and perceptions of green/blue spaces must be assessed at the local level with community members and balanced against the benefits of addressing climate change and biodiversity crises.

3 Development of GI Factors for Urban Planning in Europe: Exploring Methodologies

Green space factors have potential to provide a means to increase and improve green infrastructure for climate change adaptation and biodiversity in city contexts; such tools are not meant to replace building standards, such as BREEAM (Building Research Establishment Environmental Assessment Method, to assess, rate, and certify building sustainability) in the UK, but would improve upon them and have potential to work at wider scales (e.g. a neighbourhood). Different types of surface areas are scored based on their ability to absorb water, provide cooling, and in some cases contribute to biodiversity. This approach was taken in Berlin in the 1990s and influenced the development of the GRaBS green space factor, which also drew from work on UGI already undertaken in Malmo (SenUVK, 2019; Kruuse, 2011). Green space factors have been tested in cities such as Stockholm and Southampton, using simple spreadsheets to generate calculations. The Berlin and GRaBS approaches will be considered in more depth, as such approaches have influenced the Natural Capital Standard method used in Edinburgh.

3.1 Berlin

Berlin developed an adaptation tool for green infrastructure called the Biotope Area Factor (BAF), which launched in 1994 and is still used today (SenUVK, 2019). The Factor is meant to ensure that a percentage of surfaces in developments is absorbent (green space), and it includes commercial, residential, and public infrastructures. The scoring system, as updated in 2021 (SenUVK, 2021), includes sealed surfaces which have a weighting of 0.0 per m^2, partially sealed surfaces (no plant growth, e.g. mosaic paving) with a weighting of 0.1 per m^2, semi-open surfaces (no plant growth, e.g. sand or gravel) having a weighting of 0.2 per m^2, and greened surfaces (with plant growth, e.g. gravel with grass) weighted at 0.4 per m^2. Categories of surfaces with vegetation span those unconnected to soil to those connected to soil, with the latter having a weighting of 1.0 per m^2. Vertical greening, or green walls, is part of the scoring system, along with roof greening, with higher weightings based on higher substrate thickness.

The area of each surface is multiplied by the score defined for the surface (per m^2), then added together and divided by the total development area. Commercial buildings are required to achieve a BAF of 0.3, while residential and public spaces must attain 0.6. Developers have flexibility to choose solutions within the proportion they must leave as green space. This approach has been viewed as simple but effective (see Participatory Planning Canada, 2019).

3.2 GRaBS Green Space Factor and STAR Tool

The European project GRaBS (green and blue space adaptation tool for urban areas and eco-towns) addressed lack of adaptation planning in new developments, creating and promoting tools to ensure green and blue spaces were included in planning processes. The city of Malmo, Sweden, developed a green space factor, also known as the Green Area Factor (GAF), contributing to GRaBS with this work; like the BAF, the tool was meant to ensure that developers included an adequate amount of green and blue space in their developments, and it served as an exemplar approach for other European cities (Kruuse, 2011). Revisions to the system used in Malmo, part of the GRaBS project, changed the scoring system and attempted to consider biodiversity, which has proven crucial to ecosystem functioning in small-scale studies (Gonzalez et al., 2020). The revised scoring system included increased weightings for those surface types that could deliver multiple ecosystem services. The improved GAF was also able to take into account overlapping layers of vegetation to result in a higher score (e.g. grassland with a tree canopy) (Kruuse, 2011, p. 5). The GAF was similar to Berlin's original BAF in terms of generic categories of vegetation (on ground, on trellis/façade, on beams), green roofs, water, and sealed surfaces, with vegetation on ground scoring 1 and sealed areas receiving 0 (see Kruuse, 2011, p. 10).Various sizes of trees and bushes were allocated specific metreage per tree or bush as part of the scoring system; this matters when it comes to infiltration capacity for flood regulation. District planners also included a green points system, which allowed developers to choose 10 out of 35 options to increase biodiversity or biodiversity value on their sites; these options included, for instance, bird and bat boxes, diversity in tree and shrub species, frog habitats, and swallow nesting areas (Kruuse, 2011, p. 6).

The STAR tool (GRaBS, n.d.) developed as part of the GRaBS project has potential to complement GI Factor approaches at a small scale with a future view. It includes two components: online calculators for surface temperature and surface runoff. The surface temperature tool can generate maximum surface temperatures for a neighbourhood area, depending on what scenarios are chosen (temperatures and land cover). Similarly, the surface runoff tool generates a percentage of surface runoff volume in the area (based on the amount of precipitation and land cover). Inputs required to obtain temperature results, for instance, include percentages of different land cover types in the area selected, such as buildings, major roads, other impermeable surfaces, green and blue surfaces, gravel, and bare soil surfaces. Temperature scenarios must also be inputted for areas outside of the Northwest of England, including the baseline temperature for the area (1961 to 1990), 2050s' high temperature (10% probability), 2050s' high temperature (50% probability), and 2050s' high temperature (90% probability) (see GRaBS, n.d., also for explanation of the surface run off tool).

The Southampton Green Space Factor (GSF) is derived from the GRaBS Malmo tool, and calculations are completed using an Excel spreadsheet; Table 3.1 lists surface types and their GI Factor scores, as extracted from Southampton Green Space Factor tool spreadsheet (Southampton City Council, 2015).

The Southampton GSF has been reconsidered to address the potential issue of scientific reliability of scoring different vegetation or surface types (Farrugia et al., 2013). Criticisms of Factor scoring include how

Table 3.1 Southampton Green Space Factor surface types and Factor scores

Surface Type	Factor
Primary (Ground Level) Layers	
Building surface area with no green roof	0.0
Extensive greenroofs	0.6
Intensive greenroofs	0.7
Non-permeable surfaces	0.0
Permeable paving	0.2
Semi-permeable surfaces e.g. sand and gravel	0.4
Grassland (short, amenity)	0.4
Grassland (long, rough)	0.5
Shrubs	0.6
Trees on shallow soil/ tree pits	0.6
Woodland/ Trees on deeper soil	1.0
Open Water	1.0
Secondary Layers	
Green walls with a height limit of 10 meters (area of)	0.6

Source: Southampton City Council (2015)

quantifications are calculated in the approach, which must abstract a number (comparative value) from the relationship between surface/vegetation type and ecosystem functions. For instance, Berlin's BAF and Malmo's GAF both refer to vegetation generically but all vegetation types are not created equal in terms of their ecological role. Malmo's system added more specifics in parallel with the use of a green points system, but in this case to allow focus on improvements to green spaces for biodiversity (wildlife). Farrugia et al. (2013) proposed a two-tiered system to be scientifically robust, less generic, and increasingly focused on actual green infrastructure in context. They referenced the JNCC Habitat Mapping System for vegetation categories to derive GI Factors for flood control and cooling that would be combined to deliver an Aggregate Green Space Factor (AGSF) (Farrugia et al., 2013, p. 141). The scoring of vegetation considering flood control reflects infiltration capacity associated with particular vegetation or surface types, for example, as explained by Farrugia et al. (2013, p. 140):

> Habitats with taller vegetation, such as trees, were assumed to require deeper, more permeable soil to accommodate an extensive root system and would thus have a higher infiltration capacity.

Cooling potential was determined through the leaf area index (LAI), which also included water habitats (with a factor of 1), mapped onto the habitat system. There were 27 categories based on the JNCC Habitat Mapping System: semi-natural broad-leaved woodland with dense undergrowth scored 1 for flood control and urban cooling, individual trees scored 0.9 and 1 respectively, parkland with scattered trees scored 0.7 for both, amenity grassland scored 0.5 for both, and buildings and impermeable surfaces received a Factor score of 0.

Habitat mapping does involve time-consuming site visits to go beyond the surface area approach available with reference to Ordnance Survey MasterMaps, but there are significant benefits to this at smaller scale within urban contexts. Farrugia et al. (2013, p. 142) concluded that individual tree mapping provides more accurate results for urban cooling and flood regulation at a small scale (see also Skelhorn et al., 2014). They suggested the use of the two-tiered system based on habitat mapping for development sites and neighbourhoods, with the use of surface type ecosystem services maps derived from Ordnance Surveys at city and region scale to identify areas for interventions (Farrugia et al., 2013, p. 143; see Carter et al., 2018). This work also highlights the importance of mapping sites that already have green/blue spaces, to ensure improvements to green space Factor scores when any development changes are made.

3.3 Natural Capital Standard for Green Infrastructure in Scotland

The Scottish Wildlife Trust developed the Excel-based Natural Capital Standard (NCS) to assess the biodiversity and ecosystem services value of urban green and blue spaces, with the standard meant to be applied in development planning as well as to existing sites (SWT, 2016). Development planners could map a site lacking in green space with certain vegetation types to obtain a target GI Factor score, and existing sites could be scored as they are and then improved. Each vegetation type in the NCS has been comparatively scored, or given a weighting, based on its biodiversity and ecosystem services value. Similarly to methods used in other tools, the score for each vegetation type is multiplied by its area, summed, and then divided by the total area, resulting in the GI Factor. Weightings of different types of green and blue spaces, between 0 and 1, were determined after reviewing the GRaBS method, Berlin BAF, and other existing Factors, but with a view to ensure visibility of biodiversity value. Examples of types of green/blue spaces that receive weightings include stand of 10+ trees/woodland retained with high biodiversity value (weighting of 1), retained native hedgerow with three or more native species (1), retained native tree (0.8), established wildflower meadow (0.8), green roof with high biodiversity value (0.8), naturalized grassland (0.6), natural or naturalized water feature (0.6), planted native tree (0.4), amenity grassland (0.4), green roof with low biodiversity value for instance sedum (0.4), permeable paving/porous surface with green element (0.2), and sealed areas such as tarmac and concrete (0), with 36 GI surfaces (Keegan, 2018).

Ecosystem services considered within this scoring system derive from the UK National Ecosystem Assessment (NEA), which includes biodiversity and local climate regulation. Cultural services such as aesthetic and spiritual value, recreation and tourism, or community preferences for different types of green and blue spaces are not calculated within the scoring system. The weightings for each vegetation type are not fixed and require refinement based on local trials and priorities. The NCS provides more detailed categories than the Berlin BAF and the Malmo GAF, important granularity to be able to address heat and flood risk, as noted.

It appears more aligned with the Southampton GSF, but it captures retained vegetation clearly in surface categories. The digitization of the NCS, its use, and need for revision will be discussed in detail next.

4 Use of Digital Tools for UGI Planning

Digital tools have been developed to assist in UGI planning for climate change adaptation and biodiversity protection. Crowdsourced data and citizen science puts such tools in the hands of the public, generating more data quickly about climate change and biodiversity, while also investing citizens in decision-making (see for example Meier et al., 2017; Lauro et al., 2014). The use of local knowledge and a collaborative approach can lead to more successful sustainable development (Møller et al., 2019). Møller et al. (2019) introduce what they describe as "place-based e-tools" or "digital approaches that gather information from specific places, generated by citizens—or in interplay between citizens and professionals." However, challenges in the use of e-tools include the digital divide, privacy issues, and lack of governmental resources (skills, budget, leadership support) (Møller et al., 2019, p. 246).

Digital tools to support improvements in UGI are often based on the use of GIS to make sense of spatial data. They perform on different scales such as the region, city, or neighbourhood. GIS-based tool examples at city scale include the Belgrade GIS GA, which maps 3000 hectares of public green areas in the city as part of the Plan of General Regulation of Green Areas in Belgrade (Crnčević et al., 2017; see also Carter et al., 2018); green area mapping can then be overlaid with flood risk and temperature maps to better understand the needed improvements for adaptation. The Thriving Green Spaces Future Parks Accelerator project, led by City of Edinburgh Council (CEC, n.d.) to improve green spaces in Edinburgh, includes use of a similar approach based on the Ecological Coherence Protocol (EcoCo, n.d.), considering habitat networks, ecosystem services, and areas of opportunity for improvement. The Ecological Coherence Plan uses GIS to map broad habitat types across the city and overlays flood and heat risk; consultation has involved key stakeholders in the city. The more granular approach of calculating GI Factors, which can work at the neighbourhood or individual development scale, appears to rely most heavily on Excel spreadsheets, as apparent in examples introduced; developers did not express the need for use of GIS or programming to deliver GI Factors. The GI mapping tool developed by the University of Edinburgh incorporates the scoring system from the Natural Capital Standard, formerly in Excel, into an application that provides a means to map spaces and calculate GI Factors using the widely known ESRI platform, which provides solutions to problems using GIS.

4.1 GI Mapping App Development: University of Edinburgh Case Study

Between Spring 2018 and Autumn 2020, the University of Edinburgh piloted the digital GI mapping tool based on the Scottish Wildlife Trust's NCS on its campuses and in parks for the City of Edinburgh Council Thriving Green Spaces project (CEC, n.d.). This work developed out of discussions with city partners to place biodiversity/nature and climate change adaptation at the heart of campus and city planning.

4.2 How Green Is Your Campus App

Campus green infrastructure mapping began in 2018 through a student living lab placement project that used the original paper and spreadsheet NCS tool. Difficulty using the paper tool led to a discussion between EDINA, University of Edinburgh's digital experts, and the Department for Social Responsibility and Sustainability (SRS) to create a digital version of the NCS using ESRI, a GIS platform available to other universities and city councils. The app, "How Green is Your Campus" (EDINA, n.d.), provides the University with an easy method of quantifying how "green" it is and identifying ways it could make improvements in terms of climate change adaptation and biodiversity. The end goal of the project is to deliver GI Factors for every campus and a dashboard for both staff and students by the end of the academic year 2022/23. The project has mapped existing space at campus scale, but the aim is to embed this view in development planning as part of a new data hub and bespoke sustainable building design standards.

The app allows for mapping of vegetation types and automatically calculates the GI Factor. Instead of having 36 separate categories as in the NCS, EDINA developers were able to nest some categories such as "trees" and "hedgerows," for example, with sub-categories for ease of use. "How Green is Your Campus" has so far resulted in mapping of two campus sites, Pollock Halls and King's Buildings. Pollock Halls received a GI Factor of 0.367 and King's Buildings received a GI Factor of 0.146 (see Figs. 3.1 and 3.2); as noted, the NCS has set 0.3 or above as the goal for development sites in urban areas. King's Buildings has larger areas of impermeable surfaces and industrial buildings, in comparison to Pollock Halls, which is in part defined by its botanical garden grounds. Mapping allows for this comparative view through GI Factor quantification; subsequently, the University has identified the need for improvements in locations like King's Buildings considering the campus scale. King's Buildings campus has experienced significant episodes of flooding, which led to an infrastructure project to increase site resilience that can benefit from the use of the GI mapping tool. A recent site visit to King's Buildings identified several car park areas with non-permeable surface types to target for an increase in the GI Factor score, as well as conversion of some areas of

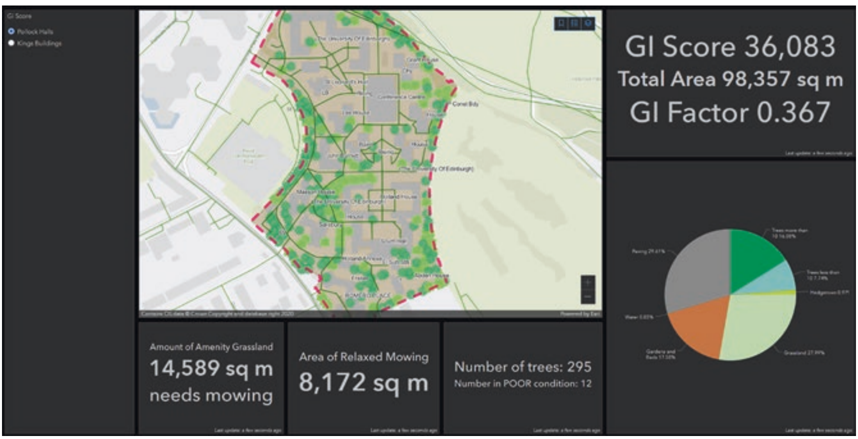

Fig. 3.1 Pollock Halls site and GI Factor dashboard, University of Edinburgh

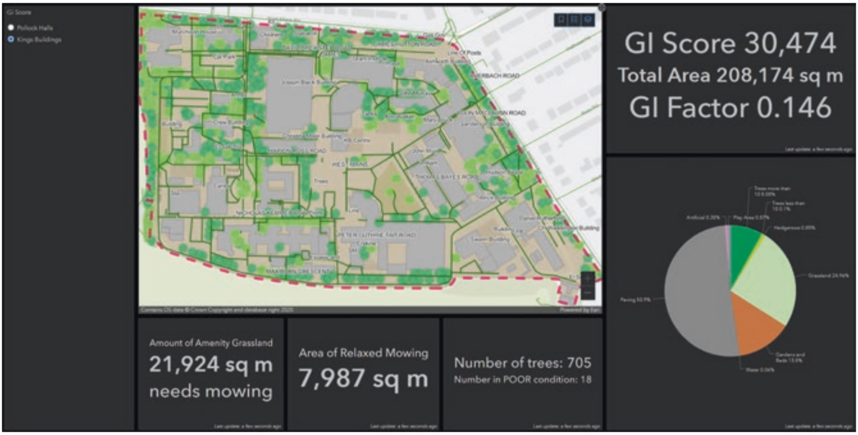

Fig. 3.2 King's Buildings site and GI Factor dashboard, University of Edinburgh

amenity grassland to wildflower meadows. A proposed project to adapt a category B listed building on site, the Hudson Beare Lecture Theatre, which suffers from overheating, includes consideration of the grounds and re-establishment of a pond and green space to replace paving. These existing non-permeable surfaces can be re-designated in the GI mapping tool to particular permeable surfaces to understand how much this could increase the GI Factor of the site and thus address flood and heat risks.

4.3 GI Mapping for City Parks: Thriving Green Spaces

The campus GI mapping app is now being applied in the wider city context, as part of the Edinburgh Thriving Green Spaces project (CEC, n.d); the University of Edinburgh is a project partner, delivering a GI mapping pilot. During Phase 1 in 2020, the pilot mapped six park sites using the GI mapping app, calculating GI Factors for each park (see Fig. 3.3):

1. The Meadows/Bruntsfield Links
2. Burdiehouse Burn Valley Park
3. Cramond Foreshore

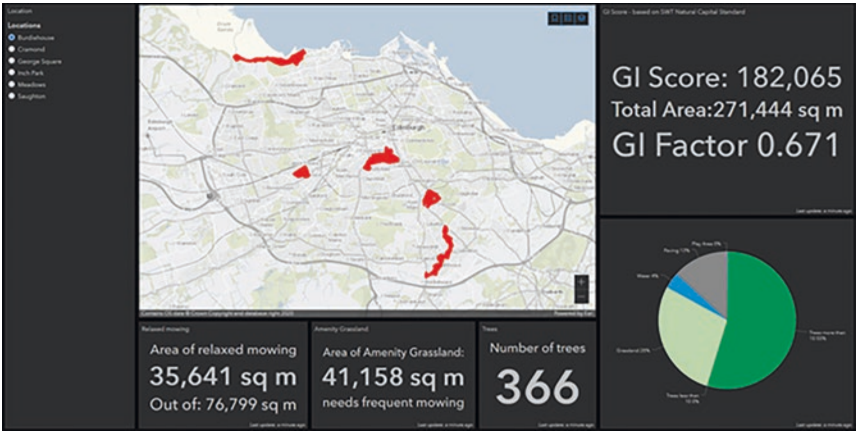

Fig. 3.3 Park sites and GI mapping dashboard showing Burdiehouse Burn Valley Park data

4. Inch Park
5. Saughton Park
6. George Square Gardens

It may seem problematic to use this tool on sites such as parks since they are already dedicated to green and blue infrastructure; however, its use can lead to improvements in planting for biodiversity and adaptation, while ensuring that the current value of existing green/blue spaces is recognized.

GI mapping using citizen science resulted in the collection of vegetation type and blue space data to generate the GI Factors for each park site, as noted in Table 3.2. Percentages of vegetation types and water in each park were also calculated.

City of Edinburgh Council could set a Parks GI Factor goal of at least 0.7, since a score of 0.6 or higher has been set in similar scoring systems as the goal for residential and public sector developments that are not dedicated to green space (see Farrugia et al., 2013 regarding green field sites). One point to raise, however, is the need to investigate the quality of bodies of water, as the burn or river at Burdiehouse is considered to be polluted, but this has not been captured in GI Factor data gathering.

Table 3.2 Park GI Factors and sq. m. of relaxed mowing, grassland and trees

Park	Burdiehouse	Cramond	George Sq	Inch Park	Meadows	Saughton
GI Factor	**0.671**	**0.599**	**0.536**	**0.532**	**0.414**	**0.395**
Relaxed mowing (sq. m.)	35,641	243,881	5599	12,188	73,631	1445
Amenity grassland (sq. m.)	41,158	36,321	8781	123,089	281,198	85,471
Trees	366	151	182	436	1407	172

Phase 2 of the GI mapping pilot for Thriving Green Spaces begins in Spring 2022. It will include setting a GI Factor target and using the app to create a range of intervention scenarios for a neighbourhood to improve green infrastructure for biodiversity and climate change adaptation; decisions on what interventions to implement will be community led. A key aim is to strengthen the GI Factor method by expanding on and refining categories in the GI mapping app. Biodiversity value of different vegetation types can be captured in more detail, with consideration of specific plants for pollinators. Concurrently, adaptation value could be included with greater legitimacy using the two-tiered system to capture flood control, based on infiltration capacity associated with different vegetation types, and cooling potential, based on leaf area index, to calculate an aggregate score (Farrugia et al., 2013). GRaBS STAR tools will also be considered for use alongside NCS-based GI mapping, for a view that checks current surface area configurations (existing and proposed) against *future* temperature and rainfall scenarios. Use of the GI mapping approach at neighbourhood level in Phase 2 for the most part aligns with recommendations set out by Norton et al. (2015, pp. 128–130) to identify priority neighbourhoods based on climate change risk and social vulnerability, characterize UGI and grey infrastructure (through GI mapping), identify particular locations for interventions based on mapping and choose vegetation interventions that are "fit-for-place." Public demand for different types of green and blue spaces must also be part of decision-making, and this point is considered in the subsequent section.

4.4 App Challenges and Potential: Using the NCS Methodology

Several challenges became apparent when piloting the GI mapping app, both on university campuses and on city park sites. These included issues with app use, surface type categories, and competing values of green/blue spaces. Most volunteers who provided responses regarding their citizen science experiences found the app itself easy to use in the field, with main issues occurring initially when trying to download it. All participants had access to mobile phones or iPads, but the digital divide could mean that citizen science projects of this type fail to be inclusive; provision of iPads to volunteers for use in the field would address this potential problem.

Categories in the digital tool appeared to simplify areas, for instance if a polygon being mapped for GI had an undergrowth of naturalized grassland but also more than ten trees. To address this problem, volunteers collected information about vegetation at ground level, and a separate calculation was made for tree cover (unless there were specific areas of dense trees with no significant understory). The NCS does include instructions to count tree area and understory separately. It also provides instructions to give individual trees default area values similar to Malmo's GAF. App developers used datasets of surveyed trees from the Council and University of Edinburgh Estates to calculate individual values for trees (based on size and age), which were then added to the surveyed areas' values. Such detail is important to capture when considering infiltration capacity for flood regulation and cooling potential of leaf cover.

Alongside GI mapping app citizen science data collection to determine GI Factors for the Thriving Green Spaces pilot, an emotional mapping survey was conducted to understand how local residents comparatively valued different green spaces/vegetation types. Expressed preferences were also meant to be compared against the high or low adaptation/biodiversity value scoring given to green and blue spaces in the GI mapping tool. Ninety-three residents responded to the survey. Survey participants ranked a list of 12 types of green and blue spaces found in Edinburgh that derived from the NCS, considering which spaces they preferred over others and why. The survey used a simple star ranking system of 1–5 stars (Likert scale). Respondents explained their ratings in a text box, referring to their most positive and most negative responses.

Woodland, lochs, and rivers received the highest ratings in comparison to other types of green spaces, while parks with grass, ornamental trees, flower beds, green roofs, and grassy play parks received the lowest ratings, aligning with Natural Capital Standard valuing in the case of woodlands as highest rated and grassy play parks having a low ranking. Comparative value is important to remember; some participants did note that they enjoyed all green spaces but preferred some over others depending on activity (e.g. mown areas for sports and socializing in summer, woodlands for walks with the dog). These participants expressed use value rather than recognition of biodiversity or adaptation value of green and blue spaces. However, most survey participants did express clear preferences for particular green and blue spaces, calling for more trees in the city and more wild spaces that are of benefit to wildlife (biodiversity), human health, and overall wellbeing. They desired an escape from the noise, air pollution, and crowds that they associated with urban areas to immerse themselves in nature.

GI mapping based on the NCS, using citizen science, has the potential to capture a level of detail that is of value to local communities and is not captured by other tools that may quantify in terms of human preferences for green spaces (willingness to pay) or economic value (allayed health-care costs), as apparent, for example, in the approach in the Natural Capital Accounts for Public Green Space in London (Vivid Economics, 2017). Collation and mapping of vegetation type data in green spaces through citizen science provides an important local granularity not seen in high-level visualizations of habitat types (see Skelhorn et al., 2014) and involves local residents in the process. GI Factor scorings provide more than a notional understanding of biodiversity and ecosystem quality, comparable across different areas in the city. The tool can be used in decision-making for areas that score poorly, at neighbourhood scale, to determine biodiversity and adaptation solutions through GI. Interventions have potential to lead to community health benefits, especially in areas of deprivation that often have less or poorly managed green/blue spaces (Tieges et al., 2020).

5 Conclusion: The Need for Green Space Factors to Preserve and Enhance UGI for Climate Change Adaptation and Biodiversity?

GI Factor scoring of green and blue spaces is being used in some European cities, primarily at the commercial development scale, as a means to improve upon surface areas for climate change adaptation. Vegetation categories, in cases like Berlin and Malmo, are relatively generic and may not adequately capture detail, especially when integrating biodiversity values. The scoring of different surface types could also be criticized, however arguably less so than economic valuations which abstract to a greater degree based on cost-benefit analyses. Skelhorn et al. (2014) detail the importance of the micro-scale in the city (see also Khalaim, 2021), confirming that knowledge of individual trees and other vegetation, such granularity, is valuable specifically in understanding microclimates (different types of vegetation have different cooling effects on the microclimate, see also Farrugia et al. (2013) on both cooling and flood regulation). Recent research has identified the importance of community-based collection of urban vegetation inventories to understand how to mitigate climate change impacts such as UHI effect and flooding (Khalaim, 2021) and to fully engage local residents in adaptation and biodiversity actions. Specific city contexts must be considered, in terms of local residents' investment in green and blue spaces, their concerns, preferences, and knowledge; as noted by Møller et al. (2019), measures for sustainability are more successful when they are inclusive and bottom-up.

The Edinburgh GI Factor can serve as an example to follow, in terms of development and citizen science use of an app, a place-based e-tool, that can visualize space rather than relying on Excel. The method behind the app can be improved by refining biodiversity scoring and capturing water body quality, while using the two-tiered flood regulation and cooling potential scoring developed by Farrugia et al. (2013). This approach can also include use of the GRaBS STAR tool for a future view. Further research is required to follow GI Factor use, in its different forms, and resulting interventions over time in particular contexts to fully understand the value of this method. Use of NBS for cooling, flood regulation, and biodiversity in the face of climate change will be a necessary means to adapt cities.

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4

Agroecological Approaches for Climatic Change Mitigation and Adaptation: Experiences from the South to Encourage Direct Producer-Consumer Relationships

Eduardo López Rosse

1 Introduction

Climate change has received much attention due to its direct impact on the environment and people's livelihoods. Scientific reports, such as the fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), project that by 2100, global mean surface temperature would increase by 1.1–6.4 °C over the 1990 level in the non-mitigation emissions (IPCC, 2007). On the other hand, there are more optimistic reports, such as the IPPC, which stated a minimum increase of the temperature in the earth from 1.5 to 2 °C. Scientific research posits many theories and future scenarios that are shared during important global meetings (e.g., conferences and symposia) in order to guide policy

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makers in modeling their global as well as local policies based on these adaptation and mitigation strategies.

Some of the consequences of the rise in temperature are environmental and agricultural. Environmental consequences include changes in rainfall patterns (e.g., sea levels rising and flooding) and seasonal patterns (e.g., increased number in hurricanes and a generally longer hurricane season). Agricultural consequences include landscape fragmentation, natural resource exploitation, pollution, and the emergence of new pathogens from the wild (Lu et al., 2015). The disturbance to natural resources generated by human activity causes physical contact with hosts that carry diseases such as hanta and coronaviruses that can cause outbreaks among human populations (Markotter et al., 2020). Examples include the Influenza and SARS-1 outbreaks, which gravely affected Hong Kong, South Korea, and China a few years ago (Moratelli & Calisher, 2015); a more recent example is the coronavirus (SARS-CoV2) struck last December 2019 in Wuhan, spread worldwide, and caused a global pandemic from which the world is yet to emerge at the time of this chapter's publication.

Agricultural trends show that there will be 20% more malnourished children in 2050 due to climate change. In fact, the IPCC projects that crop productivity would increase at mid to high latitudes for local mean temperature increases of 1–3 °C (depending on the crop). High temperatures will increase the frequency of droughts and floods, and consequently, they will negatively affect local crop production (IPCC, 2007). Conventional agriculture also releases a significant amount of carbon dioxide, methane, and nitrous oxide into the atmosphere. Overall, these emissions amount to approximately 10–12% of the total global anthropogenic greenhouse gas emissions annually.

The major problems of conventional agriculture can be placed into three categories: (i) environmental (i.e., predatory activities such as deforestation that causes soil and biodiversity erosion as well as GHG emissions), (ii) economic (i.e., credit dependency for acquiring genetically modified seeds and agro-chemicals), and (iii) social (i.e., seasonal migration of crop harvests and the social exclusion of small farmers). Strategies for addressing climate change must include both adaptation and mitigation, but ecological agriculture has the potential to do both (IFAD, 2006). This chapter contributes to advancing knowledge on how organic agriculture can be a vector for combating climate change and is structured as follows: Section 3 briefly reviews the history of agricultural ecology and its certification. Section 4 describes the major certification schemes for agricultural produce classified according to their governance characteristics (third-party, private, and voluntary certification). Section 5 describes two PGS case studies from Bolivia and Colombia and details of their innovations. Section 6 synthesizes key learnings from the case studies, and finally, Sect. 7 summarizes and concludes the chapter. Methodologically, this chapter is based on the collection of scientific information from reports and papers about global warming, agricultural ecology, as well as certification, and innovation or upgrading in short value chains. The selection of two study cases is based on their importance in the development of certification and verification protocols in different scenarios such as the Bolivian and Colombian PGS.

2 Adaptation and Mitigation Strategies

Currently available reports and studies present scenarios under which we can limit the rise of global temperature to a 2 °C threshold. However, in order to stay within this threshold, we need to move toward net-negative global emissions. This would require mobilization on a global scale as well as improvements in our approaches to mitigating and adapting to global warming. Adaptation can be defined as the adjustment of natural or human systems in response to actual or expected climatic stimuli as well as its effects, which moderates harm produced and exploits beneficial opportunities (McCarthy et al., 2001). Biotechnology offers the opportunity to adapt to the changing climate conditions. The development of vegetal species, for example, creates resistance to plagues and high temperatures. Mitigation can be understood as relieving the effects of climatic change through physical, political, and economic measures. Political measures can refer to signed agreements in international meetings and summits such as United Nations Conference on Environment and Development (UNCED), United Nations Conference on Sustainable Development (UNCSD), and the 2012 United Nations Climate Change

Conference. Physical measures can be subdivided into the use of alternative fossil fuels (biofuels) and environmentally friendly agronomical practices.

Environmentally friendly agriculture is characterized by the adoption of physical, cultural, and political practices. These practices can be divided into other agricultural branches, from political to scientific approaches such as ecological agriculture, permaculture, organic agriculture, bio-agriculture, and agroecology. To be more efficient, this text considers all these environmentally friendly branches as synonyms. On the other hand, ecological agriculture is an autonomous mitigation strategy that involves the following: high resilience to natural stresses (this resilience is achieved through to the use of different cultivars); soil preservation (by keeping natural soil flora and fauna that enhances soil fertility and humidity); and carbon sequestration (agroecological agriculture is self-sufficient in nitrogen due to the recycling of manure, livestock, and crop residues). Depending on political scenarios, ecological agriculture can also be referred to as organic agriculture. For example, in Ecuador and Bolivia, there are public policies for enhancing a more environmentally friendly agriculture, which is also called organic or ecologic (DeLind, 2002).

3 Background: The History of Agricultural Ecology and Its Certification

Following the enslavement of Indigenous people (*Indios* in Spanish), colonizers started to introduce industrial crops (sugarcane, tobacco, grapes, cotton, and coffee). Subsequently, deforestation and the emergence of new diseases affected native populations, and local traditional crops such as potatoes, maize, and cocoa were seized and sold to Europe. Colonizers promoted local agroecological systems and the destruction of social organization (e.g., M'itha, Ayni) to encourage the production of the introduced crops but kept ancient irrigation systems to water these crops (Alcorn, 1990).

In the 1920s, the term "agricultural ecology" was introduced into the agricultural arena. Northern think tanks from Europe were the first to adopt and introduce Inca agricultural practices. *Indios* have their own agro-food systems, based on an environmentally friendly agriculture that uses local knowledge named cosmovisions or worldvisions. These cosmovisions are formed from ancestral traditions, such as the use of moon cycles and multicrops. The pioneers of the agricultural ecology introduced these practices as an ethical response to the harmful effects of the agricultural-industrial revolution characterized by the use of monocultures and the overuse of agro-chemicals.

For example, Cuba was a Spanish colony in which industrial crops (sugarcane and tobacco) thrived. Centuries passed; independence was fought for and won; and new political, economic, and social organizations were created to produce, process, and commercialize raw and industrialized products (e.g., rum and cigars). The emergence of multinationals such as the United Fruit Company produced, processed, transported, and distributed bananas to the North from production centers in Costa Rica, Nicaragua, Guatemala, Mexico, Ecuador, and Colombia under private standards (Fallas, 1955). These multinationals imposed Green Revolution techniques to magnify production yields, such as employing harmful chemicals and over-exploiting human labor.

In 1962, *The Silent Spring* was a best seller. The author, researcher, and environmentalist Rachel Carson captured the toxic effects of dichlorodiphenyltrichloroethane (DDT) in her book. Her groundbreaking study suggested that insecticide killed insects and other animals (Carson, 1963). The research conducted in *The Silent Spring* showed that DDT had a harmful effect on people and the environment. Even graver, Carson revealed that DDT was used worldwide. During the 1990s, more studies were conducted on agroecology. Many universities also integrated agroecology as an academic subject (Wezel et al., 2009). More specifically, the first think tanks dedicated to agroecology were established in Latin America (e.g., AGRUCO in Cochabamba) and promoted agroecological research in Bolivia and overseas.

4 Certification

The contemporary food sector is far more globalized than ever before. The quality standards result in the transmission of more information to consumers, such as origin, food composition, and other special attributes (Ponte, 2004). These certification standards were also described as "hidden barriers" (Murray et al., 2006) because they block the entry of organized small producers into specialty markets (e.g., niche and boutique) in which they can access better monetary incomes. Generally, producers are asked to adopt production protocols which can be private or voluntary. These social practices (fair trade) have helped organize producers enhance their livelihoods. In order to join the fair-trade movement, a producer must be affiliated with a cooperative and adopt the social and economic protocols to fulfill the fair-trade standards (Soto, 2005). Fair trade emerged after World War II through the active involvement of churches and other agencies linking producers from the South to consumers in the North through distribution stores (Parrish et al., 2005).

In the agricultural sector, there are four types of certifications: third party, private, voluntary, and fair trade. Among these four varieties, the most popular certifications during the last 30 years have been the organic and fair trade. During the last ten years, other types of certification schemes have come to the fore. In the coffee sector, rapid expansion in the market has seen the creation of the Rainforest Alliance, UTZ Certified, and Starbucks Coffee Company certification schemes. Figure 4.1 represents this information visually. The first group is composed of the newest certification schemes, which communicates the codes and guidelines integrated by sustainability criteria (economic, social, and environmental). Finally, the third group comprises environmental schemes that are more radical and show a lack of orientation in social criteria. The next section overviews these types of certifications in more detail.

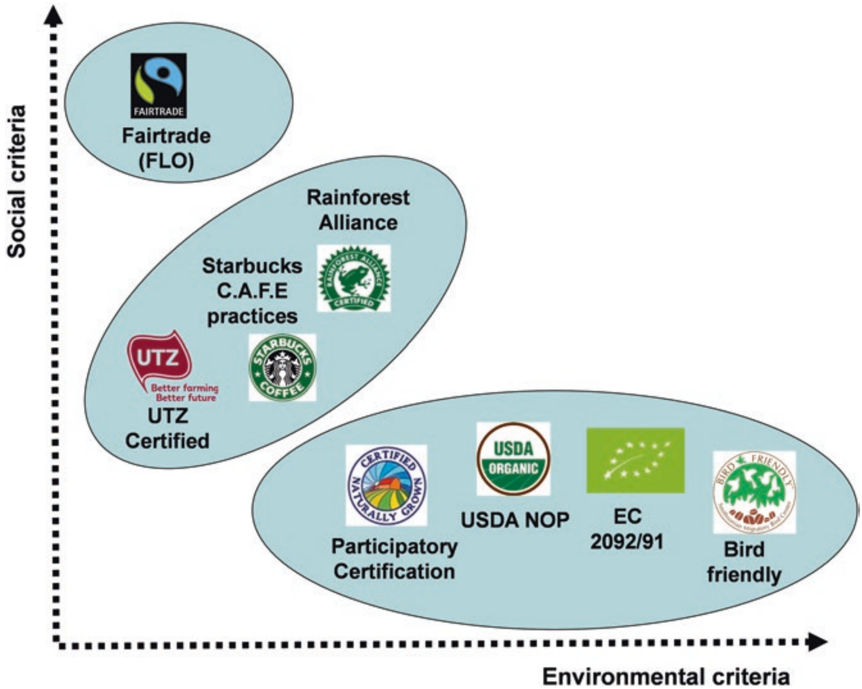

Fig. 4.1 Social and environmental criteria for agricultural products. (Source: López Rosse, 2008)

4.1 Third-Party Certification

"Certification is a procedure by which a third party provides a written assurance that a product, process or service conforms to specified standards, on the basis of an audit conducted to agreed procedures" (Bass et al., 2001). According to Conroy (2005), certification implies that producers must adopt accurate engagements to respect the demanded quality standards of a product. Certification is a useful tool that allows producers and processors to access niche markets. Nowadays, there are a series of certification schemes given by private agencies.

4.2 Private Certification Schemes

These schemes were developed by companies to establish more direct relationships between providers and buyers. These marketing tactics have their own codes of conduct that consider economic, environmental, and social criteria. These practices have been developed by adapting the existing criteria from different schemes such as the International Labor Organization (ILO), which fights against child labor and was then also introduced into Nestlé's Corporate Social Responsibility Program. These companies originally prepared these codes with no consideration of the impact that they could have on their providers in the medium to long term. Some private schemes incorporate monitoring and verification in their codes of conduct, authorizing third-party certification agencies in these tasks (Conroy, 2005).

4.3 Voluntary Certification Schemes

There exist many different types of voluntary certification schemes. These include:

Organic agriculture: Organized producers might adopt organic production methods for ideological reasons, health reasons, and environmental reasons. For example, coffee producers adopt organic practices because they cannot afford to buy the expensive agro-chemical cocktails or technological packages (Bacon, 2005). The adoption of organic practices is voluntary but requires the certification and verification of a third-party agency that controls organic production standards. The most used organic standards were developed by the International Federation of Organic Agriculture Movements (IFOAM). The IFOAM is an umbrella federation that establishes production and processing standards for organic products and the adoption of environmentally friendly cultural practices (e.g., biological control and crop rotation).

Bird-friendly: This certification scheme is the most rigorous of the group because additional environmental criteria are included such as shadow or forest native species (12 species); organized or private farmers must have a previous organic certification and other criteria from the Smithsonian Migratory Bird Center (SMBC), which is then verified by a third-party agency.

Fair trade: Since the 1950s, fair trade has evolved considerably thanks to the labor of churches and cooperative organizations that created networks between the South and the North (Parrish et al., 2005). The innovation of using commercial networks to allow organized producers from the South to access new opportunities from Northern markets was possible thanks to the first Dutch Fair Trade Association (Max Havelaar) established in 1988. Fair-trade criteria can be sorted into two groups: social and economic. The first, social, considers that buyers of fair-trade products must pay the established floor price for mainstream and fair-trade goods. For example, the mainstream fair-trade price of coffee was US$ 1.31/lb and US$ 1.51/lb for organic fair-trade coffee. The second, the economic criteria, considers the direct purchasing from the producer organizations with no middleperson, long-term contracts, transparency, cooperative agreements between organizations, and a ban on child labor. Fair-trade criteria were established by the International Fairtrade Labeling Organization (FLO-I) in 1997. Two organizations make up the work of FLO-I. The FLO-I e.V establishes the criteria for fair trade, and the FLOCERT GmbH certifies to the producing, processing organizations, retailers, and roasters.

Rainforest Alliance: This scheme does not offer a price premium directly, but the correct use of the Rainforest certification seal may result in it being commercialized at supermarkets. For example, Kraft Foods and McDonald's purchase huge volumes of certified coffee Rainforest Alliance, the first for selling at supermarkets and the second for restaurant chains such as McCafé of the United Kingdom (Whelan, 2007).

UTZ certified: This is private scheme that has its own code of conduct. UTZ Kapeh is the name of the foundation established in 1999 by Ahold, a Dutch multinational supermarket chain, and by Guatemalan coffee exporters. This scheme does not recognize a price premium for coffee. Instead, it provides technical and marketing services to organized producers charging a percentage of these services to cover the transaction and certification costs.

Participatory certification: Participatory certification is an internal control mechanism (social control) of organized producers who want to commercialize their products domestically. Participatory certification is voluntary and was promoted by NGOs. The most well-known NGOs that promote alternative certification schemes are Nature & Progress (France), REDE ECOVIDA (Brazil), and ORO VERDE (Costa Rica). Also, there are some outstanding national endeavors such as Law 8542 in Costa Rica (Chapter II Art.5 Inc f page 1) on the development, promotion, and enhancement of the organic agriculture and husbandry, which defines the participatory certification schemes as "the developed systems by direct relationships between organic producers and consumers who guarantee the origin and condition of the organic products for the national market." This system is integrated into the law, to act as an alternative to organic third-party certification for the organic production and commercialization at national level (Lizano et al., 2007). For example, VECO-Costa Rica (a Belgium NGO) promotes this mechanism involving other local actors to commercialize their products in organic fairs and bio-shops. Other participatory schemes exist in Brazil, New Zealand, and India. In these countries, participatory certification acts as guarantee system for the commercialization of products for domestic markets, but it is not recognized as a formal certification. In other words, under this scheme producers gain experience for new and more complex endeavors.

5 Case Studies from the South on Agricultural Ecology

5.1 The Bolivian Scenario for Progressist Policies

"The rebellion against the capitalism that causes overall crises": this is not a communist slogan, but rather communicates findings from the meetings, conferences, and summits that were held in criticism of the signed agreements in Japan (Kyoto Protocol in 1998 and Copenhagen in 2009) and advance an argument that these were not feasible for "developing countries." Activists, scientists, citizens, students, and policy makers in developing countries decided to rebel against "developed" countries, which do not sign on to international agreements on climate change issues.

The Plurinational State of Bolivia is a useful example in the definition of contra-movements against the capitalism, which is considered the number one culprit for the climate, financial, and social crises that affects the natural environment and mankind; it provides an indicative scenario that can serve as a model for climate change mitigation. As a matter of fact, the new social public policies that were adopted in the Bolivian context allowed the organization of a climate change committee that attended to the Copenhagen Summit in 2009, where the richest and most developed countries failed to meet their commitments to reduce GHG emissions. In this unfair paradigm, Bolivia decided to lead and be the organizer in gathering the demands of those who were excluded or not taken seriously in the World Summits organized by the more polluting countries.

The first event was "The World People's Conference on Climate Change and the Rights of Mother Earth", which was held in April 2010 at Tiquipaya, Cochabamba. This conference gathered well-known representatives in the arena of climate change mitigation and adaptation, such as the Via Campesina and other worldwide coordinators of Indigenous and land-working communities. Over the course of two days, the 17 workgroups succeeded in the definition of political, economic, and social issues that must be addressed in future summits, such as changing the capitalist development model, drafting Mother Earth's Rights Declaration, and dealing with the International Climate Change Justice Tribunal. During this international conference, all attendants agreed to reject the Copenhagen Agreement on Climate Change and carbon markets, such as those promoted by "Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries" (REDD++). In contrast, the overall affirmation was guided by Indigenous worldviews or cosmovisions that can be the key to cooling the planet and thus acting on IPCC reports on climate change.

In June 2014, The G77+China Summit was held in Santa Cruz, Bolivia, joining 133 countries; the chairman was the former president Evo Morales Ayma, and the principal objective of this summit was the building of the basis of a new world order for "Living Well." All findings from this event were used to develop the new Development Goals for 2020–2030; indeed, most of the United Nations development goals are the same as the Bolivian Patriot Agenda 2020–2025. Stemming from the independence movement, this agenda was based on the "Vivir Bien" (Living Well) philosophy, and it is also cited in the State Constitution ratified in 2009, which emphasizes poverty reduction and the production of high-quality and healthy food for all (Grondona et al., 2016).

5.2 Agroecological Agriculture in Bolivia

The Plurinational State of Bolivia has a total cultivated area of some three million hectares. Currently, the most important agro-industrial crop is the soybean, representing for more than one-third of the cultivated area (1.16 million ha), of which 90% is planted with genetically modified soybeans. The latest statistics show that more than 1 million ha are dedicated to genetically modified crops, compared with a little over 117,000 ha under organic production. Despite this situation, the government has invested millions to prepare a legal framework to promote organic agriculture.

Law 3525/2005 for the promotion of organic agriculture allows for participatory certification through a Participatory Guarantee System (PGS), which is based on IFOAM guidelines. These refer to a voluntary process developed by actors involved in the short organic value chains that verify the production, process, and commercialization at the local level in order to certify them. Furthermore, the Bolivian Association of Organic Organizations (AOPEB) has a broad representation of organizations and low-income farmers. Its work revolves around the principles of sustainable agriculture, product processing, marketing in alternative spaces, and the establishment of PGS, in addition to other areas of activity, such as organizational self-management, leadership training, and advocacy. AOPEB is important in public policy because its advocacy has resulted major outcomes, including the development and approval of key legislation such as the above-mentioned Law 3525 on organic production and implementing regulations. The UC-CNAPE and the National

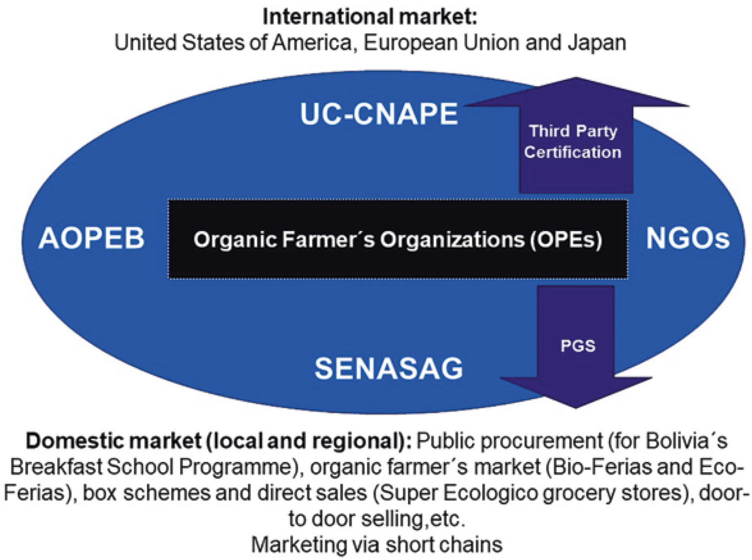

Fig. 4.2 Institutional enabling framework for organic value chains in the Plurinational State of Bolivia. (Source: Chambilla & López, 2016)

Secretary of Agriculture and Husbandry (SENASAG) are the monitors of the organic agriculture in the country (Fig. 4.2).

5.3 Innovative Mechanisms for Cost Reduction

In scientific literature on value chains, the enhancement of production, processing, and even marketing is known as innovation or upgrading. Small, organized producers can innovate in four ways: (i) product innovation, (ii) process innovation, (iii) functional innovation, and (iv) intersectoral innovation (Humphrey & Schmitz, 2000). Product innovation involves improving the production system, for example, using new equipment to add value to products. Process innovation requires transforming inputs into outputs more efficiently by reorganizing the production system. Functional innovation involves performing new activities that help to increase the product's value, such as marketing (brand promotion).

Inter-sectoral innovation is achieved by moving into new production sectors with new products and services.

I argue that short value chains and the PGS are integrated innovations. Short value chains are seen as a functional innovation that structures the supply chain more effectively by reducing the number of intermediate links and by establishing more direct relationships between producers and consumers in local markets. PGSs are seen as horizontal innovations and cooperative mechanisms of trust between producers and consumers, which call for alternative guarantee systems to be created in local trading spaces. In Bolivia, PGSs comply with established standards and a regulatory framework for process; they use social control to improve organic production verification and monitoring. Both of these innovations are aimed at developing more direct relationships between the actors involved (producers and consumers) and toward expanding social control between producer and consumer groups, thereby reducing transaction and certification costs.

In the Plurinational State of Bolivia, these innovations have typically been supported by a number of private institutions, like NGOs, although more recently public institutions have been promoting a more sustainable and organic form of farming to add value. However, little importance has been given to marketing and linkages between producers and consumers in local markets, with the result that some sustainable products are sold in conventional markets without any of the extra production costs being reflected in the price. This poses a range of challenges to producers, the biggest being access to fair and differentiated local markets. Initiatives by producers, consumers, NGOs, and as previously mentioned, the involvement of public institutions and some municipal council have led to the emergence of alternative spaces for the local promotion of organic farmers' access to and integration into alternative markets, also giving consumers access to safe and healthy food. These alternative spaces are located in different areas of the country at organic farmer's markets (*bio-ferias* and *eco-ferias*).

5.4 Participatory Guarantee Systems (PGSs)

PGSs emerged as an alternative way to giving organic farmers and farmers in transition access to a local certification scheme that is more solidarity based and increasingly in touch with the on-the-ground reality of farmers. From a technical view, third-party certification is further geared toward specialized products for international markets (coffee, cocoa, and bananas for the United States and Europe). Nevertheless, for products to be exported to countries in the Northern Hemisphere, they must meet international standards assessed by certification agencies that have been accredited by a set of public and private actors. However, certification is far too expensive for most farmers, especially in the early organizational stages. Consequentially, it has excluded smaller farmers from available value chains serving specialty markets such as organic and fair-trade products (Soto, 2005; Murray et al., 2006). In response to this social and economic marginalization, NGOs, social movements, consumer networks, and farmers' organizations have coordinated PGSs as an alternative to third-party certification (Meirelles, 2005). While PGSs have appeared in the Plurinational State of Bolivia's Law 3535/2005 since its enactment, it was not until 2012 that the Technical Norms and Regulations for PGSs were published. In Bolivia, however, private PGSs, such as Eco-Feria in Cochabamba, have existed since 2003. PGSs differ in the context of their geographic scope (national or municipal), composition (public or private), and social and cultural context (Indigenous, low-income farmer, or community). Bolivia's legislation views PGSs and direct marketing in local markets as instruments for promoting organic farming based on participatory social control to verify as well as monitor local and national compliance with technical standards. The main features of these systems are Recognition of Non Wood Forest Products (NWFP) and Recognition of ancestral practices or Worldviews.

The Municipal PGS of Achocalla set up their PGS in 2012, involving 275 families grouped in 13 communities. The Ecologic Guarantee Committee of the Municipality of Achocalla (CGEMA) is responsible for running the PGS and is made up of producers, processors, service providers, and consumers (Fig. 4.3).

Fig. 4.3 Organic produce variety at Achocalla Municipality in a peer-to-peer PGS verification, La Paz, Bolivia, 2013. (Source: Personal Collection)

The PGS has created direct relationships between producers and consumers, with benefits for both. For the farmers, the PGS has improved their chances of accessing differentiated local markets and has raised their profile as organic producers. Meanwhile, citizens are no longer reduced to passive consumers. Achocalla is the star organic municipality because all of its actors in the value chain work together in harmony and are supported by the municipal organic and social development platform. The Bio Caracollo PGS involves ten nearby communities and trades their products at the Bio Caracollo Fair. CNAPE and SENASAG verify the PGS standards and allow certified producers to use the National Seals for Ecologic and Transitional products. As such, the municipality of Achocalla provides a wonderful example of how direct producer-consumer relations in the agroecological context can mitigate many of the challenges associated to and consequences of climate change (Fig. 4.4).

Fig. 4.4 Bolivian Participatory Guarantee Systems seals. (Source: CNAPE, 2013, p. 83)

Table 4.1 Organic agricultural land including in conversion in South America

	Total of organic hectares: 5,603,752	
South America	Hectares	Percentage (%)
Argentina	3,061,965	54.64
Uruguay	1,307,421	23.33
Brazil	705,233	12.58
Peru	263,012	4.64
Plurinational State of Bolivia	114,306	2.03
Paraguay	54,444	0.97
Ecuador	45,818	0.81
Colombia	31,621	0.56
Chile	19,032	0.35

Source: Adapted from Willer et al. (2016)

5.5 The Familia de la Tierra Participatory Guarantee System

The Colombian Ministry of Agriculture provides a certification mark for organic products that are certified by third parties. The latest report of Willer et al. (2016) on organic production shows that Colombia has 31,621 hectares under organic agriculture (0.56% of the certified organic area) (Table 4.1).

This is an indicator of the lack of attention to other alternative certification schemes in these countries. The situation has led to civil movements organizing environmentally friendly events through fairs and rallies that gather organic producers and consumers.

The Familia de la Tierra Network was created in 2009 in an institutional agreement with the Bogotá's Economic Development Secretariat to conduct market research on an alternative way to market organic products. Many actors (producers, processors, public service staff, civil society organizations, and consumers) fall under the umbrella of the District Development Plan created by Bogotá's mayor that provides small grants to civil society organizations. In Bogotá's mayoral elections, the population voted for change and the development of a public policy for regional integration called "Humane Bogotá." The principal objectives of this plan were (i) the ecological recovery of the urban and peri-urban scenarios, (ii) the implementation of organic farming as a model for Bogotá, and (iii) the protection of the population against "Genetically Modified Organisms" (GMOs) in the city of Bogotá.

The private sector (restaurants, hospitality, and industry sectors) had been key players in the development of the Familia de la Tierra Network because they responded to the new demand for healthy food consumption, such as private procurement for schools. To enrich this procurement, school visits to Familia de la Tierra's farms were necessary to reinforce the new trust bonds. Before these new endeavors, Familia de la Tierra was forced to sell their products at the same price as conventional products; otherwise they would not sell their organic products at all—in theory this result is termed "side-selling." At this micro-level of analysis, two controversies arise. The first is the social and economic marginalization of potential producers that produce organically. The second is the generalized doubt that organic production is feasible. In response to these controversies, Familia de la Tierra Network prepared an alternative agriculture framework that differs from neoliberal agricultural models that hinge on networking small farmers in horizontal networks, where wealth is distributed along the chain. To re-connect with the land, Familia de la Tierra's members created a PGS to help them develop different kinds of trading relationships with consumers and create a close relationship with consumers (Nieto, 2016).

5.6 The Participatory Guarantee System of Familia de la Tierra

As previously stated, PGSs are based on organic approaches and social processes. Participatory certification differs from third-party certification in its approach, which aims to involve consumers in production systems to build trust and reciprocity in a continuous relationship between producers and consumers. Familia de la Tierra's nationwide network includes diverse production, such as grains, quinoa, wheat, 18 maize varieties, 39 varieties of haricot beans, amaranth, rice, 10 leafy vegetable varieties, and tomatoes. There are also other processed products from organic origins like dried yacon and coca noodles. Familia de la Tierra's sustainable agricultural practices consist of a closed-loop production approach related to thermodynamics and energy fluxes, which defines a set of criteria that ensure sustainability (such as the use of local native seeds and fair trade). This system may be viewed as an ally to niche markets and, indeed, climate change mitigation.

A four-stage process exists for an on-farm assessment of the criteria. Stage 1 involves the initial contact and analysis of the production system with the scheduled visits by the inspection team and the questionnaire filling with information on crops, soil preparation, seeds management, and historical records. Stage 2 involves soil analysis through soil chromatography, which is a method for separating mixtures to conduct a qualitative soil assessment on their own terms. These analyses show the interaction between minerals and microorganisms. Stage 3 involves consumer visits; this can be considered as a farm validation system, in which consumers are invited to tour the farms to verify the criteria and then enjoy a lunch with the harvested products, thus creating an interesting and interactive experience for consumers. Every tour to a farm lasts approximately four hours. Up until 2016, eight verification visits were made that led to the certification of 35 farms in Colombia. Finally, Stage 4 involves the issuing of certification to farms. As far as 2016, 36 farms (1 hectare) have been certified under the program. Overall, the Familia de la Tierra PGS enabled producers to access markets managed by Familia de la Tierra in Bogotá that include 18 restaurants, 7 eco-shops, and 1 responsible consumption network. Once stage 4 is reached, the development of an internal control system is required.

5.7 Upgrading in the Familia de la Tierra PGS

The sustainable model that promotes Familia de la Tierra consists of spaces for production and community labor in preserving, producing native seeds, organic farming practices for food production, processing, and marketing. Jaime and Ari are the keepers of Utopia Farm in Bogotá. Jaime is also the president and leader of Familia de la Tierra. Utopia farm is called *Finca Madre* (Mother Farm) because it preserves and propagates the native seeds of organic products for all members of the Familia de la Tierra. The spouses, Jaime and Ari, grow beans, potatoes, and vegetables as well as raise trout that are fed with farm by-products. While Ari takes care of the children, he also harvests potatoes and vegetables for home consumption; the surplus of potatoes is used for the production of potato chips that are sold at a private school. The vegetables are sold at Bio-Plaza organic stores in the affluent neighborhood of Usaquén. The principal products commercialized from Familia de la Tierra's farms are fresh potatoes and vegetables (Fig. 4.5a and b). Other processed products are dried yacon, chocolate, organic panela, and coca tea noodles; these diversify the production and enable more domestic and national producers to be part

Fig. 4.5 (a) (left) and (b) (right): Organic potatoes and lettuce, respectively, at Utopia Mother Farm, Bogotá, Colombia, 2015. (Source: Personal Collection)

of Familia de la Tierra (Fig. 4.6). Familia de la Tierra also invites consumers to visit their farms during the PGS verification process.

This product upgrading was the result of organic sustainable production made by a closed-loop production approach, which helps to optimize the use of inputs (such as water) and provides protection against winds and temperature drops. These special and environmentally friendly conditions, in which agricultural products are grown, provide better prices for these products, ranging from 20 to 400% above those of mainstream products. The process of upgrading enhanced the agricultural farm practices at Utopia Farm, and all disposals are now re-used. This functional upgrading involves the marketing of organic and transitional products. The economic spaces for organic products in Bogotá consist of 37 outlets (15 specialist shops, 17 large retail stores, and 5 private sales distributors). Most of these economic spaces are located in the richest neighboring cities of Bogotá such as Usaquén, Chapinero, and Teusaquillo (Fig. 4.7).

Fig. 4.6 Organic chocolate and panela at Bio-Plaza Eco-Shop in Usaquén, Bogotá, Colombia, 2015. (Source: Personal collection)

Fig. 4.7 The Bio-Plaza Eco-Shop at Usaquén, Bogotá, Colombia, 2015. (Source: Personal collection)

5.8 The Gastronomic Approach of Familia de la Tierra

To link the rural with the urban scenarios, agro-tourism represents an opportunity for the development of Local Agro-Food Systems (LAFS). Agro-tourism offers tourists participation in productive activities, such as milking and cheese preparation. Also, these activities can be seen as alternatives to development and generate extra income for small producers in rural contexts. Typically, the tourism potential of gastronomical activity is narrowly seen as going to restaurants. Producers usually have barely any participation in the gastronomical universe, but the PGS allows for their active participation.

In sum, food is part of the cultural heritage of a country, and when it is connected to gastronomy, it enhances tourists' experience while celebrating heritage value of the food itself. Gastronomical tourism is focused on enhancing and disseminating a country's food profile, so the principal activity is to discover the food-based traditions of that location. These features are not necessarily driven by cuisine connoisseurs, but rather by people that love to taste new flavors and have new experiences. The activities range from visiting local marketplaces to an immersive activity involving insight onto the producer's daily life and food preparation methods. This type of tourism can also be focused on different specific regions, for example, the routes of cocoa and coffee in Central America, wines in France, and olives in Spain (Iglesias & Navarro, 2014). There are many gastronomical, wine, and alcoholic spirit routes in the region relevant to this study, such as the wine and s*ingani* (distilled grape liquor) routes in Tarija, Bolivia, and the cheese route in Santa Cruz de Turrialba, Costa Rica.

6 Discussion

Per Humphrey and Schmitz (2000), the discussion section herein is organized to reflect the three types of agroecological upgrading (production, process, and functional). The case study of Achocalla PGS shows a product upgrading through the adoption of the Bolivian PGS certification that recognizes private and public verification. The Achocalla PGS allows for the participation of all actors involved in the value chain. Process upgrading is achieved through the adoption of physical and cultural practices to guarantee organic production such as PGS legislation. The functional upgrading is possible using Information and Communications Technologies (ICTs) for marketing organic produce, for example, the use of virtual platforms (Facebook and WhatsApp groups). On the other hand, the Familia de la Tierra PGS is an example of a private PGS that established a regional PGS certification despite the lack of a national legal framework. Product upgrading is made possible by participatory certification along the national networks of Familia de la Tierra. Process upgrading occurs through the adoption of cultural and physical practices to ensure participatory certification. Finally, functional certification takes place through a direct purchasing system that involves the private activity of selling potato chips to a private school's kiosk. In addition, some products are sold by eco-shops at local and regional levels.

In both cases, there are three upgrading types that are widely described in the academic literature, but innovation is identified in the functional upgrading through ICTs. Nowadays, functional upgrading is crucial in ordering healthy (organic) food during the COVID-19 pandemic that changed our ways of buying food abruptly and dynamized the delivery services of organic baskets. According to the reviewed academic literature, product upgrading can be done by incorporating value through tools such as labeling, as exemplified by the PGS labels for the Bolivian case study, which allows two types of certifications: transition and organic; both are recognized at the national level. On the other hand, the Familia de la Tierra PGS had no certification label and depends exclusively on trust and confidence between actors. Both make valuable contributions to organic agriculture's challenge to climate change.

7 Conclusion

Environmentally friendly agriculture is a mitigation strategy that is being adopted by some governments according to international agreements since RIO 92; it can vary by the adopted standards (bio, organic, permaculture, Rainforest Alliance, etc.) used in different contexts and regions. These standards can be sorted into three important groups (social, environmental, and mixed). This chapter explores PGS certification schemes, which are characterized by their transparency, flexibility, and inclusivity features. As of November 2019, there were 242 PGSs worldwide, showing that this certification is becoming more widespread. This chapter describes two case studies that are part of this movement. Both PGSs were developed in different scenarios; for example, the Achocalla PGS was developed under the Law No 3525/2005, and in contrast, the Familia de la Tierra PGS was developed with no national legal framework but a strong producer commitment to create participatory certification standards. Based on these detailed studies, this study suggests three recommendations. The first is that PGSs must work with national or regional legislation to empower production. Second, it is necessary to foster demand among public and private actors. Third, labeling must be enhanced to communicate product, processing, and functional upgrading to consumers; this recommendation has the added benefit of creating additional product value.

The Bolivian experience of networking developing countries through international events is an alternative to the capitalism that both causes and aggravates the global environmental crisis. Governments must agree to adapt to and mitigate climate change, but this endeavor seems difficult due to the complexity of the agreements involved and the lack of accountability to which international leaders are held. To overcome these failures, a new world order based on solidarity and the adoption of more environmentally friendly agriculture, as is seen in the Living Well paradigm, is urgently required. Worldwide activists and sustainability-minded individuals are following ecological practices to reduce GHG emissions, develop local markets, and create short value chains. Nevertheless, the hope for combating global warming depends on reworking larger systems within the capitalist mainstream; direct producer and consumer relations in organic agriculture, as well as agroecology more generally, provide us with a different model to this end.

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5

Sustainable Renaturation in Desertification Control: Expediting the Natural Succession of Large-Scale Vegetation in Drylands

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1 Introduction

Restoration measures are important in the fight against desertification and the loss of arable land that is caused or aggravated by climate warming and a growing population (Huang et al., 2016; UNEP, 2019; Wang et al., 2012). Such measures must seek to control desertification in an

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ecologically neutral way, make necessary large-scale revegetation efforts more resilient to future climate challenges by using the process of natural succession of vegetation, and expedite this process in arid and semi-arid drylands. The Chinese "Three-North Shelterbelt Program," a long-term program with a total restoration area of more than 3 million km² today, is an interesting case study (Cao et al., 2011; Huebner, 2020; Liu et al., 2008; Sun et al., 2006). For the past 40 to 50 years, families have been working in reforestation programs at the grassroots level. The initiative shows a positive regional impact on soil, climate, and agronomy (Tan, 2016; Zhuang et al., 2017). However, numerous hydro-ecological risks were reported. Planting campaigns often were not adjusted to the various climate and soil types, resulting in sometimes disastrous consequences for vegetation and soil. As an example, the dense planting of trees in the Loess Plateau, a semi-arid region of Northern China, resulted in the lowering of the water table. Consequently, grasses and other native plants were unable to survive. High water loss due to the evapotranspiration of trees finally resulted in the loss of deep soil water as well as high tree mortality (Cao et al., 2011; Wang et al., 2019).

This and similar examples show that more climatically adaptable and ecologically sustainable solutions are urgently needed—globally—for the large-scale restoration of degraded semi-arid and arid lands. The hydro-ecological lessons learned here are a treasure of long-term ecological experiments, and the learnings can, and should, be transferred to any desert border region with a comparable harsh climate. It is a highly valuable restoration measure to remove the cause of disturbance and to let nature do the work of revegetation. The process is called "natural succession," and it results in a vegetation suited best to local environmental conditions and with climatic adaptability (Chazdon, 2008; Liu et al., 2018). In this chapter we review the potential of natural succession in semi-arid and arid drylands and a model to combine the planting of greenbelts and certain soil treatment to achieve an expedited process of

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succession within protected compartments. Without such assistance the process may take one or more decades as seen with first results from China, where succession is being used for large-scale revegetation of drylands since about 2006 (Gerlein-Safdi et al., 2020). So far, greenbelts are used to protect cities and agricultural areas in arid climate. Here we suggest their additional use to enable and accelerate successional processes as a systematic and economical tool in revegetation and restoration. Using rather narrow twin greenbelts to connect the vegetation areas of a region could create self-supportive hydrological networks.

The following attributes were essential in arid and semi-arid renaturation projects (Cao, 2008; Cao et al., 2011; Jin et al., 2011; Wang et al., 2019):

(1) Ecology: Vegetation should match the ecological situation and climate; this often refers to a low density of woody plants and the active protection of native vegetation.
(2) Hydrology: The low water consumption of vegetation is essential; even after decades trees may outgrow available water resources.
(3) Selection of species: The use of native, drought-resistant species is preferable.
(4) Long-term maintenance: Emphasis should be placed on protection, maintenance, and monitoring over decades.
(5) A large-scale network of vegetation and threshold: The planting of vegetation that covers 20% and above of the area in question successfully transformed desert into agroforestry land in Jiangsu, China; the vegetation blocked the impact of hot dry storms (Zhuang et al., 2017).
(6) Natural succession: Since 2006, natural reforestation has been done in China by closing off areas over many years to enable vegetation recovery in natural succession (Gerlein-Safdi et al., 2020). This is the long-lasting process in which nature recovers, by itself, from disturbances such as over-grazing or fire. The method has resulted in an increase in both photosynthesis and plant biomass in these areas, as became measurable after more than a decade (Gerlein-Safdi et al., 2020). Important benefits of natural succession include biodiversity and the climatic adaptability of the resulting vegetation.

It is questionable whether planted trees or "forests" are a natural feature in the desert-bordering areas and if they would be an ecologically sustainable solution here. We know that climate change contributes to the poor sustainability of densely planted (non-native) trees (Anderegg et al., 2018; Noulèkoun et al., 2018; Yao et al., 2019). The percentage of woody cover in African savanna ecosystems is typically 10 to 30%. It is strictly adapted to the mean annual precipitation (MAP) of the region (Sankaran et al., 2005; Veldman et al., 2015). Therefore, sustainable restoration here should mimic open, native savanna-like vegetation rather than "forests."

Greenbelts are tree formations planted in arid environments that protect cities, oases, and fields from hot wind and sand. Based on the above criterion, we suggest a revegetation model for arid and windy areas, in which native grasses and shrubs develop in natural succession within compartments formed by two greenbelts (Huebner, 2020). The belt system aims to hydrologically connect the existing vegetation patches of a region. A hydrologic network forms (see Fig. 5.1) in which vegetation supports its own persistence in a dry environment which, generally, is at risk of even more extended spells of drought in the future.

Here, we further develop our network renaturation model in order to systematically combine the advantages of the active planting of greenbelts with those of natural succession. However, apart from the Chinese examples of "natural reforestation" in numerous degraded (semi-) arid places (Gerlein-Safdi et al., 2020) and the theorizing of a "quasinatural restoration" method (Wang et al., 2019), few restoration concepts involve the process of natural succession in degraded drylands. Natural succession requires a long period of development, done in regions where no disturbance from humans and nomadic herds over many years is possible. Globally, climate may change within a few short decades. This could potentially happen at a faster rate than it takes for one generation of trees to develop. Hence, in this race against time there is a need for ways to create climate-resilient vegetation in an expedited fashion. We therefore seek ways to accelerate the process of succession in the climate of desert-bordering regions. The process's high value of producing climatically adaptable vegetation is an essential feature in a rapidly changing climate. We evaluate the effect of compartmentalization on environmental

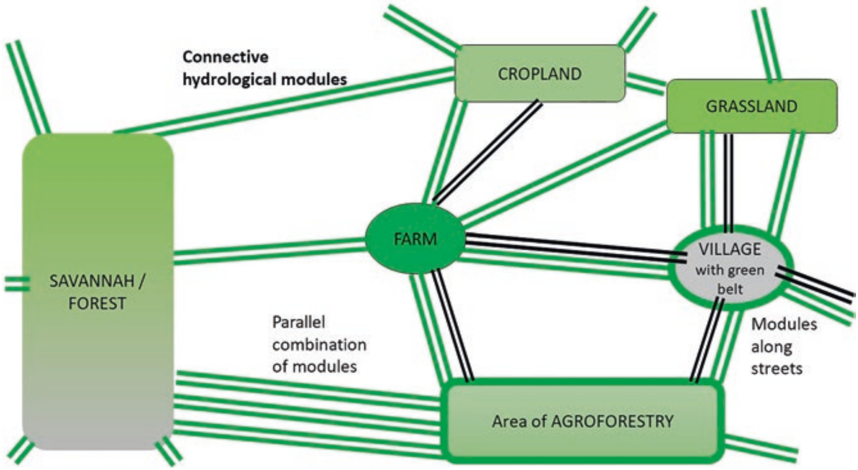

Fig. 5.1 Greenbelt modules connecting regional areas of vegetation. (Note: In (semi-) arid climates, water determines the existence of life. Individual vegetation areas—savannas, grasslands, farmlands—are hydrologically connected via twin greenbelt modules, rather than being entirely surrounded by dry degraded land. Source: Modified from Huebner (2020))

gradients as well as the process of succession and compare these against the long-lasting process in unprotected degraded drylands.

The restoration model suggested here includes the concepts of hydrologic networking and compartmentalization. We aim to expedite the process of natural succession by combining it with a 75%-reduced level of active planting, thereby combining the advantages of both methods in order to establish an alternative to large-scale afforestation in windy, arid, and any other vegetation-less environments. The use of the assisted natural succession of vegetation is expected to save water and ground water levels, as well as efforts in tree planting.

2 Use of Natural Succession in Restoration

The process of natural succession (or ecological succession) is characterized by a typical sequence of biological communities that, with environmental change, replace each other in a predictable sequence. The final development stage is a stable community of plants and animals, called climax, that remains until a next event of disturbance occurs (e.g., agricultural change or fire). Restoration ecology defines a desired climax community and the methods applied to gain an expedited succession in order to reach this community, for example, attempts to restore a prairie climax within ten years, a process that would otherwise take several hundred years naturally (Emery, 2010). The methods applied include the amending of soil with organic matter, the increase of the available seed, and the reduction of competitive species that belong to early stages of succession, so that conditions of the late successional stage are matched. Such restoration requires a good understanding of successional processes, even though it is not always successful (Young et al., 2005).

The roles of soil bacteria, insects, mammals, and others in natural succession are under investigation. Mycorrhizal fungi are known to play an important role in the colonization and growth of plants. Only pioneer plants, which are not dependent on mycorrhizae, will settle in systems where these fungi are absent initially, as in sand dunes. Plants of later successional stages will be able to colonize such places once mycorrhizal diversity has increased (Koske & Gemma, 1997).

3 The Restoration of Drylands: Lessons Learned from China

3.1 Hydro-ecological Stress Resulting from Large-scale Afforestation

In the context of the "Three-North Shelterbelt" restoration program in China, a total area of 3 million km^2 was reforested by 2013 (Wang et al., 2019). However, in the same year, only 0.69 million km^2 of it (< 25%) remained as forested land (State Forestry Administrator, 2017; Wang et al., 2019). An extremely low rate of 15% for tree survival has been calculated for plantations in Northern China since 1949 (Cao, 2008). Many explanations related to local or regional hydrological and ecological stress were given as causes of tree mortality and associated economic losses. Frequently, planted trees outgrew the water supply that was available from precipitation and the water table after years or decades of growth (Cao, 2008; Cao et al., 2011; Jin et al., 2011).

A lesson learned during the last century is that in the harsh, water-restricted environment of desert-bordering regions, only vegetation that is an ecological "best fit" will be able to survive in the long term (Huebner & Al-Quraishi, 2021). In general, when it comes to changes in climate or in the environment, the adaptability of species is essential; the latter hinges on the diversity of the ecosystem. Diversity will provide species that are "specialists" in adjusting and will thrive in the new conditions, unless the change is too drastic (e.g., drought of extremely long duration).

3.2 Active Planting Versus Natural Succession in Drylands

Vegetation that develops in natural succession shows diversity and adapts to future changes in climate parameters. Also, ecosystem services are higher in cases of natural succession when compared to planted trees (Chazdon, 2008; Li et al., 2003). Yet, we do not know which levels of desertification will be amenable to successful succession; the use of the method is new in drylands and may have its limits here (Wang et al., 2019). Thus, measures of "assisted" natural succession could be helpful, per Sect. 4.

An ecological approach to active planting will use diverse species of native trees and shrubs, planted in sufficient distance from each other and in a way that allows for a connection to nearby ecosystems. In semi-arid climates, this may refer to open woodlands, various savanna types, or grasslands. Still, the most ecologically sound planting method is likely to need the same period of development as succession in order to reach the same level of diversity of micro-organisms and plants. Active planting will result in a successful plant cover within short and calculable time. It is simple to monitor the progress and development of the vegetation. Disadvantages include the high costs of nurseries and planting activities as well as a disappointingly high mortality rate because woody plants—at some point of time in the growth development—may not be adjusted to local availability of water.

In comparison, advantages that come with the use of natural succession are an adaptability to changes in climate parameters due to the diversity and sustainability of ecosystems that develop, which have other additional long-term benefits (Chazdon, 2008; Li et al., 2003). The related costs are low due to the absence of planting efforts. One major disadvantage of natural succession is that it usually requires many years or decades of development (Gerlein-Safdi et al., 2020) in an undisturbed environment with strong protection.

3.3 Efficacy of Succession in (semi-) Arid Restoration

Around 2006, China started to implement natural succession (or "natural reforestation") in numerous semi-arid areas. Farmers were financially supported when closing their degraded lands or grasslands to protect and support the development of natural vegetation over many years (Gerlein-Safdi et al., 2020; Li et al., 2013), so that dryland ecosystems would be able to recover upon the removal of any external impact (Hellden, 2008; Martinez-Valderrama et al., 2016). There are thousands of patches on which natural reforestation is done, which explains the difficulty in assessing the outcome of these measures. Restoration based on natural succession requires a long period of time: in the (semi-) arid climate of Northern China, it took around 12 years for an increase in biomass to be measurable by means of remote sensing, whereas active planting of woody plants created such a signal immediately, or within a few years at most (Gerlein-Safdi et al., 2020). This was the first time that successful results of the natural reforestation method in drylands were noted, in direct contrast to restoration areas where the active planting of trees had been undertaken. In addition to the Moderate Resolution Imaging Spectro-radiometer and the Enhanced Vegetation Index, new methods were applied in order to assess water content and the photosynthetic activity of the vegetation (Gerlein-Safdi et al., 2020).

Increases in biomass and vegetation productivity were found for both natural reforestation and active planting. However, due to the high mortality rates usually seen with active planting, the authors were more surprised by the latter.

4 A Network Using Twin Belt Modules to Expedite Natural Succession

4.1 Hydrological Networking: Connecting the Green Spots

We suggest a network restoration concept as an alternative to the hydro-ecological stress found with compact large-scale afforestation (Huebner, 2020). It aims to hydrologically connect larger patches of any kind of vegetation in (semi-) arid regions, per Fig. 5.1, by means of hydrological modules of native vegetation, resulting in a network of increased relative humidity (RH), and this could have a self-supportive effect on the spare vegetation in dry arid regions.

We query if such restoration would be possible in a hydro-ecologically neutral way. Few methods make use of the process of natural succession in degraded drylands, which is combined with the active planting of greenbelts in our model. We develop further features of such a restoration model in order to demonstrate the feasibility of this concept in the sustainable restoration and greening of degraded land in semi-arid and arid drylands.

4.2 Why Twin Greenbelts?

Since the early twentieth century, greenbelts have been used in arid areas to protect settlements and cities from hot desert winds that bring sand, dust, and heat. Mauritania, for example, has experience with numerous greenbelts that protect the capital and larger cities in Saharan climate, also using greenbelts of few hundred hectares of size, used for protection and wood production (OSS, CEN-SAD, 2008). The twin greenbelt module (Fig. 5.2) was suggested in order to achieve a protected internal microclimate of increased RH and soil moisture content (SMC) over distances between vegetation areas (Fig. 5.1); thus connectivity and compartmentalization are its main functions. The two greenbelts can be 10–50 m wide with four, five, or more rows of native woody plants to protect from prevailing winds. Belt plantations should be a dense mix of shrubs and trees to give some protection during drought, when leaves are dry. In areas with higher water tables or where irrigation is possible, experimentation with the limited and cautious use of fast-growing species might be explored. At a low water supply level (25% of evapotranspiration), *Tamarix* species reached a height of 5 m and *Eucalyptus* species up to 8 m after having been planted with a height of around 40 cm and grown for less than 2.5 years in arid climate (Ohlde et al., 2019). Wind fences (e.g., straw mats) can give further protection where necessary.

Belts are planted in parallel, 100–300 m from each other (depending on the expected final height of belt trees) because windbreak between the belts is reached over a compartment width of up to the 27-fold of final height (in m). Narrower versions, with a width of 10- to 20-fold final height, will offer more effective protection, as per the findings of Campi et al. (2009). The outer sides will also show a windbreak of up to 22-fold (leeward) and 5-fold (windward). Optionally, ditches or walls on the outside will collect rainwater, leading it into the ground or storage pool (Fig. 5.2). The inner compartment is, to some degree, protected from wind and related drought. Savanna-like grasslands with or without trees can develop here in natural succession, in accordance with local MAP.

Fig. 5.2 Connective hydrologic module. (Note: Twin greenbelts (planted shrubs and trees) with area of natural succession between them)

A minimum vegetation cover of 20–25% was found to be the threshold in the successful control of desertification (Gao et al., 2011; Zhuang et al., 2017) and soil erosion (Snelder & Bryan, 1995). The belt modules comprise around 25% planted belt and 75% succession area. The active planting of twin belts on 5% of a region's surface will, therefore, increase its vegetation cover by 20% some years later.

4.3 Expediting Natural Succession

The process of natural succession supports a number of ecosystem services, such as the biodiversity of the native vegetation that develops, with its high adaptability to changes in climate (Liu et al., 2018). In the case of degraded land, left exposed to the harsh climate of desert border regions, it may take many years for a native vegetation cover to develop in successional mode. However, changes to climate are observable within only decades, maybe even within less time than it takes for a generation of trees to develop. Expediting the important process of natural succession that is leading to climatically adaptable vegetation may, therefore, become crucial. Several options exist for accelerating the development of vegetation cover:

- Measures of "assisted" natural succession that expedite the development of vegetation inside the twin belt system and on the outside include the hoeing or harrowing of compacted soil to support soil microbial life, water uptake, and the water storage capacity of deeper ground (Boydak & Caliskan, 2015).
- Similarly, available water capacity will increase by the addition of organic matter (e.g., wood pellets, branches, straw) to the upper soil layer and/or surface. The soil's organic matter content is directly related to soil fertility (plant nutrients) and its capacity for water retention (Boincean & Dent, 2019). The development of mycorrhizal fungi, which are important in the succession of plants (Koske & Gemma, 1997), will increase from this measure as well.
- Existing plants are kept for their protective and nursing effects (Castro et al., 2002).

4.4 Compartmentalization to Assist Natural Succession

The windbreak of the twin belt module as well as the evapotranspiration of its vegetation and ground will lead to increased RH between the belts. This will also limit the deposit of sand and dust. In addition, RH here will increase from the enhanced SMC due to ditches, as in the loosening of the ground and the addition of organic matter in the natural succession area, as described in Sect. 4.3. The climatic-hydrological situation within the compartments and outside of the belts is compared to succession in an unprotected environment in Table 5.1.

The hot, dry wind from deserts is partially blocked, which can reduce the exposure of vegetation to drought, thereby promoting and accelerating its development. The various gradients listed in Table 5.1 will lead to the increased diversity and adaptability of the plants and micro-organism societies developing there.

A hostile local climate may require additional protective compartmentalization, which can be done by planting transverse lines of trees (Fig. 5.2) to further support a growth-enhancing microclimate.

5 Network Management and Further Questions

5.1 Monitoring and the Control of Fires

The diverted belt system requires long-term maintenance and protection; the involvement of locals would be most useful for this task. Regular control visits may otherwise require travel over long distances. The module's narrow shape (120–400 m wide) will ease regular monitoring of the vegetation area as well as control over and extinction of fires when compared to compact afforestation territory. The influence of climate change is likely to increase the risk and frequency of wildfires (Flannigan et al., 2016). We see clear advantages over compact afforestation, as the shape of the module will allow fire to spread in only two directions because firebreaks in regular intervals can prevent further spread.

Table 5.1 Comparison of natural succession in unprotected environment and within/around twin belt compartments

	(Semi-) arid natural succession, unprotected	(Semi-) arid assisted natural succession within compartments of twin greenbelts
Gradient: Wind speed	None, wind speed high	Some protection, highest close to greenbelts
Gradient: Temperature	None, wind-driven heat, no shadow	Some shadow and protection from wind-driven heat close to greenbelts
Gradient: Light	None, full light	Some shadow close to greenbelts
Gradient: RH, SMC	None, somewhat low	Increased close to greenbelts: evapotranspiration and some blocking of hot, dry wind
Gradient: Soil organic material	None, not increased	Increased close to greenbelts
Deposition of sand, dust	High, depending on location	Some protection, highest close to greenbelts
Soil treatment	None	Optionally: loosening of upper soil layers (Boydak & Caliskan, 2015) and/or addition of organic material (Boincean & Dent, 2019) to support microbial life, as well as to increase water storage capacity and related SMC

5.2 Dryland Network Model: Remaining Questions and Limitations

The following questions could provide the basis for enquiry in the future pilot testing of the twin belt module:

- What is the optimal width for climatic protection of the succession area? How do climate, soil, and the native vegetation used in belts impact this figure? What is the optimal protection of modules from disturbances?
- What is the duration, in years, to reach 50% and 100% vegetation cover in the succession area, again depending on climate and soil?

- To what extent will the treatment of soil (loosening, aerating, adding of organic material) increase SMC and RH? Will it expedite the succession of the new plant cover?
- What is the best approach to involve local residents and other stakeholders? How should we coordinate maintenance?
- Over what distance can hydrologic connectivity be maintained? Is there a need for the duplication of modules over long distances?

6 Summary: Hydrological Network Versus Large-Scale Afforestation

Table 5.2 summarizes the main features of the hydrological network and the twin belt modules, in comparison to the respective features of large-scale afforestation.

7 Discussion

This study addresses the issue of restoring degraded drylands in an ecological way. We consider re-introducing vegetation in natural succession with a savanna-typical proportion of woody plants, a hybrid method that has been suggested as an alternative to the compact, large-scale plantation of dense "forests." This approach systematically combines the active planting of native shrubs and trees as twin belts, with the restoration of the savanna that develops in succession within the inner compartment, where it is somewhat protected from hot and dry desert wind.

Would tree plantations represent a natural and sustainable feature in desert-bordering regions, and if so, what is the ideal density of trees and shrubs? Regarding the natural African savanna, we know that "MAP drives the upper bound on woody cover in arid and semi-arid savannas" (Sankaran et al., 2005). A 15–20% woody plant cover of savannas was found for a wide MAP variability of minimum 250–1100 mm, whereas 30% cover was already correlated with a MAP of minimum 300 mm (Sankaran et al., 2005). Consequently, sustainable renaturation concepts

Table 5.2 Features of hydrological network of twin belts compared with those of large-scale afforestation

	Hydrological network of twin greenbelts with areas of assisted succession	Large-scale afforestation, active planting
Time to reach vegetation cover	Planting of protective twin belts is fast; succession area needs years to develop vegetation cover; whether or not protection +/− soil treatment accelerates and reduces time to biomass increase to less than around 12 years (per Gerlein-Safdi et al., 2020) requires further investigation	Few years of seedling nursery, otherwise fast
Effort to create	Somewhat low, active planting on 20–25% of area; requires lower number of seedlings	High, depending on density of plantation; nursery of large number of seedlings
Maintenance effort	Narrow structure of twin belts: long distances, but easier to control	Compact structure, some difficulty to protect and control
Costs	75–80% lower costs of planting; additional costs of soil treatment (optional)	Four to five times higher
Resulting vegetation	Diversity high due to environmental gradients; development of native savanna ecosystems	Diversity not high; ideally planting guided by ecosystems of comparable environment
Hydro-ecological adaptability	High in succession area (75–80%): native, savanna ecosystems	Low, may become a problem even after decades of growth
Climate adaptability	High, high diversity of ecosystems	Low to medium, but diversity may further evolve over years
Control of fires	Easier due to narrow structure	Difficult

here should combine low percentage of trees with larger areas of grassland. Woody species of the belts should be native and resilient to future extended drought events. The species most suited to restoration may not yet be present locally. A "prestoration" concept can identify suitable species and predict changes in the fittingness of habitats in future decades (Butterfield et al., 2017).

Natural succession as the main component of our model takes years of protected development; it results, however, in numerous ecosystem services, like biodiversity and the climatic adaptability of vegetation, leading to sustainable renaturation (Liu et al., 2018). The role of succession and, particularly, the comparatively slow development of fungal communities and their importance in soil stability were shown by Zhang et al. (2017). Semi-arid degraded cropland when left to natural succession showed increases in fungal diversity, paralleled by soil stability. A meta-analysis has shown the high drought resilience of grasslands (Matos et al., 2020), which contrasts the picture of tree plantations in semi-arid Northern China that outgrow available water resources in a matter of years (Cao, 2008; Cao et al., 2011; Jin et al., 2011).

Natural succession is being used in drylands, in regions where it is possible to close an entire remote area for a long time to protect it from human activity, as reported for a renaturation project in Inner Mongolia, China (Wang et al., 2019). In areas with severely progressing desertification, for example, constant strong encroachment of sand sheets, the method may therefore not be applicable. For the first time, Gerlein-Safdi et al. (2020) demonstrate that the method called "natural reforestation" resulted in an increase in biomass in drylands of Northern China after some 12 years (Gerlein-Safdi et al., 2020), as assessed by remote sensing.

Single greenbelts have been planted in the Saharan climate since the early twentieth century; also systems with two or more concentric belts are in use. The Dakar greenbelt, Senegal, is a network of forests, plantations, green spaces, and roadside plantations (OSS, CENSAD, 2008). These belt systems are planted locally. Characteristic of the structure of the hydrologic network modules is the systematic use of two parallel belts in order to create protected compartments between them. Their purpose, in addition to the protective effect, is the compartmentalization that enables and eases natural succession. By keeping up an internal microclimate over certain distances, they will hydrologically connect distant patches of vegetation in rather vegetation-less desert border regions. This will, therefore, require planning and coordination on regional or national level.

8 Conclusions

Numerous lessons can be learned from reviewing the large-scale revegetational efforts of the past several decades that seek to combat desertification and to restore degraded land, both of which have been aggravated by a changeable climate trending toward drier conditions. We refine a restoration model that combines the planting of trees and shrubs with an element of protected, expedited succession of native savanna vegetation within greenbelt compartments. Our aim is to increase the connectivity, climate adjustability, and viability of revegetation measures in the desert-bordering areas.

We conclude that restoration models for drylands should make use of natural succession to develop diverse native vegetation with its important superior adaptability to climate change.

The compact planting of trees ("forests") in drylands bears hydro-ecological risks. In comparison, restoration that mimics savanna with 15–25% woody plant cover could save (ground) water. Moreover, the systematic combination of active planting and natural succession in the form of twin belts could save around 75% of the planting efforts required for large-scale afforestation. Further, greenbelts that form compartments with a microclimate of increased RH and SMC are likely to expedite succession. Introducing numerous additional environmental gradients will increase the diversity of vegetation that develops here and its adaptability to potential climate change. Finally, we suggest the twin belt module to hydrologically connect the existing spare vegetation of arid regions. In comparison to compact afforestation, the narrow structure has clear advantages in terms of maintenance, monitoring, and preventing fire spread. The density of the network could be increased gradually, finally leading to a regional climate that supports the further development of vegetation.

Pilot testing of the twin belt module on degraded ground will help to understand the kinetics and quality of vegetation developing in such "assisted natural succession." Future research will need to investigate whether or not the concept of creating a protected environment to accelerate natural succession in hostile arid climates will indeed have benefits. Likely, vegetation will develop with more ease on heavily degraded ground when there is some protection from constant hot wind and wind-driven drought. The direct comparison of vegetational succession, within belt compartment and without any protection in the same location, will show the impact.

The economic advantage of using natural succession instead of planting, or, in our case, in combination with some planting, is obvious. Vegetation resulting from this method has high climatic adaptability and hydro-ecological advantages in comparison to large-scale plantation. The long development time of succession, particularly in drylands, probably has been limiting its use. A network based on compartments that are formed by twin belt modules is suggested to expedite succession and to keep up a growth stimulating microclimate over long distances. This way the coverage of a region with savanna vegetation could be increased within several years and the local climate could improve once a certain vegetational threshold of 20–25% is reached, as found by Zhuang et al. (2017) in the Northern Jiangsu region. If this is done region by region, a regional or even partial continental change in humidity and reduced wind speed will become possible, supporting the further vegetational development and agronomy.

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Part III

Finance and the Economy

6

Weaknesses in Corporate Commitments to Climate Change Adaptation and How to Fix Them: A Systemic Scenario Assessment Approach

Anita Lazurko, Norman M. Kearney, Natalya Siddhantakar, Jude Herijadi Kurniawan, and Vanessa Schweizer

1 Introduction

1.1 Background

Climate change is expected to increase the frequency and severity of extreme climatic events, such as heavy precipitation events, droughts, and hurricanes (Hunt & Watkiss, 2011; IPCC, 2014b). Regional climate

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patterns are also expected to shift, impacting food and energy production (Diaz et al., 2001; Tol, 2020). A hotter, wetter, more variable, and more extreme climate will force societies to adapt to increasing social, environmental, and economic risks. The severity of these risks is determined by exposure (i.e., proximity to climate threats) and vulnerability (i.e., sensitivity to harm and lack of capacity to adapt) (IPCC, 2014b). Individuals and organizations equipped with the fewest resources or options to adapt to these impacts could suffer the harshest consequences (Tol, 2020). In this context, climate change adaptation (CCA) becomes crucial, defined as "the process of adjustment to actual or expected climate and its effects" (IPCC, 2014a). CCA requires systemic and collective action across scales, ranging from incremental to transformative change (Haasnoot et al., 2020).

Businesses are pursuing strategies for CCA, often through a corporate risk management lens. For example, asset management frameworks consider operational and financial risks associated with environmental events (Mercer, 2015). Similarly, supply chain managers run cost-benefit analyses on multiple supply options to prepare for climate-related disruptions (Bals, 2012; Norton et al., 2015). While these measures identify direct, quantifiable physical and economic climate risks, corporate risk managers are increasingly concerned with broader future developments such as indirect societal and environmental impacts, and reputational risk (Goldstein et al., 2019). Similarly, scientists are increasingly concerned with the human dimensions of climate change, where the state of socioeconomic systems has as much impact on human consequences as environmental change (IPCC, 2012). Thus, business efforts to address direct climate risks neglect the indirect—but potentially greater—risks associated with broad social and economic determinants of CCA, such as the strength of institutions, quality of infrastructure, technological innovation, information and skills, equality, and access to capital in preparing

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for and in managing extreme events (Klein et al., 2015). It follows that advancing CCA depends not only on efforts to adapt directly to climatic change, but also on actions taken across sectors, including reducing exposure and vulnerability, as well as increasing adaptive capacity (Butler et al., 2016; IPCC, 2014b; Sanchez Rodriguez et al., 2018).

The United Nations (UN) Sustainable Development Goals (SDGs) and the Shared Socio-economic Pathways (SSPs) are globally recognized frameworks that characterize the broader social, economic, or ecological determinants of CCA. In the SDGs, all three targets under SDG 13 (Climate Action) address CCA, including target 13.1: *strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries,* target 13.2: *integrate climate change measures into policy and planning*, and target 13.3: *build knowledge and capacity to meet climate change*. The SSPs were developed to enhance climate change research—including research on CCA—by describing alternative futures of global socio-economic trends, where each future poses greater or lesser socio-economic challenges to climate change mitigation and to CCA. Thus, the SSPs point to the reality that efforts to advance CCA are affected by progress on most other SDGs (Schweizer, 2019). Importantly, SSPs with high socio-economic challenges to CCA are characterized by high income inequality within and between countries (i.e., poor progress on Goal 10 (Reduced Inequalities) and Goal 1 (No Poverty)); high mortality (poor progress on Goal 2 (Zero Hunger) and Goal 3 (Good Health and Wellbeing)); unequal or low levels of educational attainment driven by lack of gender equality (i.e., poor progress on Goal 4 (Quality Education) and Goal 5 (Gender Equality)); unequal or low access to health, water, and sanitation facilities (poor progress on Goal 6 (Clean Water and Sanitation) and Goal 9 (Industry, Innovation, and Infrastructure)); and poorly managed or mixed urban settlements, that is, slums (poor progress on Goal 11 (Sustainable Cities and Communities)).

Recent research carried out in the Global Sustainable Development Report (GSDR) 2019 offers a science-based assessment of how each SDG directly affects all others through co-benefits and trade-offs (Independent Group of Scientists appointed by the Secretary-General, 2019; Pham-Truffert et al., 2020). This study shows that progress toward several SDGs including Goals 2 (Zero Hunger), 14 (Life Below Water), and 15 (Life on

Land) strongly promotes SDG 13. For example, targets 2.3, 2.4, and 2.5 under SDG 2 (Zero Hunger) address agricultural productivity, resilient agricultural practice, and crop diversification respectively, which are common CCA strategies in agriculture and food security (Palazzo et al., 2017; Vermeulen et al., 2013). Conversely, the study shows that progress toward SDG 13 (Climate Action) strongly promotes progress toward several SDGs including Goals 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Wellbeing), and 15 (Life on Land), and has trade-offs with Goal 14 (Life Below Water). The interactions between CCA and other SDGs are characterized in Sect. 3 in Fig. 6.2. Thus, we consider business contributions to CCA to include both commitments to CCA through SDG 13 and commitments to other SDGs that are directly linked to CCA through co-benefits and trade-offs discussed in the GSDR 2019.

Fortunately, many businesses addressing CCA are also pursuing corporate sustainability strategies, thereby indirectly addressing socio-economic determinants of CCA. At the scale of individual businesses, management tools like the balanced scorecard (Kaplan & Norton, 1992) are modified to include environmental, social, or ethical dimensions and are often referred to as sustainability balanced scorecards (SBSCs) (Figge et al., 2002). Importantly, global initiatives like the United Nations (UN) Global Compact encourage businesses to prioritize, set targets for, and report on their direct contributions to SDGs (UNGC, 2020). While these initiatives may improve transparency and advance corporate sustainability, they have not yet assessed the cumulative impact of corporate SDG commitments on overall SDG attainment, nor attempted to situate CCA within the broader web of systemic interactions among the SDGs.

1.2 Purpose

In this study, we demonstrate a scenario-based approach for systematically evaluating businesses' strategic commitments to CCA and other SDGs. We model internally consistent or "plausible"[1] outcomes of

[1] Plausibility is a complex concept in scenario literature (Schmidt-Scheele, 2020). Here we consider plausibility as determined by the CIB method, where an internally consistent scenario is considered plausible. See Fig. 6.1.

complex interactions between SDGs (i.e., pairwise co-benefits and trade-offs from GSDR 2019) using cross-impact balances (CIB), which is a mixed method that outputs a set of internally consistent (i.e., stable) scenarios from a database of system interactions (Weimer-Jehle, 2006). In CIB, scenarios are combinations of variable states (in our case, SDG states, where each SDG is in either an "improving" or a "worsening" state). CIB can animate the interactions in GSDR 2019 through a dynamic analysis that reveals the potential consequences of "where" businesses are currently intervening in the system of SDG interactions (i.e., in which sector or sustainability domain). Our analysis did not address the choice of "how" to intervene (e.g., advocacy campaigns, supply chain adjustments), as the "how" depends on the capacities and contexts of individual businesses.

By focusing our analysis on SDG 13 (Climate Action) and the other SDGs with co-benefits and trade-offs linked to SDG 13 (Fig. 6.2), we highlight the relevance of human dimensions of climate change to corporate risk management and the need to improve policy coherence between corporate CCA and sustainability strategies. Here, we answer the following questions: (1) what are the plausible future scenarios for SDG attainment, given the current state of knowledge of SDG interactions? What factors within these interactions most significantly enable or inhibit progress toward CCA, and vice versa? (2) How might corporate commitments to the SDGs affect progress toward CCA? From our findings, how can the business community strengthen corporate commitments to CCA, either directly or indirectly by decreasing socio-economic challenges to CCA?

2 Materials and Method

CIB is a computational method for making sense of interactions in a complex system. CIB uses categorical variables, which allows for the representation of qualitative aspects of a system. The inputs for a CIB model are observational judgments about the interactions between pairs of variables. Since CIB uses categorical variables, the "state" of each variable is judged for how it impacts the states of the other variables. A Likert scale, typically in the range of −3 to +3, records these judgments, which are drawn from interviews with experts and/or relevant literature.

Our model consists of 17 variables, one for each of the SDGs. Each variable has two states: an "improving" state and a "worsening" state. For judgments about how the variables interact, we use the 2019 Global Sustainable Development Report (GSDR). The scientific team behind the GSDR reviewed 65 UN flagship reports and international scientific assessments, as well as 112 scientific articles (Pham-Truffert et al., 2020). The GSDR team assessed pairwise interactions among the SDGs (at the global level) using a seven-point Likert scale. Co-benefits (positive points) and trade-offs (negative points) were recorded separately through multiple interactions for every pair of SDGs. For example, SDG 13 (Climate Action) has trade-offs with SDG 14 (Life Below Water) because coastal measures to adapt to rising sea levels may negatively impact coastal conservation and restoration. Similarly, SDG 2 (Zero Hunger) has co-benefits with SDG 13 (Climate Action), because climate-smart agriculture may reduce hunger while improving the capacity to adapt (Pham-Truffert et al., 2020).

We adapt the co-benefits and trade-offs scores from the GSDR to a format appropriate to CIB by calculating the net value of co-benefits and trade-offs for each pair of SDGs. For example, for the interaction between SDG 1 (No Poverty) and SDG 2 (Zero Hunger), the GSDR identifies five co-benefits (in total, +12 points assessed) and one-trade off (−1 points assessed). The net value for this interaction, then, is +11 (= +12 − 1). This means that if SDG 1 is improving, then this has an impact of +11 on SDG 2 improving. Since CIB modeling is conditional, meaning that the interactions between system variables are state specific, our CIB model includes inverse assumptions for all SDG interactions. For instance, based on the data available from GSDR, if SDG 1 is worsening, then this has an impact of +11 on SDG 2 worsening. Likewise, if SDG 1 is improving, then this has an impact of −11 on SDG 2 worsening. Through communication with one of the co-authors of the GSDR, we have verified that this is a reasonable interpretation (Pham-Truffert, personal communication, September 15, 2020).

We verify all possible combinations of variable states (scenarios) for internal consistency using a specialized software for CIB analysis called

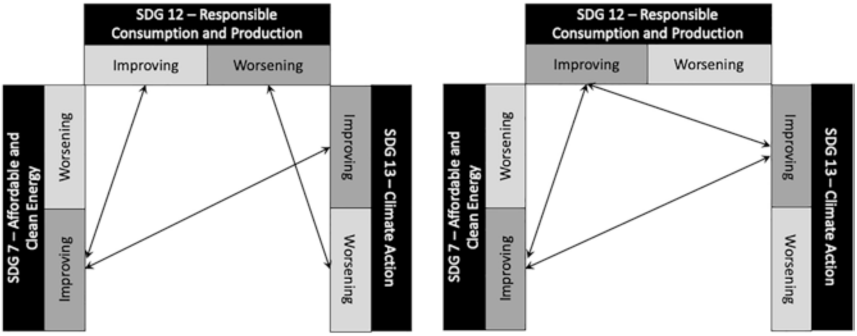

Fig. 6.1 Verification of all possible combinations of variable states (scenarios) for internal consistency using Scenario Wizard

Scenario Wizard. Figure 6.1 demonstrates the difference between internal inconsistency (Fig. 6.1a) and consistency (Fig. 6.1b) through combinations of states for three variables. In CIB, a scenario is internally consistent when the combination of variable states is self-reinforcing and stable; scenarios lacking internal consistency are unstable and prompt system corrections. While Fig. 6.1 shows interactions among only three variables, Scenario Wizard checks the internal consistency for all possible combinations of system states.

We used Scenario Wizard to conduct a dynamic "succession analysis" on scenarios lacking internal consistency. Succession analysis involves loading a starting scenario that represents initial conditions (e.g., Fig. 6.1a) and then repeatedly updating the variable states until they yield an internally consistent scenario (e.g., Fig. 6.1b).[2] We project where current trends in the SDGs might take us and test how interventions might shape the course of progressing the SDGs through succession analysis.

Our data sources and coding rules are summarized in Table 6.1. We modeled interactions among the SDGs following the Global Sustainable Development Report, which, through an exhaustive review by experts of the existing literature on SDG interactions, assigned weighted, pairwise impact scores (Independent Group of Scientists appointed by the

[2] The order in which variables are updated is governed by a "succession rule." We use the global and local succession rules, which produce similar results.

Table 6.1 Summary of model elements, input data, role of respective input data in the scenario model, and how respective input data are coded

Model element	Input data	Role in model	Coding rules
Variables, states, and judgments	Global Sustainable Development Report 2019	Defines the system of SDG interactions	If co-benefits > trade-offs, then improvement in SDG X improves SDG Y If co-benefits < trade-offs, then improvement in SDG X worsens SDG Y
Initial conditions	UN SDG Progress Chart 2020	Represents the current state of progress toward the SDGs globally	Optimistic: SDG is improving if more than 50% targets are at moderate distance to target and not deteriorating Pessimistic: SDG is improving if more than 50% targets are at moderate distance to target and progressing
Intervention	UN Global Compact Report 2020	Represents the effect of a significant push by businesses for progress	SDG is important to businesses if more than 50% businesses surveyed prioritized it and set targets

Secretary-General, 2019). Table 6.2 shows a few examples of the rationales used by the experts to specify an SDG interaction. Using UN data on current trends in the SDGs (UN, 2020), we derived two sets of initial conditions: an optimistic scenario, in which 12 of the SDGs are currently progressing, and a "pessimistic" scenario, in which 5 of the SDGs are currently progressing. Finally, to get a sense of where business efforts are currently concentrated, we relied on the UN Global Compact Report (UNGC, 2020). We found that businesses are currently emphasizing 5 SDGs: 3 (Health), 5 (Gender Equality), 8 (Decent Work), 12 (Sustainable Economy), and 13 (Climate Action). Of these, three SDGs are currently improving in both initial scenarios: SDGs 3 (Health), 5 (Gender Equality), and 8 (Decent Work). SDG 12 (Sustainable Economy) is improving in the optimistic scenario, but not the pessimistic scenario, while SDG 13 (Climate Action) is worsening in both initial scenarios.

Table 6.2 Select examples of evidence used in the "Knowledge for sustainable development: Interactive repository of SDG interactions" linking progress toward CCA to other SDGs and vice versa

CCA influencing progress toward other SDGs		Other SDGs influencing progress toward CCA	
SDG	Example score from GSDR 2019	SDG	Example from GSDR 2019
1 No poverty	"Building resilience to climate change and variability are vital to ensuring that basic services are stable and that people remain out of poverty." (UN-Water, 2016, p.19)	2 Zero hunger	"Resilient agricultural practices and maintaining and giving access to seeds/plant/animal genetic diversity should reinforce adaptation to climate change." (Nilsson et al., 2017, p. 63)
2 Zero hunger	"Global temperature increases of ~4°C or more above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally." (IPCC, 2014c, p.13)	14 Life below water	"Action taken to strengthen the health of coastal and marine ecosystems including fish stocks will reinforce the strengthening of environmental and societal resilience and adaptive capacities to climate change, and vice versa." (Nilsson et al., 2017, p. 206)

Source: Pham-Truffert et al. (2019)

Thus, we tested how a shift toward progress on SDGs 12 (Sustainable Economy) and 13 (Climate Action) might affect overall trends in the SDGs.

For evaluating the SDGs relevant to CCA, we consider SDG 13 (Climate Action) alongside SDGs that are both influencing and influenced by SDG 13. These SDGs are depicted in the heatmap in Fig. 6.2, where the dashed row highlights progress toward CCA influencing other SDGs and the dashed column highlights progress toward other SDGs influencing CCA. Later in the discussion, we focus on the SDGs showing higher degrees of influence to SDG 13 (i.e., darker gray boxes in Fig. 6.2), excluding SDGs focused on mitigation over adaptation (e.g., SDG 7 on Clean and Renewable Energy).

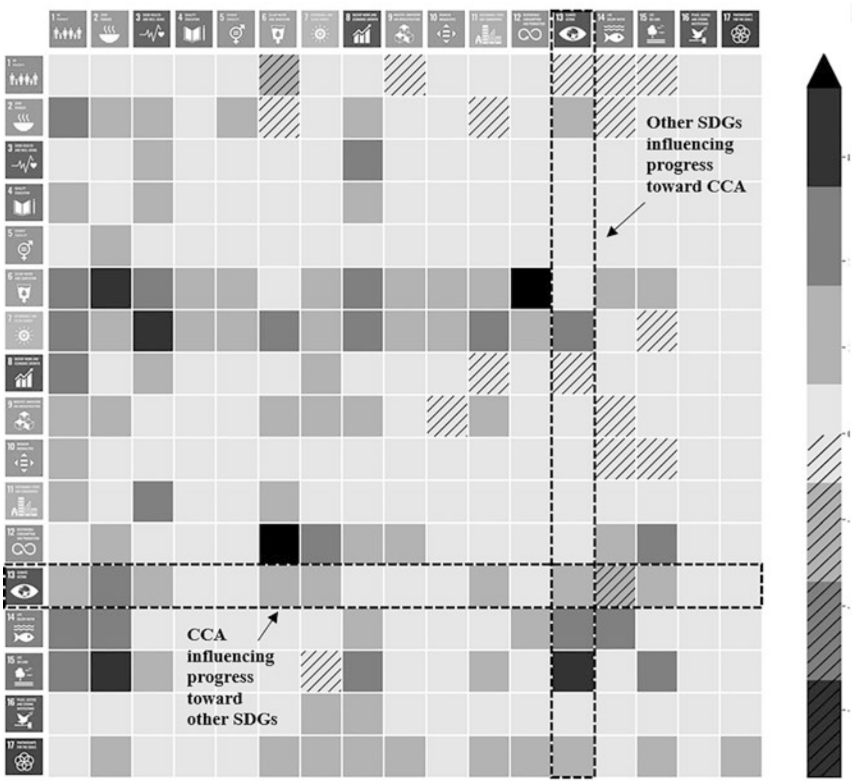

Fig. 6.2 Heat map of interactions among the SDGs

3 Results

3.1 Internally Consistent Scenarios for Trends in the SDGs

We identify six internally consistent scenarios emerging from interactions among the SDGs, as shown in Fig. 6.3. In the first two scenarios, all SDGs are improving (F1) or worsening (F2). In scenario F3 (humans over nature), most SDGs related to human needs and systems are improving, but most SDGs related to biophysical systems are worsening. Conversely, in scenario F4 (nature over humans) most SDGs related to biophysical systems are improving, but most SDGs related to human

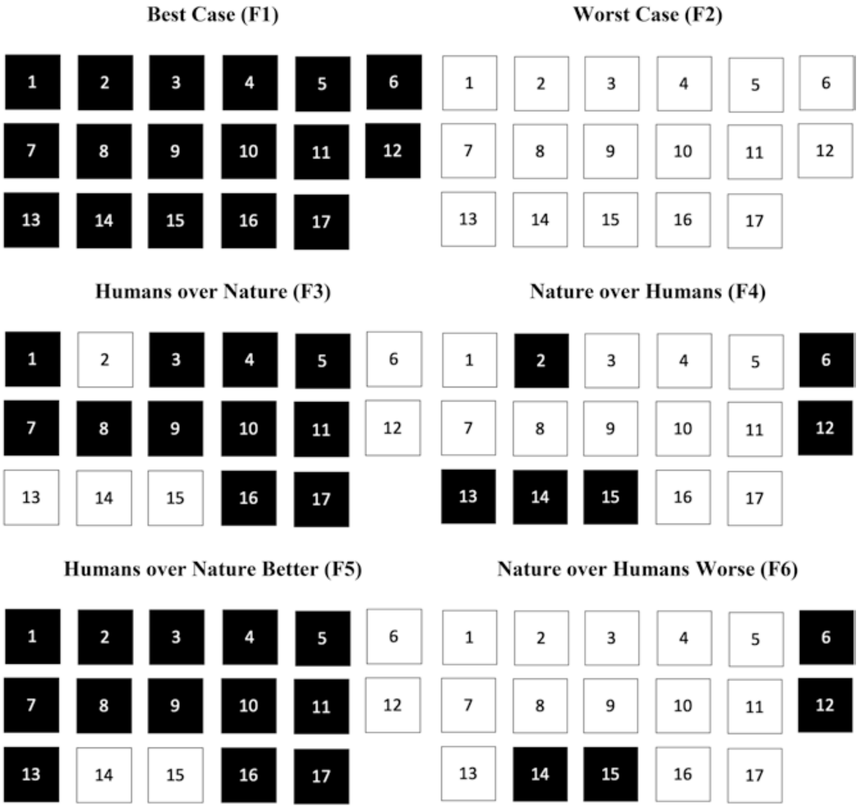

Fig. 6.3 Internally consistent scenarios (combinations of trends in SDGs)

needs and systems are worsening. F5 is a slightly better version of F3 with two additional positive trends: SDG 2 (Zero Hunger) and SDG 13 (Climate Action). Similarly, F6 is a slightly worse version of F4 with two additional negative trends: SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

Figure 6.3 presents the CCA trend for SDG 13 (Climate Action). SDG 13 is improving in F1, F4, and F5 scenarios, but is worsening in scenarios F2, F3, and F6. Interestingly, the only difference between scenarios F3 and F5 is that in F3, SDG 2 (Zero Hunger) and SDG 13 (Climate Action) are worsening, while in scenario F5 they are improving. Similarly, in F4, SDG 2 and SDG 13 are improving, while in F6 they are

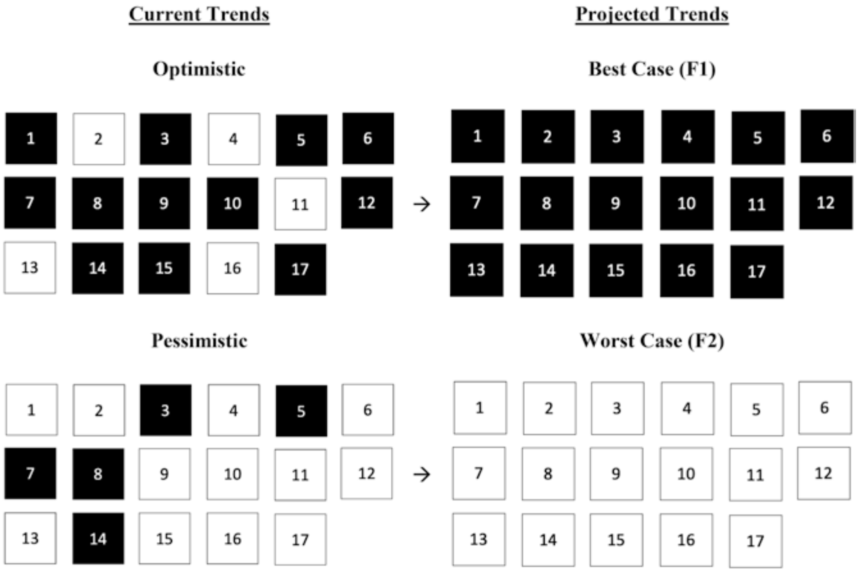

Fig. 6.4 Projected trends in the SDGs, based on current trends

worsening. These results suggest that progress toward climate action can emerge from interdependencies across goals, such as eradicating hunger and climate action.

Figure 6.4 presents our projections of current trends, based on optimistic and pessimistic initial scenarios. These outcomes are the result of succession analysis *without* further intervention by businesses. We project that current trends in the SDGs (optimistically) may result in F1, that is, a future in which all SDGs are improving, thereby decreasing socio-economic challenges for CCA. Alternatively, current trends in the SDGs (pessimistically) may result in F2, that is, a future in which all SDGs are worsening, thereby increasing socio-economic challenges for CCA. Thus, our projections are highly sensitive to initial conditions and reveal that progress in CCA—in addition to all other sustainability goals—has the systemic tendency to settle into all-or-nothing scenarios. These results are not predictions for 2030 or any particular year. Rather, they represent internally consistent combinations of trends in the SDGs, given current knowledge of SDG interactions.

3.2 Impacts of a Business Intervention on CCA and the SDGs

Figure 6.5 summarizes the results of our succession analysis *with* intervention by businesses. Assuming only SDGs 3 (Good Health), 5 (Gender Equality), 7 (Clean Energy), 8 (Decent Work), and 14 (Life Below Water) are currently progressing, we posit that if businesses are able to shift SDGs 12 (Sustainable Economy) and 13 (Climate Action) from worsening to improving, then the system shifts to scenario F1, that is, a future in which all SDGs are improving. Under this scenario, business commitments to CCA work in synergy with their contributions to CCA's human dimensions, such as Good Health and Wellbeing and Decent Work and Economic Growth.

We conducted a sensitivity analysis to check whether any of SDGs 3, 5, 7, 8, 12, 13, and 14 can worsen without compromising overall efforts toward the remaining SDGs. We find that any one of SDGs 3 (Good Health), 5 (Gender Equality), and 8 (Decent Work) can flip from improving to worsening without undermining progress toward F1. Importantly, these goals are relevant to socio-economic challenges for CCA. Should two or more of these goals flip, then the projected outcome shifts to the disastrous F2 scenario. Importantly, if any of SDGs 7 (Clean Energy), 12 (Sustainable Economy), and 13 (Climate Action) are not improving, the projected outcome is F2. This analysis suggests that clean energy, responsible consumption and production, and climate action are cornerstones of SDG achievement, as depicted in Fig. 6.6.

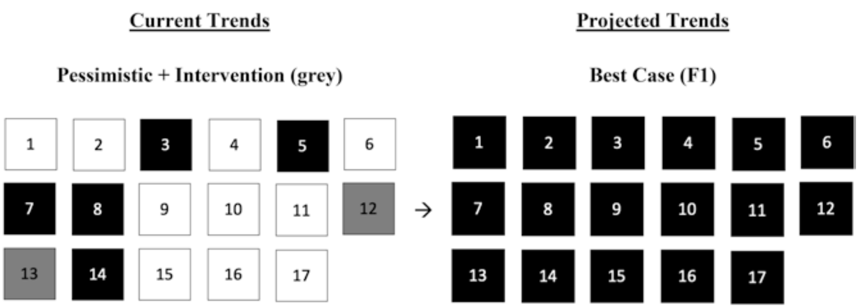

Fig. 6.5 Projected trends in the SDGs, based on current trends (pessimistic) plus additional efforts by businesses (gray)

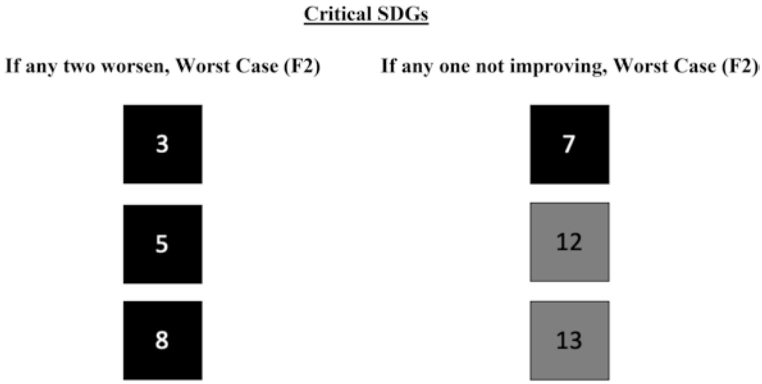

Fig. 6.6 Critical SDGs

4 Discussion

Our analysis depicts CCA, socio-economic conditions influencing CCA, and sustainability goals as complex and interdependent. The results identify six internally consistent scenarios for how the SDGs may collectively improve or worsen (Fig. 6.3). At a basic level, these scenarios reveal potential co-benefits and trade-offs between SDG 13 (Climate Action) and other sustainability goals, including SDG 8 (Decent Work and Economic Growth). This trade-off reflects the historical positive correlation between economic growth and global greenhouse gas emissions (Ansuategi & Escapa, 2002), matching broad tensions between the economy and the environment of similar analyses. For example, Randers et al. (2019) conclude that only 13 of the 17 SDGs overall could be achieved in the best-case scenario through conventional efforts, and O'Neill et al. (2018) reveal that meeting all the needs of seven billion people requires resource use to become two to six times more efficient. These trade-offs have implications for CCA, due to both the impact of SDG attainment on greenhouse gas emissions and the impact of socio-economic goals on the capacity to adapt.

Innovation is required to break feedback loops that drive synergies between economic growth, rising greenhouse gas emissions, and CCA. Green growth strategies and the "doughnut economics" model offer opportunities to enable economic development while remaining within planetary ecosystem boundaries (Raworth, 2012; Rockström et al., 2009). Moreover, decision tools and frameworks can clarify the economic benefits of CCA (Fankhauser, 2010; Watkiss et al., 2015), such as the role of CCA in mitigating financial losses from extreme events (Hallegatte et al., 2016; Jongman, 2018). Systemic analyses reveal these complex interdependencies, helping decision makers negotiate trade-offs or identify win-win strategies.

We consider progress toward CCA as both direct commitments to SDG 13 (CCA) and indirect commitments to addressing the human dimension of climate change through other SDGs. These interdependencies emphasize that businesses and consortiums like the UN Global Compact should consider how their priorities for CCA contribute to the SDGs' relative success overall. Businesses can leverage synergies between commitments toward cornerstone goals like SDG 13 (Climate Action) and other sustainability strategies. For example, using nature restoration as a flood mitigation measure can address SDG 13 and SDG 15 (Life on Land) simultaneously (de Vriend et al., 2014). Similarly, finding ways to improve water use efficiency can contribute to CCA (i.e., for impending water scarcity), while also addressing SDG 6 (Clean Water and Sanitation) and SDG 12 (Responsible Production and Consumption).

Our findings reveal that CCA and several SDGs relevant for socio-economic challenges of CCA play cornerstone roles in overall sustainable development outcomes. SDG 13 (Climate Action) and SDG 12 (Responsible Consumption and Production) are cornerstone SDGs that individually play a critical enabling role in shifting the world toward scenario F1 and avoiding regression toward scenario F2. Consequently, business commitments to CCA may avoid catastrophe and buoy commitments toward other goals. Additionally, maintaining progress toward SDGs 3 (Good Health and Wellbeing), 5 (Gender Equality), and 8 (Decent Work and Economic Growth) may be required for successful CCA, as the system may regress toward the F2 scenario if any two of these goals trend negatively. Businesses can leverage such interdependencies by targeting poverty reduction or healthcare efforts in regions with low adaptive capacity and high vulnerability to extreme events.

Our analysis shows that CCA may depend on efforts to pursue all SDGs collectively. However, SDGs are attained through uncoordinated actions across scales and domains, resulting in a situation in which certain SDGs and targets may be pursued more rigorously than others. Such uneven commitments add complexity to CCA and SDG attainment. Our analysis shows that a systemic bias to pursue some SDGs over others could result in two scenario archetypes: (1) humans over nature scenarios (F4 and F6), where socio-economic SDGs improve, while environmental SDGs worsen; or (2) nature over humans scenarios (F3 and F5), where environmental SDGs improve while socio-economic SDGs worsen. This analysis reveals a blind spot in business decisions to narrowly mitigate direct climate risk with infrastructure investments or pursue more sustainable supply chains.

Different scenarios of the SDGs create different contexts for setting CCA and sustainability priorities, reflected in the Shared Socio-economic Pathways (SSPs). Under the humans over nature archetype scenarios (F3 and F5), climate change impacts may be severe due to worsening conditions of SDGs 2 (Zero Hunger), 6 (Clean Water and Sanitation), 12 (Responsible Consumption and Production), and 13 (Climate Action). Under these conditions, transitioning from F3 or F5, and toward an ideal F1 scenario requires attention to cornerstone goals SDG 12 and 13. This archetype aligns with the SSP that deprioritizes both international development and climate action, *Regional Rivalry* (SSP 3). Socio-economic challenges for CCA are particularly daunting under SSP 3, as domestic security concerns weaken cooperation on environmental issues and stall broader forms of development like CCA (O'Neill et al., 2017). Conversely, under nature over humans archetypes (F4 and F6), unfavorable climate impacts may be less severe, but commitments to CCA may have greater benefits if they target effects to improve adaptive capacity. This archetype aligns with low fossil fuel development scenarios SSP 1 and SSP 4. However, socio-economic challenges for CCA are high under the *Inequality* scenario (SSP 4) as low levels of development in lower-income countries and differentiated access to effective institutions impact the capacity to cope and adapt to any degree of climate change locally. These problems are sufficiently widespread to be perceptible at the global level (O'Neill et al., 2017).

While companies are not the only stakeholder group responsible for CCA, they may have substantial knowledge, networks, facilities, and capital to direct toward CCA. Tools like SBSC expand on conventional performance indicators to align direct (financial) or indirect environmental, ethical, and social factors with core strategic issues or performance drivers (Figge et al., 2002). A major strength of SBSC is that it recognizes cause-and-effect relations between long-term environmental and social goals—like CCA—and firm-level targets. However, limited information is available to assist in deciding which strategically relevant goals will serve the needs of stakeholders and the overall success of a company's strategy (Nikolaou & Tsalis, 2013). Our approach tackles these weaknesses by dynamically modeling the potential outcomes of interactions between priorities in the context of limited or imperfect data.

Corporate sustainability and CCA strategies often apply to the organizational level without clear connections to system (or societal)-level goals (Hahn & Figge, 2018). In addition to challenges in obtaining the executive support, partnerships, and investment required to conduct such analyses, a major argument against incorporating societal objectives in organizational performance measurement is that a single organization may have limited impact on the system in which it operates (Hansen & Schaltegger, 2018). SBSCs are not usually used to measure systems-level sustainability goals, save a few isolated examples (Hansen et al., 2009; Hansen & Spitzeck, 2011), so the contributions of organizational-level goals to societal goals are often fortuitous (Hansen & Schaltegger, 2018). However, the cumulative impact of many businesses contributing to these broader goals can be significant and may involve trade-offs, as demonstrated in our analysis of the state of CCA amid interactions among the SDGs. Our approach helps to connect organization-level initiatives to wider-scale CCA or sustainability strategies; for example, we highlight that improved agricultural efficiency and sustainability plays an enabling role in CCA, which plays a cornerstone role in overall SDG progress.

While our findings are suggestive, they have important limitations. First, we do not scrutinize our data sources, so any issues regarding these sources may impact our findings. For example, only direct impacts should be included in CIB to avoid inflating effects, but we are unable to confirm that all the judgments in the GSDR represent direct impacts.

Second, our findings rest on the current state of knowledge of SDG interactions, which is still nascent. In our view, the GSDR may present an overly optimistic picture of SDG interactions, as co-benefits vastly outnumber trade-offs. If future research reveals additional trade-offs, our findings could change. While the science advances, businesses, policymakers, and other stakeholders face the necessity of acting imminently to ensure a better future. Our study combines the best available science on SDG interactions with a powerful method for making sense of complex and uncertain situations.

5 Conclusion

A more variable and extreme climate is pushing societies to adapt to increasing risks. While often treated separately, interventions for CCA are pursed in the context of the SDGs, due to interdependencies between human development and adaptive capacity as well as the historical coupling of economic growth and greenhouse gas emissions. A mere nine years remain to achieve the SDGs, but several analyses, including our own, reveal trade-offs between socio-economic and environmental goals. The business community plays a crucial role in advancing CCA and the SDGs.

Our chapter benefits from recent research about co-benefits, trade-offs, and synergies between SDGs to connect corporate CCA and sustainability strategies to systemic, long-term outcomes. We used CIB to identify six plausible future scenarios, including scenarios in which all SDGs are improving (F1), all SDGs are worsening (F2), human needs are prioritized over nature (F3 and F5), and nature is prioritized over human needs (F4 and F6). We also identify cornerstone SDGs that play a key enabling role in overall SDG attainment, including SDG 12 (Sustainable Consumption and Production), which is relevant for businesses, and SDG 13 (Climate Action), which is relevant for CCA. In addition, SDG 13 proves to be highly interdependent with SDG 3 (Good Health and wellbeing), 5 (Gender Equality), and 8 (Decent Work and Economic Growth), which have been recognized elsewhere as SDGs relevant for decreasing socio-economic challenges to CCA. Moreover, SDG 13 is interdependent with SDG 7 (Clean Energy) and 12 (Responsible Consumption and Production). Based on these findings, we offer applicable insights for the business community to help adopt a systemic lens on their direct and indirect commitments to CCA as well as other sustainability commitments.

Our analysis reveals the plausible global outcomes that emerge out of the structure of relationships between CCA, business commitments, and SDGs. Thus, our model views business as one collective force impacting the global system. While the results that emerge from this assumption offer strategic insight relevant to organizations operating at global scales—for example, multi-national corporations and consortium bodies like the UN Global Compact—the structure and weight of these interactions at regional and local scales may vary. Similar analyses conducted at local and regional scales, where new cross-impact judgments and assumptions (e.g., initial conditions) are defined, can bring this type of analysis to companies targeting outcomes on smaller scales. In sum, our analysis contributes clarity to corporate strategy by unpacking the complexity of the interdependencies within and between CCA and the SDGs.

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7

Climate Finance: A Business-Ethical Analysis

Manuel Wörsdörfer

1 Introduction

The finance industry plays a crucial role in the context of climate change mitigation and adaptation. The main reason is that financial institutions are right at the center of the global political economy, linking the 'real economy' or 'Main Street' with the finance sector or 'Wall Street'. Therefore, financial decision-makers are among the most powerful players in the global political economy. They resemble economic pacemakers, or powerhouses, that keep the economic 'blood circulation' alive. For instance, by providing financial means to their clients (e.g., in the form of corporate loans as well as managing, underwriting, and/or assisting with the issuance of shares and bonds) banks possess a substantial influence-leverage over their business partners. Furthermore, financial institutions are those which (co-)determine whether or not financial

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resources are used in an ethical and environmentally friendly manner. They are the key actors in our transition toward a green (carbon-free) economy. By voting with their money, they ideally help in catalyzing the transitional process toward economic, ecological, and social sustainability (Conley & Williams, 2011).

This chapter picks up the discussion on finance ethics and (political) corporate social responsibility (CSR) and analyzes the relevance and ethical responsibilities of financial institutions in relation to climate change mitigation and adaptation. It does so by analyzing the status quo (i.e., business link between banks and the fossil fuel industry) as well as the latest market trends and developments, including the emergence of the climate bond market. It also provides both theoretical and empirical arguments for a business case for climate finance and, hence, for corporate social and environmental responsibility. This chapter not only shows that banks are a vital element in achieving the targets of the Paris Agreement; it also demonstrates that it is most logical from a business perspective to divest from fossil fuels and to invest (considerably more) in renewable energies.

The chapter is structured as follows: Sect. 2 takes a closer look at the current business relationship between the banking sector and the fossil fuel industry. Sections 3 and 4 analyze the recent trends in the finance industry, including the divestment movement and the climate bonds market; they also discuss additional measures financial institutions could (or should) adopt to further promote climate change mitigation and adaptation. Moreover, Sect. 5 examines whether or not a business case for climate finance—and climate action—exists and what this would mean for the finance industry. The chapter concludes with a summary of its main findings and presents an outlook on future research questions.

2 Banks and the Fossil Fuel Industry

To begin with, let us take a closer look at two recently published studies which portray an intimate relationship between the banking sector and the fossil fuel industry: the *Fossil Fuel Finance Report Card 2018*, published by Rainforest Action Network et al. (RAN et al., 2018), found that extreme fossil fuel financing amounted to $126b in 2015, $104b in 2016, and $115b in 2017. *Extreme fossil fuels* include all those energy (and related industry) sectors that are the most Greenhouse Gas (GHG)-intensive, environmentally destructive, and detrimental to the local, project-affected communities. Of particular importance are tar sands, Arctic and ultra-deep offshore oil, coal mining and coal-fired power, and liquefied natural gas export terminals. As shown by the NGO report, all three years saw investments of more than $100b per annum. The report also reveals that the largest contributor toward the overall increase in extreme fossil fuel financing is the tar or oil sands sector, which plays a substantial role especially in North America. Here, financing increased by more than 110% from 2016 to 2017, and the total financing amounted to almost $100b. The lead financiers in this industry sector are RBC, TD, and JPMorgan.

Regarding the aforementioned energy sectors, the report shows that *arctic oil* was financially supported with approximately $5b from 2015 to 2017; the lead supporters were BNP Paribas, Deutsche Bank, and CIBC. *Ultra-deepwater oil* financing totaled $52b—led by JPMorgan, HSBC, and Bank of America. Financial institutions invested an additional $45b in LNG export terminals (and other LNG-related activities)—led by Morgan Stanley, Société Générale, and MUFG. Regarding *coal mining*, financial institutions such as China Construction Bank and Bank of China (the global leaders in this industry) as well as Goldman Sachs and Deutsche Bank (the biggest Western banks) invested $52b between 2015 and 2017 in this particularly harmful industry sector. It is noteworthy that investments stagnated globally, but outside of China, coal mining financing more than doubled between 2015 and 2017. Lastly, the *coal power* industry sector received $94b over the same three-year period and the lead financiers were ICBC, China Construction Bank, and other Chinese banks. The report found that the coal power sector leveled off globally; yet it remains one of the most highly funded energy sectors—along with the tar oil sector.

Overall, the report found that 36 largest private-sector commercial and investment banks invested in total more than $345b over a three-year period in extreme fossil fuels (tar sands, Arctic and ultra-deep offshore oil, coal mining and coal-fired power, and LNG). The biggest bankers in 2015–2017 include China Construction Bank (leading financier in the coal mining industry), RBC (leading financier in the tar sands industry), JPMorgan, ICBC, Bank of China, TD, HSBC, Agricultural Bank of China, Citi, and Bank of America. In 2017 alone, the lead financiers of extreme fossil fuels included RBC, JPMorgan, TD, China Construction Bank, ICBC, Bank of China, HSBC, Citi, Scotiabank, and CIBC.

The *Fossil Fuel Finance Report Cards of 2019* and *2020* (RAN et al., 2019, 2020) are remarkable because they consider all the lending and underwriting activities involving more than 30 global banks and the fossil fuel industry in its entirety. These reports reflect the global financing for approximately 2000 corporations across the coal, oil, and natural gas sectors from 2016 to 2018/2019. They also consider the entire fossil fuel life cycle—from the exploration to the extraction, transportation, storage, and energy generation stage. Finally, the latest Fossil Fuel Finance Report Cards look at the so-called *fossil fuel expansion* sector, which considers companies investing in or being active in new fossil fuel extraction, infrastructure, and power projects (more than 100 of those companies are reflected in the 2019/2020 reports). The reports reveal that the biggest banks invested more than $2.7 trillion over a four-year period. Most importantly, financing is on the rise, that is, more money has been invested in extreme fossil fuels each year since the adoption of the Paris Agreement ($640b in 2016, $674b in 2017, $700b in 2018, and $736b in 2019).

The sectoral breakdown reads as follows: tar sands oil (total: $102b), Arctic oil and gas ($23b), offshore oil and gas ($188b), fracked oil and gas ($296b), LNG ($76b), coal mining ($54b), and coal power ($139b). In addition to that comes more than $975b over the past four years for investments in the fossil fuel expansion sector—plus other forms of financial services. Based on the 2020 report card, the biggest financiers of fossil fuels worldwide over the four-year period are JPMorgan, Wells Fargo, Citi, Bank of America, RBC, MUFG, Barclays, TD, Mizuho, and Scotiabank. Regarding the financing of the top 100 companies expanding fossil fuels, JPMorgan leads ahead of Citi, Bank of America, Wells Fargo, TD, RBC, MUFG, Scotiabank, Bank of Montreal, and Barclays. In the years following the adoption of the Paris Agreement, JPMorgan was the number one financier of extreme fossil fuels, leading by 36% and investing a total of $269b; the company was also the number one financier of the top 100 companies expanding fossil fuels. Regarding the individual sectors, JPMorgan was the number one financier worldwide of Arctic and offshore oil and gas, and fracking, and the biggest US-financier of coal mining and tar sands oil.

All the data published by various finance NGOs are confirmed by other publications as well: for example, Hunt and colleagues estimate that in 2014 alone, the entire fossil fuel industry—not just the coal industry—raised an estimated $900b from bank loans, bonds, equity, and project finance (Hunt et al., 2016; Hennig & Wörsdörfer, 2015).

Noteworthy in this context is also the active involvement of international finance organizations, such as the World Bank (Group) or the International Finance Corporation (IFC). For example, Hunt et al. found that the *World Bank* increased its fossil fuel investments and financing by 23% in 2014 to an estimated $3.4b (Hunt et al., 2016). The Washington-based international finance institution primarily uses loans, grants, guarantees, risk management, and equity to finance and support fossil fuel projects. These results are confirmed by a series of studies published by Inclusive Development International in 2016 and 2017 (IDI, 2016, 2017a, 2017b) as well as by a 2019 urgewald report. These reports found that the *IFC*, the private-sector lending arm of the World Bank Group, funds coal through its support for financial intermediaries (e.g., commercial banks and private equity funds). These intermediaries received an estimated $40b in IFC funding between 2011 and 2015, which represents over half of the IFC's lending portfolio (a portion that has constantly increased over the past several years). It is important to note that the IFC-supported financial institutions funded at least 41 new coal projects mostly in India and Southeast Asia (IDI, 2016, 2017a)—either the companies that own them or the facilities directly—since the World Bank announced its 'coal ban' in 2013. In total, the projects account for 56,137 megawatts of new coal capacity and are also closely linked to land grabbing and/or deforestation, which negatively contributes to climate change (IDI, 2017b). Lastly, the World Bank Group's active energy project finance (budget) for fossil fuel projects is said to be approximately $21b; this amount is considerably more than for all renewable energy projects (approx. $7–15b). It is worth noting that the fiscal years of 2014–2018 saw the World Bank Group's approval of over $12b for coal, oil, and natural gas projects (urgewald, 2019).

One of the main problems with the previous data is that every new fossil fuel-fired power plant 'locks in' additional annual emissions of millions of tons of CO_2 for the next 30–40 years, which is the lifetime of a power plant (i.e., *locked-in emissions*). That is, today's investment decisions are tomorrow's GHG-emissions. Besides, it is estimated that depleting all fossil fuel fields and mines currently in operation or production would blow the planet past the Paris Agreement's (maximum) goal of 2 °C; and even just by ending the burning of all coal reserves right now, the existing oil and natural gas fields alone would tip us over the 1.5 °C-target of the Paris Agreement (Partington, 2019; RAN et al., 2018, 2019).

3 Recent Trends in the Finance Industry

Aside from this somewhat 'dark side' of the finance industry, there are also some bright spots worth mentioning: *first*, more and more financial institutions engage in voluntary and self-regulatory (transnational) *CSR-initiatives* that try to tackle climate change, for example, Carbon Principles, Climate Principles, Equator Principles, Global Reporting Initiative, Principles for Responsible Banking/Investment, and UNEP-FI. Yet most of those initiatives suffer from a soft-law language resulting in a legally non-binding framework with inadequate implementation (and only limited impact in reality). Hence, the goal should be to close and/or overcome the various loopholes, gray areas, and discretionary leeway of these initiatives, and to establish a legally binding 'shall' instead of a non-binding 'should' terminology. A crucial element during this process of 'hardening the soft law' is to set up effective governance institutions, including proper enforcement, monitoring, and sanctioning mechanisms (Wörsdörfer, 2015b, 2017).

Second, financial institutions play a central role in the context of *cap-and-trade schemes*, also referred to as *emissions trading systems* (High-Level Commission on Carbon Prices, 2017; IMF, 2019a, 2019b; Nordhaus, 2013): these schemes follow a government-mandated market-based approach to climate change mitigation. The basic idea is that the government sells or allocates a limited number of permits or carbon credits to companies, which allows them to discharge a certain number of pollutants (e.g., CO_2 emissions) per year. Corporations can sell unneeded permits or purchase additional ones, in case they will exceed the emissions targets, using secondary (e.g., stock) markets. The aim of emissions trading schemes, such as the one established by the EU, is to control and limit environmental pollution by giving companies economic incentives to reduce their GHG-emissions.

Third, the finance industry, together with insurance and accounting firms, is also essential when it comes to the implementation of integrated or *ESG (environmental, social, and governance) reporting* requirements and other forms of environmental regulations. Important in this regard are ESG-linked credit and climate stress tests (and enhanced capital and liquidity requirements), climate-related risk disclosures, and impact assessments (Ceres, 2020; Wendt, 2015).

Fourth, another way that banks could contribute to climate change mitigation is via *financed emissions reporting*. The main idea is to assess, measure, and report on direct *and* indirect GHG-emissions, to set up a so-called GHG-emissions inventory, also referred to as 'carbon footprinting', and hence track the banks' climate impacts (Carbon Disclosure Project, 2019; Greenhouse Gas Protocol, 2019). Critical is that financial institutions also report about their financed emissions, that is, all those emissions which are associated with loans, investments, and other forms of financial services. These so-called financed emissions or scope-3 emissions include all indirect emissions that result from other sources such as the use of a company's products or services. Financed emissions reporting—and climate impact disclosure in general—should be accompanied by establishing a sufficiently ambitious annual portfolio and business unit emissions reductions targets (i.e., climate impact target setting), including a timeline to reduce those emissions as well as performance tracking (PRI, 2020). The main problem, however, is that most financial institutions do not report their financed or scope-3 emissions (Novethic, 2015).

Fifth, *covenants* are another effective way for financial institutions to contribute to climate solutions. Through their contractual business relationship with their clients, banks could easily integrate human rights or climate clauses into their loan agreement. These clauses could include explicit references to environmental, social, and human rights due diligence, as well as climate change mitigation and/or adaptation measures. If these clauses or covenants are breached, this would give banks the opportunity to withdraw their investments, and to terminate the business relationship or to sue their clients. Covenants are, thus, a very important part of global supply and value chain management (screening and monitoring) (Wörsdörfer, 2015a).

Sixth, probably the most significant action taken by banks is *fossil fuel divestment* (Allianz, 2018; Crédit Agricole, 2019; NatWest Group, 2020; UBS, 2019; see 350.org, 2019; Climate Action 100+, 2019). That is, banks should disengage and divest from companies and industries that constantly violate basic socio-environmental and human rights standards; they should terminate (in-)direct business relationships, as an exit option and means of last resort, to 'decarbonize' their portfolios (i.e., '*footprint* approach') and align their policies and practices with the Paris Agreement. This implies:

- Ending the funding of dirty projects or dodgy deals (those that involve severe human rights violations and/or the violation of socio-environmental standards).
- Terminating the (in-)direct support for coal, oil, and natural gas extraction and delivery, fossil fuel-fired power plants, MTR-mining, tar sands, and so on.
- Phasing out the underwriting of share or bond issues which are used to raise capital for fossil fuel projects and ceasing the provision of corporate loans for (extreme) fossil fuel companies.

Note that it is crucial to not only divest from the fossil fuel industry—which stands for environmental destruction (and technologies of the past)—but also to redirect those funds and to invest them into renewables, energy conservation and efficiency, zero-carbon transportation and infrastructure, and other climate solutions including climate adaptation measures (e.g., city planning and construction, flood protection, irrigation systems). The main idea behind those reinvestment strategies, and the '*handprint* approach' in general, is to shift or reallocate capital flows to zero-carbon investments (i.e., 'green financing') and to accelerate the transition to a zero-carbon economy.

Lastly, an entirely new (climate) finance sector is emerging—the so-called *climate or green bond* market, which is closely aligned with the social impact bond market (CBI, 2018a) and impact investing in general (Flammer, 2018; Wendt, 2015). The idea is to shift investments from environmentally and socially *ir*responsible and *un*ethical investments toward environmentally and socially responsible and ethical investments to finance climate solutions and adaptation measures. These investments are conducted based on so-called ESG-indicators and get certified, for example, by the Climate Bonds Initiative's (CBI) Standard Board. CBI estimates that climate bonds worth approximately $350b were issued in 2020—which would be four times the amount in 2016 where bonds worth circa $80b were issued (CBI, 2020a). The green bond market is, thus, one of the fastest growing segments in the global finance industry, and many companies—including big tech—as well as pension funds have invested in it. The climate finance market has received further stimulation by the Green Climate Fund (Bowman & Minas, 2019; Steckel et al., 2017), which was launched with the Paris Agreement. Banks play a vital role here as well, mostly as financial intermediaries and fund managers.

4 Climate Bonds

Bonds are a tool for raising money for a specific cause or project (e.g., infrastructure) and for refinancing. They function as a form of debt or loan security. The most common bond types include project bonds, corporate bonds, securitization, and sovereign or government bonds. In recent years, social impact bonds, and especially climate or green bonds, have emerged as an additional bond category—both of which can come in many forms, including corporate and sovereign bonds (Flammer, 2018). Climate bonds are a thematic (bond) market where the use of proceeds is specifically dedicated to a particular purpose, such as climate change mitigation and adaptation and other environmental issues. That is, "[c]limate bonds are where the use of proceeds is used to finance—or refinance—projects addressing climate [change]. They range from wind farms and solar and hydropower plants to rail transport and building sea walls in cities threatened by rising sea levels" (Kidney & Boulle, 2015, p. 582). For example, the World Bank Green Bonds are allocated to climate areas such as renewable energy and energy conservation and efficiency lending. The main idea is to shift a substantial amount of already existing capital into low-carbon projects and other climate solutions, including adaptation measures, with the help of 'green financing'.

Climate bonds have a threefold function to fulfill: *first*, they help attract institutional (financial) capital, especially from socially and environmentally responsible investors such as pension funds, central banks, and corporations. *Second*, they help mobilize institutions and resources because bonds are a means for governments to channel funding into climate action projects (e.g., via preferential tax treatments or the provision of governmental guarantees). *Third*, climate bonds also send politico-economic signals to other stakeholders (Kidney & Boulle, 2015).

The International Energy Agency estimates that $1 trillion global investments in the energy, transportation, and building sectors are needed each year to reduce GHG-emissions in line with the 2 °C-target (Fankhauser et al., 2016; International Energy Agency, 2015). Since a considerable amount of the money needs to come from the private sector (e.g., institutional investors), the global bond market—and particularly the climate bond market—could provide much of the capital and investments needed (as bonds are a suitable financing instrument for high capex and long-life projects such as renewable energy projects).

The year 2019 saw the issuance of new green bonds worth almost $259b, distributed among 1802 deals and 506 issuers—a 51% increase over the previous year, and since its inception in 2007, almost 6000 deals by approximately 1000 issuers worth $754b were concluded. For 2020, CBI estimates an increase of almost $100b in the green bond market—reaching an all-time high of $350b (which is an almost fourfold increase over the last four years) (CBI, 2020a). The 2019 green bond issuance ranking is led by the US with 105 issuers, a market share of 20%, and an overall investment amount of $51.3b; it is followed by China (79 issuers, $31.3b investments, 12% market share), France (19, $30.1b, 11.6%), Germany (12, $18.7b, 7%), and the Netherlands (15, $15.1b, 6%). The number one issuer in 2019 was Fannie Mae with $22.8b investments in green bonds, followed by the German KfW ($9b), the Dutch State Treasury ($6.7b), the Republic of France ($6.6b), and ICBC ($5.9b) (CBI, 2020b).

The substantial growth rates of the green bond market are important to note. For example, from 2016 to 2017, the market grew by 78% (the 2019 increase was 51%), and the single largest green bond was worth more than $10b (CBI, 2018b). Over the past five years, the highest growth rates were in the Asia-Pacific region, and particularly China is playing an increasingly important role in terms of issuer numbers as well as overall investments. In 2018, for example, Chinese issuance topped for the first time $30b (the country still ranks second worldwide right after the US). Other emerging markets are also gradually entering the market; for example, the State Bank of India issued its first green bond in 2018 (overall, 2019 saw eight new countries, including Russia and Saudi Arabia, and 291 new issuers entering the market [CBI, 2020b]). Finally, recent data also show the growing prominence of municipality and city bonds; even universities have started issuing green bonds (CBI, 2018c). Most of the capital raised by green bonds was used in 2017 to finance renewable energy projects ($51b or 33% overall [>$80b, 32% in 2019]), low-carbon buildings and energy efficiency projects ($45b, 29% [30%]), clean transportation projects ($24b, 15% [20%]), sustainable water management projects ($20b, 13% [9%]), sustainable waste management projects ($6b, 4% [3%]), sustainable land use and forestry projects ($5b, 3% [3%]), and climate change adaptation projects ($4b, 3%) (CBI, 2018b, 2020b).

Although climate bonds are widely considered a remarkable success story, they currently face several systemic challenges. One of those challenges relates to the conflicting interests that might arise when companies make financial (business) decisions, that is, the potential (perceived) trade-off between socio-environmental (ethical) and economic imperatives—and especially between short-term *share*holder and long-term *stake*holder value optimization (Wörsdörfer, 2015b). This problem is also reflected in the following numbers: the traditional global bond market is worth approximately $130 trillion; yet the green bond market—despite all its progress in recent years—represents only a small fraction of the overall investments (approx. $350b). Another potential issue is greenwashing and window dressing: some companies might use green bonds as a public relations tool that might help them to pacify their critics (e.g., NGOs, civil society, government agencies) and to avoid public naming and shaming campaigns and/or customer boycotts (Wörsdörfer, 2015b, 2015c). Also, many climate bonds lack proper standards and certification, both of which are needed to ensure that investments are making a genuine contribution to climate change mitigation and adaptation. What is required are clear, transparent, and publicly available socio-environmental impact criteria for bonds to be classified as 'green'. This, in turn, requires reliable and credible third-party auditing (CBI or ICMA's Green Bond Principles (International Capital Market Association, 2018) are considered a first step in the right direction). Finally, green bonds also need some form of government or regulatory oversight (monitoring), including sanctioning mechanisms in case actors fail to adhere to performance standards and criteria (Park, 2018).

5 Business Case for Climate Finance

Several arguments speak in favor of financial institutions investing considerably more money in climate solutions (Federal Reserve Bank of San Francisco, 2019). The main argument is that climate change must be considered a systemic financial risk and climate action (i.e., mitigation *and* adaptation) as a form of risk management—one that helps to address various risk categories, including financial, operational, reputational, and legal-political risk. The following paragraphs provide reasons for this way of arguing.

First, climate change poses severe financial (i.e., credit and investment) and operational risks for banks and their clients. To begin with, there are the physical risks to investment assets, for example, from rising sea levels, flooding (Berman, 2019), storms, droughts, and wildfires. The expected increase in the frequency and intensity of severe weather events presents additional property (e.g., real estate [Bernstein et al., 2019]) and casualty risks to a broad range of clients and, subsequently, also for the portfolio stability of banks themselves and the stability of financial markets as a whole (Bolton et al., 2020; Ceres, 2020; Federal Reserve Bank of San Francisco, 2019; Görgen et al., 2019). These physical risks alone could reduce the value of global financial assets by more than $24 trillion—a loss that would be far greater than the economic damage caused by the 2007/2008 financial market crisis (Dietz et al., 2016).

Second, many banks have become the targets of public naming and shaming campaigns—mostly due to their (extreme) fossil fuel investments, they have been denounced and stigmatized as 'coal banks' or 'climate killer banks'. These campaigns often attract media attention and cause public outcry and/or are followed by a call for customer boycott, all of which have the potential to negatively affect the reputation and furthermore the stock market value of the companies involved. Increasing public concern and awareness about climate change—especially in many OECD-countries (see the 'Fridays for Future' demonstrations and other forms of climate activism)—add more reputational pressure on financial institutions, which are already under scrutiny by the public because of the 2007/2008 financial market crisis. Another related risk category is the one associated with the growing public opposition and resistance to banks' (fossil fuel) projects. For example, protests by local (indigenous) communities might delay a project and/or increase its costs. To avoid those additional costs, a 'social license to operate' is required, which goes above and beyond a 'legal license' issued by a government agency and encompasses the support of the local, project-affected community (Wörsdörfer, 2015b).

Third, the social landscape is not the only one that is gradually changing. The legal-political landscape is shifting as well and this includes several US municipalities and states (potentially also the Biden administration), as well as several of the emerging markets, for example, India and China (which recently announced that it intends to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060). Many countries, in particular EU member states, have released tightened socio-environmental regulations over the last couple of years, which will sooner than later force fossil fuel-fired power plants and technologies into early retirement. This causes stranded assets and financial losses, for example, in the form of write-downs, not only for the directly affected companies, but also for their financiers (other reform proposals include obligatory climate stress tests conducted by central banks, the mandatory assessment and disclosure of climate risks, including carbon emissions from all types of investment (e.g., enforced by securities and exchange commissions), new ESG-reporting requirements, climate-risk audits and accounting, reform of credit ratings, and so on [Ceres, 2020]). Furthermore, there are also other types of liability risks for the involved firms, for example, in the form of a potentially looming climate litigation. Failures to adequately manage and mitigate climate-related risks may constitute a breach of a director/CEO's duties to the corporation and may result in personal liability if corporate value becomes impaired. In other words, the failure to disclose climate risks, or withholding certain crucial information from the market and regulatory agencies, has the potential to trigger securities fraud legislation. For example, ExxonMobil has already been accused of misleading investors, government agencies, and the public regarding its corporate climate risks (Marjanac & Patton, 2018) (note that event attribution science (CAI, 2017; ECIU, 2017; Skeie et al., 2017) could become a major driver of climate litigation).

Fourth, the so-called carbon bubble poses another severe risk to banks' fossil fuel investments and financial market stability in general: respecting the 2 °C-redline implies staying within the remaining carbon budget of approximately 600–1000 gigatons of CO_2 (yet as of 2020 every year 40–50 gigatons of CO_2 are used globally) (Figueres et al., 2017; IPCC, 2018; Millar et al., 2017; Rogelj et al., 2015). If humankind wants to adhere to the 2 °C-target, then most of the remaining coal, oil, and natural gas reserves must remain in the ground. Namely, if we want to avoid the worst effects of climate change, an estimated (at least) 60–80% of fossil fuel reserves of listed firms are unburnable (Carbon Tracker Initiative, 2014; Global Carbon Project, 2016; McGlade & Ekins, 2015). It is calculated that these unburnable and, subsequently, unprofitable or stranded assets are worth up to $100 trillion (Caldecott, 2018; Carbon Tracker Initiative, 2019; Mercure et al., 2018)—which represents a substantial financial risk of business as usual to all financial investors and financial markets as a whole (Renew Economy, 2015).

Besides these (climate) risk management advantages, climate action (i.e., mitigation *and* adaptation) also offers a variety of investment and employment opportunities. Billions of dollars need to be invested every year to protect urban areas, rural regions, and entire countries against flooding, rising sea levels, storms, and other extreme weather events (i.e., climate resilience and adaptation investments [Cleveland et al., 2019]). These investments could help create additional business and job opportunities for entrepreneurs, engineers, and researchers, for example, in the fields of renewable technologies, energy storage, conservation and efficiency, alternative fuel vehicles, sustainable architecture and design, urban planning, ecological agriculture, as well as green or sustainable financing. One recent study estimates that more than 65 million new jobs could be created by 2030, resulting in overall economic gains of $26 trillion (Global Commission on the Economy and Climate, 2018). Hence, there are lots of business opportunities associated with the transition to a low- or zero-carbon economy. Pioneering companies and financial institutions can gain competitive advantages, thereby outperforming their competitors and/or increasing their market share and corporate profits (note that many renewable energy sectors already outpace the fossil fuel industry, especially coal and oil, in terms of economic growth, job creation, and investments; this trend is most likely going to accelerate).

As the previous sections have indicated, a business case for climate change mitigation and adaptation seems to exist at the theoretical level; that is, sound (economic and environmental) ethics and good business go hand in hand—for the most part and in the long run (i.e., 'good ethics is good business'). But what about the empirical research supporting this so-called ethics pays argument? One important study comes from In et al. (2018): the authors analyzed almost 75,000 observations of more than 700 US companies over a ten-year period (2005–2015). They found that "carbon-efficient firms are those with [a] better financial performance as well as better governance" (In et al., 2018, p. 4). Not only do those companies yield annual returns of 3.5–5.4% on average, they also—and this is remarkable—outperform their 'carbon-inefficient' competitors. Another study conducted by Flammer found that "green bonds yield i) positive announcement returns, ii) improvements in long-term value and operating performance, iii) improvements in environmental performance, iv) increases in green innovations, and v) an increase in ownership by long-term and green investors. Overall, these results indicate that green bonds are effective—companies invest the proceeds in projects that improve the company's environmental footprint and contribute to long-term value creation" (Flammer, 2018, p. 1; Glanemann et al., 2020). Hence, empirical research also indicates a positive correlation between the corporate socio-environmental performance and the corporate financial performance.

6 Concluding Remarks

The Paris Agreement aims at preventing dangerous anthropogenic climate change—and the crossing of so-called tipping points which would lead to irreversible consequences/effects. This, however, implies limiting global warming to well below 2 °C relative to pre-industrial levels, with efforts being made to limit warming to 1.5 °C. It also implies stabilizing atmospheric CO_2 concentrations to below 450 ppm (which requires the reduction of *global* CO_2-emissions by at least 50% until 2050 and the realization of zero global net emissions of GHGs until the end of the century, if not earlier). All of the above targets are extremely ambitious as we have already passed the 410-ppm threshold and add approximately 2–3 ppm each year. In addition, on average we have already surpassed 1 °C of global warming; when comparing the last five years with the mid-to late 1800s, roughly 10% of the earth has already warmed by more than 2 °C, and approximately 20% of the earth has warmed by 1.5 °C. It was shown that the fastest-warming regions include the Arctic, large parts of Canada and the Middle East, as well as Europe and northern Asia (Mooney & Muyskens, 2019).

What is required to be able to reach the Paris targets is a fundamental shift in personal lifestyles, daily habits, and business practices—away from (extreme) fossil fuels toward a zero-carbon economy. Of particular importance in this regard are fossil fuel divestments and the decarbonization of investment portfolios. Financial institutions are thus not only at the core of the problem; they are also an essential part of the potential solution. In fact, they might be our only hope to overcome the climate crisis given the apparent lack of political will—combined with the pervasive problem of rent-seeking and lobbyism—and the complacency and inertia of many people. As this chapter has shown, the bad news is that the finance industry has still very close and strong business ties to the fossil fuel industry and is still heavily invested in various 'dirty' projects. The good news, however, is that there is a business case for climate finance and action especially given that climate change poses severe financial risks for banks and their clients, not to mention the various investment opportunities presented by climate change mitigation and adaptation. As time is of the essence, GHG-emissions need to be reduced by (at least) 50% by 2030 and 80–90% by 2050 in most *industrialized* countries to avoid the most catastrophic and devastating effects of dangerous climate change. Banks need to act quickly and phase out their fossil fuel investments and redirect them toward climate solutions. It remains to be seen whether they are willing and able to pursue the required paradigm shift indicated in this chapter.

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8

Risk-Rating GHG Emissions Offsets Based on Climate Requirements

Quintin Rayer and Pete Walton

1 Introduction

Accumulated atmospheric emissions of greenhouse gases (GHGs), primarily carbon dioxide, cause anthropogenic global warming (AGW) (Allen, 2016). Net-zero anthropogenic GHG emissions are required for AGW to stabilize within the 1.5–2.0 °C Paris Agreement goal (Millar et al., 2018; Rayer, 2018; UN FCCC, 2015). As discussed in Rayer et al. (2021), offsetting is necessary to compensate for emissions, including those from hard-to-abate sectors, such as agriculture and aviation (Pozo et al., 2020). For unavoidable emissions, offsetting is required to achieve net-zero (emissions minus offsets) (Jenkins et al., 2021; Leach et al., 2018).

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Organizations need strategies to be carbon-neutral: reducing emissions and, ultimately, removing atmospheric CO_2 (Rayer et al., 2019). Carbon "offsets" are one tool to do this (Broekhoff et al., 2019). Massive deployment of such technologies is already assumed in scenarios for 1.5 °C, 2 °C, and higher stabilization targets (Anderson & Peters, 2016). As a result, urgent discussion and clarification around offsetting is essential.

Emissions can be "neutralized" by "deemed offsets" (Rayer et al., 2021). Deemed offsets may be verified and audited and can include atmospheric CO_2 sinks, emissions reductions, preventing climate-malign activities, or purchase of units from carbon allowance schemes. Offsetting's "quality" (in terms of ability to stop AGW) is crucial.

This chapter begins by summarizing some offset types and characteristics. We propose a framework to rate offset schemes in terms of the risk that they may not deliver the expected benefits. We apply our climate-risk ratings to several offsetting types.

We use Rayer et al. (2021)'s definitions of carbon-neutral, net-zero, atmospheric sources and sinks, "deemed offsets," and metrics to convert between different GHGs. Our offset rating is based purely on the requirement to stabilize AGW. This is not to say that other aspects of offsetting, such as the social or biodiversity benefits of nature-based solutions (NbS), are not of value, but we feel it useful to focus entirely on their ability to arrest AGW to progress the debate.

As examples, we apply our ratings to the sorts of schemes proposed by oil companies (Hook, 2019) and the PAS 2060 carbon-neutrality standard (BSI, 2014). Our rating system allows schemes to be assessed against their long-term climate risk.

2 The Risks of Misusing Offsetting

Rayer et al. (2021) discuss the risks of misusing offsetting, including:

- Reliance on unproven technologies and the temptation to postpone immediate action based on projected technological advances. Cutting emissions now is the priority (Allen et al., 2020; Anderson & Peters, 2016).

- Carbon-intensive businesses offsetting in large volume. This ignores the dangers of insufficient offsetting capacity or the creation of substandard offsetting schemes.
- Difficulties in the accurate estimation of both carbon emissions and carbon take-up by schemes.
- Using offsetting as an excuse to continue to use as well as expand reliance on fossil fuels and other GHG emitting technologies.
- The "moral hazard" that using offsets as negative emissions may deter reduction efforts (McLaren et al., 2019; Pierrehumbert, 2019).
- The risk of future leakage of carbon captured, while emissions reductions have permanent benefits on atmospheric GHG concentrations (McLaren et al., 2019).

The focus should be on reducing GHG emissions directly (and dramatically) in line with global mitigation goals. Carbon offsets should be in addition to emission reduction (Broekhoff et al., 2019).

Offsetting has benefits when used as a last resort, or as a temporary measure, while other projects are developed and implemented (Rayer, 2018). It should generally aim for hard over soft carbon storage (Rayer et al., 2021). It should also be appreciated that as technology advances, and the challenges of certain approaches are addressed, their associated risks also change. For example, at present, the primary focus should be on emissions reductions using existing technologies. However, this should proceed in parallel with the development of CO_2 capture and storage techniques (with a focus on hard storage), so that these become available once major emissions reductions have been achieved.

In this chapter, we consider how offset types may be rated in terms of their climate risks. We present the results for present-day offsetting options, noting that the situation may change rapidly towards the mid-century if policymakers succeed in drastically reducing emissions in line with commitments for a "well-below 2 °C world," or new technologies emerge.

3 Review of Offsetting Schemes

The term "deemed offsets" denotes both carbon offsets and carbon credits (Rayer et al., 2021). Deemed offsets are used to compensate for emissions and cover several approaches. They could refer to a reduction in GHG emissions, atmospheric removal and storage, or carbon credits.

PAS 2060 lists Kyoto-compliant, non-Kyoto compliant or voluntary emission reductions, and domestic schemes (BSI, 2014). Providers such as https://www.carbonfootprint.com/ also list offset schemes, including renewable energy projects, access to more efficient cooking stoves, and schemes to prevent deforestation.

Several deemed offsets are policy tools, barriers for entry into a market, or takeback schemes. The wide range of offsets available today reflects a diverse collection of different approaches united only by a common label. They are not necessarily of equal merit from a climate change perspective. We note that several commonly traded deemed offsets are not atmospheric carbon sinks and, therefore, arguably do not "offset" emissions at all.

Several schemes extract CO_2 from the atmosphere. These negative-emission technologies exist at various levels of development Anderson and Peters (2016), Smith et al. (2015), and Williamson (2016) list:

1. Bioenergy with carbon capture and storage (BECCS).
2. Direct air capture of CO_2 from ambient air (DAC).
3. Enhanced weathering of minerals (EW), where natural weathering to remove CO_2 from the atmosphere is accelerated and the products stored in soils or buried in land or deep ocean.
4. Afforestation and reforestation (AR) to fix atmospheric carbon in biomass and soils.
5. Manipulation of oceanic carbon uptake, either biologically (by fertilizing nutrient-limited areas) or chemically (by enhancing alkalinity).
6. Altered agricultural practices, such as increased carbon storage in soils.
7. Converting biomass to recalcitrant biochar, for use as a soil amendment.

All have significant implementation limits, including economic cost, energy requirements, land use, and water use (Smith, 2016).

Carbon offsets can also be generated by projects that avoid emissions or absorb/sequester CO_2, or any of the other main GHGs. Projects include renewable power, energy efficiency, fuel switching (e.g., from oil to natural gas), reforestation, or destruction of GHGs (e.g., methane, HFC23) (Ceppi, 2006). The quality of some of these offsets (which target avoided emissions instead of recapturing and sequestering CO_2 directly) rests on their ability to generate real emissions reductions. For example, company A may pay for company B to switch fuel to gain offset credits to compensate for company A's residual emissions. This results in emissions reduction overall: the sum of A's and B's emissions has reduced compared to using no offset. However, A loses control over its ability to reduce its own net emissions. If B generates emissions anyway, it is difficult to know how much was really reduced on A's behalf. The net "value" of the deemed offset is clearly reduced. While the market rightly includes these as deemed offsets, careful accounting, and monitoring to determine the extent that real reductions have occurred, is essential for such schemes.

In the voluntary sector, offsets are generally sourced from smaller projects located in developing countries. This is primarily for two reasons. First, small-scale projects typically benefit local communities providing sustainable development or social benefits. Second, usually, smaller projects are less economically attractive for the compliance market, due to the high transaction costs involved in developing these projects under compliance market rules. In the voluntary market, the burdens of certification are often lower, making them a viable source of credits (Ceppi, 2006).

3.1 Climate Science Concerns

From a physical climate perspective, there are potential concerns around different offset types.

The Kyoto Protocol established legally binding targets for developed world countries to reduce GHG emissions. Countries could either reduce emissions or use the Clean Development Mechanism (CDM), Joint Implementation (JI), or Emissions Trading. Parties with legally binding targets can trade carbon credits (Ceppi, 2006; Vrolijk & Phillips, 2013). However, realistic pricing has been a problem. In 2008, the price of carbon credits fell from around €27 per tonne to €4–5 per tonne, reaching nearly zero by 2013 (Stephan et al., 2014). Despite measures taken, credits still traded at around €4–7 per tonne in 2014 (European Commission, 2015). If such schemes do not provide meaningful emissions pricing, this throws their value into doubt, especially if prices do not reflect the cost of physical removal or reductions. A further problem is that CDM carbon credits can finance fossil fuel installations in the global south, on the basis that the technology subsidized has lower emissions than some hypothetical alternative (Shue, 2014).

Nature-based solutions (NbS) offsetting includes afforestation (restoring existing forests to maximum potential), reforestation (tree planting, including "plantation" forests), and schemes that increase soil CO_2 absorption (Bossio et al., 2020). The stored carbon could be released though fire, wind, pests, disease, or human interventions, providing only temporary climate mitigation (Murray et al., 2012). Climate change would alter the potential tree coverage from NbS. Forestry solutions also take time. A tree can take 20 years to capture the amount of CO_2 that a carbon-offset scheme promises (Rathi, 2019).

CO_2 can be extracted from the atmosphere and stored underground, for example, by pumping it into oil wells (Norwegian Petroleum, 2021). Such carbon capture and storage (CCS) can involve either DAC, or else capture at source from an industrial facility—say from exhaust flue gases. In DAC, air flows over a chemical sorbent which removes CO_2, and the resulting concentrated CO_2 is injected deep underground (Tavoni & Socolow, 2013). Many CCS projects involve separating a stream of CO_2 from a large source (e.g., power plant, cement factory) to reduce emissions. Both technologies collect CO_2, which must be stored.

Bioenergy, combined with carbon capture and storage (BECCS), can provide energy while also potentially removing CO_2 from the atmosphere (Gilbert & Sovacool, 2015). Crops draw CO_2 from the atmosphere, which are burned in a power station, with CO_2 emissions captured and stored underground[1] (Tavoni & Socolow, 2013; Williamson, 2016). BECCS power generation can help offset the additional costs (Sanchez et al., 2015). Carbon is assumed to be fully absorbed during biomass

[1] https://www.smithschool.ox.ac.uk/publications/reports/Oxford-Offsetting-Principles-2020.pdf

growth, captured before or after combustion, and stored underground indefinitely. Despite the prevalence of BECCS in emission scenarios, the UK Parliamentary Office of Science and Technology mentions only five facilities globally that capture less than 1% of the lower range estimates of BECCS potential (POST, 2020).

Methane is a potent GHG with a short lifetime (around 12 years). CO_2 is much less potent in terms of its radiative perturbation but has a much longer atmospheric residence time (centuries to millennia). Conversion between different GHGs should be in "best-equivalent" terms following the "do no harm" principles of Rayer et al. (2021). Burning the methane removes the short-term temperature response otherwise caused by the methane emission before it is broken down into CO_2. However, such offsets should be assessed on the merits of physically accurate conversion, moving away from the current common practice based on GWP100.

Similar "capture and combustion" approaches can be taken with the GHG HFC23 (CHF_3, trifluoromethane) which is generated as a by-product of the refrigerant HCFC22 (CHF_2Cl, chlorodifluoromethane) (McCulloch, 2004). Again, these should be assessed based on "best-equivalent" terms following the "do no harm" principles of Rayer et al. (2021). HFC23 elimination projects created a perverse financial incentive to overproduce HCFC22, resulting in the environmental NGO Sandbag[2] recommending prohibiting them and encouraging investment in projects hosted by least developed countries (Stephan et al., 2014). Consequently, we do not rate them.

3.2 Carbon Storage: Hard Versus Soft

Some offsets remove GHGs from the atmosphere, that is, are a "sink" while others are "deemed" removals (Rayer et al., 2021). "Sinks" are any offsetting schemes that result in the storage of GHGs including GHG removals from industrial exhaust gases. For sinks the question is how

[2] https://sandbag.be/

robustly the carbon removed from the atmosphere is stored (Allen et al., 2020).

Rayer et al. (2021) discuss the concept of "hard" versus "soft" offsets.[3] Most commercially available offsets are "soft offsets"—offsets in which emissions are netted against an avoided emission or a natural carbon sink with a short or uncertain degree of permanence (Allen et al., 2020). Hard offsets are, therefore, lower risk than soft offsets.

4 Designing the Ratings Framework

In terms of physical long-term climate risks, offset schemes vary considerably. Not all are of equal merit. The threat posed by AGW is sufficiently severe, it is therefore crucial to appreciate which types of offsetting schemes prove most reliable. Otherwise, offsetting may be carried out in good faith, but fail to deliver, while creating a false sense that AGW is being adequately addressed. Thus, offset schemes differ in terms of their climate risk.

Our framework focuses on climate science requirements. It is intended to be sufficiently flexible that it could be extended to consider other aspects of offsetting, such as economic or social benefits, or other risks. A consistent framework that assesses offset schemes independently against aspects such as long-term climate benefits, social benefits, economic benefits, and so on, helps decision-makers to better prioritize the necessary trade-offs.

For our ratings framework, we identify two stages:

1. *Preconditions*. For an offset to be rated, the initial requirements must be met. These include good practice and transparency criteria, to ensure that a scheme is as described, to avoid elementary design errors, and counter fraudulent schemes.
2. *Core rating methodology*. For schemes that meet the necessary preconditions, the core rating uses selected criteria to assign a risk grade for the quality of offset.

[3] http://www.netzero.org.uk/negative-emissions-and-offsetting

The preconditions include yes/no requirements, a “tick list,” and enhanced reporting. Offsets should meet the recommendations for existing offset standards and reporting requirements covered in Rayer et al. (2021).

We consider, in physical climate terms, the risk of an offsetting scheme failing to deliver the intended results. Rayer et al. (2021) identify key issues including comparing reductions and removals of atmospheric CO_2 as well as economic stimuli to adopt more efficient technologies to capture and store CO_2. These do not have equivalent long-term climate risk. Some offset types raise additional concerns. For example, if CO_2 is captured, it must be stored, but if CO_2 is not emitted, this need does not arise.

We address offset scheme failure risk using a scoring approach; a higher score denotes a higher failure risk. Scores are assigned with equal weighting, as we feel that any source of risk could cause an offset scheme to fail. Where schemes employ multiple approaches, we assess overall “risk,” which may arise from several sources.

As our framework addresses climate *risk*, we have assigned the resulting grades in a similar manner to those used for bond credit ratings (see, e.g., Choudhry [2010]). Thus, the lowest climate risk (best) offsets are denoted AA and the highest risk (worst) offsets rated D.

5 Climate-rating Offsetting Types

To be considered for a grade under our rating system, an offset must first meet the preconditions before examining the climate risks.

5.1 Prerequisites for an Offset to Be Climate-Risk Rated

For an offset to achieve a climate-risk rating, it must meet necessary preconditions. These baseline requirements ensure that the offset is likely to meet basic requirements and be “as described.”

As preconditions for an offset to be climate-risk rated, following Rayer et al. (2021), we require:

1. The organization state whether it is using offsetting:
   a. To address residual emissions as it already considers its emissions minimal.
   b. As a practical temporary measure, to mitigate the worst effects of emissions while a strategy to transition to lower GHG emissions is implemented.
2. The organization to state:
   a. Whether they are targeting carbon-neutrality or net-zero.
   b. Emissions of each individual GHG where known. If quantities of emissions are obtained from external parties, and known only in CO_2-equivalent terms, these should be listed separately along with the metric used (if known).
   c. Aggregated CO_2-equivalent emissions and the metric used for conversion. We recommend that metrics for conversion between different GHGs should be in "best-equivalent" terms following the "do no harm" principles in Rayer et al. (2021).
   d. The individual and aggregate CO_2 emissions in "best-equivalent" terms following the "do no harm" principles in Rayer et al. (2021).
   e. The scopes of emissions included following the GHG Protocol. All scopes of emissions should be covered.
   f. Whether each offset used is a "deemed offset" or a "sink."
   g. How each offset used is based on existing proven technologies.
3. How offsets meet existing standards including for verification, as described in Sect. 5.1.1.
4. For offsets which are "sinks," the type of storage with an indication of the expected lifetime it is expected to provide robust storage for.

5.1.1 Existing Offset Standards

All offsets should meet minimum audit and verification standards. Following Allen et al. (2020), Broekhoff et al. (2019), Ceppi (2006), Gillenwater (2012), and summarized in Rayer et al. (2021), these include:

- Avoid forward crediting
- Be complete and accurate
- Allowance for “leakage” in emissions
- Using conservative estimates
- Sound quantification methodologies
- Reductions independently verified
- Permanent reductions
- Avoid double counting
- Genuinely additional to present activity
- Third party audited

5.2 Climate Offsetting Requirements

For the climate-based rating system, we consider the risk of the offsetting scheme failing to deliver the intended results.

An offsetting type might, in principle, be highly effective at addressing physical climate requirements. However, there is a risk that it may fail to deliver its intended benefit. It may have no direct physical effect on the level of CO_2 or other GHGs in the atmosphere (direct physical consequence risk); anticipated technologies may fail to materialize (technological risk); any GHG storage required may be insufficiently robust (storage risk); monocultures may be vulnerable to disease (biodiversity risk); or it may pose a high risk of moral hazard. Furthermore, the quality of the offset may be poor or incapable of verification (quality risk). We consider the likely risks associated with each type of offsetting, emphasizing the climate science. In climate terms, lower-risk outcomes are more likely to deliver the required offset and, as such, are preferred. We do not necessarily regard this list as exhaustive, although we believe it captures many primary offset risks.

5.2.1 Offset Climate Risks

We summarize our definitions of the different elements of climate risks in Table 8.1, with further discussion below. We only identify six different types of climate risk and do not regard our list as necessarily exhaustive. However, it serves to illustrate how different types of offsets carry different climate risks and is capable of ready extension to cover a wider variety of risks. We identify risks as either "low," "medium," or "high" scored on a 1–3 scale. Different types of risks are rated equally, with higher risks denoted by a higher score.

Direct physical risk considers whether the offset in question directly removes GHGs from the atmosphere or causes them not to be emitted. As intermediate risks we identify offsets that may be vulnerable to miscalculation as to their benefit. For example, reforestation schemes may have uncertain sequestration rates, or metrics, such as global warming potential (GWP), used to convert between different GHGs may be subject to inaccuracies.

Proven, existing, and basic technologies are more likely to be able to deliver the required benefits. Speculative technologies are riskier and may fail to deliver. Even proven, but advanced, technologies are less reliable than simpler approaches. Approaches such as growing trees have minimal technological requirements. Technologies that are demonstrably feasible, but not yet implemented at scale, are regarded as high risk. These include DAC and carbon-positive cement. For BECCS, the necessary hard carbon storage is unproven at scale resulting in a high technology risk. On the other hand, natural weathering processes that result in carbon being stored in rock provides hard storage in a low-technology form.

Offsets that capture GHGs, either at source, or from the atmosphere, require robust storage of the emissions captured. Such storage must be robust on geological timescales (so-called hard storage is required). Hard storage offsets are lower risk than "soft" storage. Offsets that reduce emissions are low risk in this context. As no storage is required, there is no risk of later emission from GHG reservoirs. We regard soft storage as high risk, and this could include many NbS, as, for example, the forestry schemes involved could be vulnerable to later human intervention (within geological timescales). We rate schemes which prevent emissions by protection of vulnerable reservoirs according to the vulnerability of the reservoir.

Future research may result in reclassification of risks. For example, for schemes that pump liquid CO_2 into disused oil and gas wells, certain

Table 8.1 Summary of climate risk categorization with examples

Risk	Low	Medium	High
Direct physical risk	Direct physical impact on atmospheric GHGs either by reduction in emissions or by removal.	As low, but where the offset benefit is difficult to quantify or requires use of metrics that could be subject to error.	No direct physical impact on atmospheric GHGs either by reduction in emissions or by removal.
Technology risk	Existing proven technologies at scale. Can include low-tech and natural solutions.	Advanced, proven technologies that may be less reliable than simpler approaches. Quota schemes.	Technologies that are shown to be feasible but have not been used at scale.
Storage risk	Proven hard storage on geological timescales, or offsets that reduce or prevent emissions.	Hard storage solutions that show potential but still subject to research. Quota schemes.	Storage that is readily vulnerable to human intervention or impacts from on-going climate change.
Biodiversity risk	Offsets which enhance biodiversity or which have no harmful effects on biodiversity.	Schemes which may have indirect unproven harmful effects on biodiversity. Quota schemes.	Schemes using monocultures, increasing risk, or which are likely to have direct harmful effects on biodiversity.
Risk from moral hazard	Offsets which promote immediate action.	Hard storage in geological strata. Methane burning.	Strategies which delay action or transfer risks to another party (or future generations). Quota schemes.
Quality risk	Following Broekhoff et al. (2019) with the modifications described in the main text.		

aspects of this technology are unproven from a climate risk perspective. While the technology to pump liquid CO_2 into disused oil and gas wells is established, the understanding of how to ensure it remains over geological periods is less certain, as is the ability to verify the robustness of the storage. As a result, this form of hard storage carries a high technology risk, and we consider it medium storage risk to recognize its potential.

In terms of storage and other risks, certain offsets (such as quota schemes) are challenging to classify. The economic stimulus they generate to address emissions could result in reductions in emissions or use of other higher risk offset types. Therefore, we rate such schemes as "medium" risk.

Ecosystems with higher biodiversity are likely to be more resilient. Techniques that switch between fossil fuels we regard as having high biodiversity risk as they still permit fossil fuel combustion with resulting ecological damage. While fuel switching may not carry a direct biodiversity risk, there is proven risk, as it does not eliminate fossil fuel CO_2 emissions. The resulting failure to stop AGW carries significant biodiversity risk, which we rate as high. We regard schemes which are likely to require large land areas and do not provide obvious biodiversity benefits as medium biodiversity risk.

A further risk criterion is moral hazard (Jebari et al., 2021). Moral hazard occurs when an entity has no incentive to control a risk because the consequences are borne by another party. Examples include:

- Delaying reductions in GHG production in the hope that new technologies solve the problems associated with global warming or offsetting.
- Offsets based on technology that is speculative or unproven at scale can disincentivize action. Thus, any offset with high technological risk also carries high moral hazard, until it is proven at scale. Similarly, offsets with "medium" technological risk are treated as at least medium moral hazard.
- Use of offsetting to maintain social licence, to continue business as usual, or when the offsets are unlikely to address the scale of emissions involved.
- Fuel switching from coal or oil to gas continues reliance on fossil fuels.
- Payment to preserve fossil fuel reserves or protect forests could imply an element of coercion.
- Quota schemes which appear to be subject to verification problems and appropriate pricing. They could be used as an excuse to delay

action. We acknowledge that if proven effective at promoting meaningful emissions reduction, this view could be revised.

Some types of offsetting may carry more moral hazard than others, and considerations can be nuanced. For example, does pumping CO_2 into oil wells provide a role for fossil fuel companies and provide societal legitimacy for fossil fuels delaying emissions reductions? Alternatively, is it a worthwhile use of existing exhausted oil wells and a constructive use of current technology and skills? The fossil fuel industry knows how to safely extract (and therefore reinject) gases from oil and gas wells. As a result, we rate such CCS as "medium" moral hazard.

We adopt Broekhoff et al.'s (2019) quality risk. Some offset schemes are much more vulnerable to quality-control issues than others. For example, issues of quality control for the preservation of fossil fuel reserves in perpetuity or protection of forests would be very challenging. Moving beyond Broekhoff et al. (2019) regarding our classifications for energy efficiency, techniques using basic or established technology, and renewable energy, we have improved by one risk level as these are becoming mainstream. From a climate science perspective, we regard quota systems as high risk in quality-control terms.

As elements of the risk allocation process are judgemental, we have rescaled the resulting risk scores on a 1–100 scale and report only risk "ratings." We follow the approach used in financial markets for "credit risk" to assign the climate risk of different offset types. Therefore, offsets judged to have the lowest (best) climate risk are "AA-rated," and the highest (worst) climate risk offsets are "D-rated." Limiting the parallel with bond credit risks, we do not seek to subcategorize the grades beyond "A" and "AA," "B" and "BB," and so on, as we do not regard the concept as sufficiently well defined at present. We rate offset schemes that fail to meet the preconditions above as "D," as there is little reassurance that basic quality requirements would have been met.

The resulting climate offset grades are listed in Table 8.2.

Table 8.2 Offset climate-risk ratings

Emissions reduction due to superior basic or established tech.	AA
Investment in renewable energy low-emission energy sources to displace fossil energy sources (wind, solar).	AA
Burning methane from landfill to generate CO_2 or else flaring (the controlled burning of natural gas) during fossil fuel extraction.	BB
Payments to preserve fossil fuel reserves underground.	BB
Natural process that absorbs CO_2 resulting in hard carbon storage.	BB
Afforestation: restore existing forests to maximum potential. More likely to be biodiverse robust ecosystem.	B
Emissions reduction due to superior speculative tech.	CC
Switching fuel from oil to natural gas, coal to natural gas, and so on.	CC
Natural process that absorbs CO_2 resulting in soft carbon storage.	CC
Tech capturing CO_2 at source in industrial plant with soft storage.	CC
Tech removing CO_2 directly from atmosphere with hard storage.	CC
Crop growing and harvesting treatment resulting in soft carbon storage.	CC
Tech capturing CO_2 at source in industrial plant with hard storage.	CC
Payments to preserve forest.	CC
Reforestation, danger of plantation, difficulty in creating biodiverse robust ecosystem.	CC
Tech removing CO_2 directly from atmosphere with soft storage.	C
Building using cement that is carbon absorbing over lifecycle.	C
Arbitrary emissions quota that allows offsets to be purchased for a price. Amounts agreed by treaty or other means as being “acceptable” levels of emissions.	DD
Crop growing and harvesting treatment resulting in hard carbon storage.	DD
Fails to meet preconditions.	D

6 Case Studies

We illustrate how the offset climate-risk ratings might be applied, in the context of the carbon-neutrality standard (PAS 2060), and a scheme loosely based on that proposed by a large fossil fuel extraction firm. These examples are chosen to illustrate the current climate challenges raised by offsets.

6.1 PAS 2060

We consider the British Standards Institution’s carbon-neutrality PAS 2060 standard (BSI, 2014) in the context of our climate-risk ratings. As

PAS 2060 is a net-zero standard, the climate ratings apply to the offset choices used within PAS 2060.

6.1.1 Preconditions

Much of the reporting required to meet PAS 2060 covers requirements for the necessary climate-rating preconditions. We do not attempt to enumerate these in detail but instead draw attention to salient points. For readers interested in using our climate ratings within the PAS 2060 framework, it would be necessary to consider all our climate-rating requirements in detail.

We note that despite its name, PAS 2060 is a net-zero standard as it covers all GHGs, not just CO_2, which is a necessary reporting precondition. We would also recommend that the conversion metric between different GHGs follow CO_2be or CO_2fe rather than be based on GWP100 (used for CO_2e), to better capture the physical climate impact of different pollutants. The climate rating would also require the types of offsets to be stated.

6.1.2 Climate Rating

Assuming the preconditions and minimum standards are met, PAS 2060 permits a range of offset types to be used. This includes a wide range of possibilities, from quota systems (rated DD), to those based on renewable energy (grade AA). By using climate ratings as well as PAS 2060, this would encourage the use of lower-risk climate offset choices.

6.1.3 Discussion

The climate-risk ratings we propose can sit readily within the PAS 2060 framework. A focus on climate risk would likely result in an enhancement of the quality of offsetting and net-zero achievement above what would have been met by meeting PAS 2060 alone. For example, even if the offsets used were based on quotas (rated DD), to meet this grade enhancements would have been required, including more complete reporting, more physically representative conversions between different GHGs, and better clarity on the likely climate benefit achieved by the offsetting type chosen.

6.2 Fossil Fuel Extraction Firm

We loosely base our example on Royal Dutch Shell's recent forestry programme to offset emissions (Hook, 2019). Shell planned to spend $300m over three years on carbon storage projects, including forests in the Netherlands and Spain, and started offering motorists the option of purchasing carbon offsets when buying fuel (Hook, 2019). Shell recently adopted a target of cutting its net carbon footprint by 2–3% in 2021, compared with 2016 levels, including emissions from the products it sells. The scheme may increase the risk of moral hazard, as it allows motorists to pay a fuel surcharge to drive "carbon-neutral," suggesting that emissions reduction is not required and potentially locking in further emissions (Rathi, 2019).

6.2.1 Preconditions

While little detail is given, it would be necessary for any offsetting to meet the prerequisites in Sect. 5.1 and existing offset standards. Areas of concern might include:

- How use of offsetting fits in with a strategy to transition to lower emissions.
- How to report and cover all three scopes of emissions. It is not adequate to extract fossil fuels in a carbon-neutral or net-zero manner.
- The robustness of carbon storage.
- The moral hazard that such schemes might promote continued reliance on fossil fuels.

While fossil fuel extraction firms are notable for their CO_2 emissions, petrochemicals result in emissions of other GHGs. It would, therefore, be very important for all GHGs to be reported and accounted for, with the use of the most climate-relevant conversion metrics between GHGs.

6.2.2 Climate Rating

As described, the scheme is based on a forestry programme. Although we have not stated whether reforestation or afforestation, such schemes are rated as between B and CC. If the scale necessary were to result in monoculture plantation schemes, biodiversity risks increase (rated CC). Forests also are not robust carbon stores on geological timeframes. In this context, it is worth noting that even in a net-zero state, the activities of a fossil fuel extraction firm would represent conversation of geologically stable and robust carbon reserves in the lithosphere, to vulnerable tree-based repositories, representing an extremely significant increase in climate risk.

6.2.3 Discussion

It is challenging for fossil extraction firms to use offsetting to become carbon-neutral or net-zero at necessary scale. However, our framework allows the climate risks of such offsetting to be assessed, even if an organization's activities are not net-zero.

In terms of offset options available to fossil fuel extraction companies, the climate-risk ratings immediately identify that it would be preferable to restore existing forests to their maximum potential (rated B) rather than preserving existing forests or plantations (both rated CC). Furthermore, if the motive for such schemes were deemed to imply high moral hazard, they might be regarded as only DD rated.

Fossil fuel extraction companies also have lower climate-risk offset options available to them, through preserving fossil fuel reserves in the lithosphere (rated BB). However, such an approach would have potential to have moral hazard and high quality-control risk concerns.

Other possibilities for fossil energy firms would be significant development of renewable energy technology, to allow them to displace their use of fossil-derived energy (rated AA). Significant investment in capture technology (such as capture at industrial plant or DAC) with associated hard storage could also bring these technologies to the point where, by reduction of the technological risks, storage risks, and associated moral hazard resulting from dependence on unproven technologies, the risk ratings associated with these offset approaches are improved from CC to BB, or better.

7 Conclusion

To stabilize global warming within the 1.5–2.0 °C Paris Agreement goal, greenhouse gas (GHG) emissions need to reach net-zero. Offsetting is required for net-zero emissions (emissions minus offsets). Offset schemes differ widely in their capacity to mitigate anthropogenic global warming (AGW).

We propose a framework for rating different offset types based on their climate risk, moving beyond the usual criteria of verification, audit, and additionality. Some offsets provide little more than economic nudges towards emissions reduction. Climate offsetting requirements are more exacting. The proposed framework rates offsets from lowest climate risk (AA) to greatest climate risk (D).

We apply our offset ratings to schemes based on one proposed by a major oil company, and the PAS 2060 carbon-neutrality standard. Using ratings helps identify climate risk and propose necessary steps to reduce problems associated with specific approaches. Following Jebari et al. (2021), an appropriate response to climate risk is to consider costs and benefits of a range of offset strategies.

The ratings framework helps identify specific actions that could be taken to reduce climate risks. Ultimately, to stabilize global warming, the highest-rated offsets under the proposed framework are required.

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9

An Investigation of Climate Change Within the Framework of a Schumpeterian Economic Growth Model

Guller Sahin and Fatih Volkan Ayyildiz

1 Introduction

The effects of global climate changes are widely observed. These related changes are short-term events, such as changes in the precipitation trends, floods, hurricanes, and heat waves. They can also be long-term events, which include rising sea levels, droughts, and seasonal changes. These long- and short-term changes are the direct results of climate change, and the potential increase in short-term events is directly related to long-term changes. Climate change also has an indirect impact on disease, water

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resources, and food availability (Carman, 2020; Intergovernmental Panel on Climate Change, 2014).

Certain developments such as a change in the production and consumption patterns of societies, population increases, urbanization, and the rapid industrialization process that followed the Industrial Revolution have increased demand for energy. Economic growth became the primary goal of countries such as China, the US, and Japan, and especially after the Second World War, energy demand has increased. Human activity, such as an increased use of fossil fuels to meet this emerging energy demand, changes in land use, and deforestation, has destroyed the environment, causing a change in the composition of greenhouse gases (GHGs). Gases that create the GHG effect have accumulated in the atmosphere, which has caused a rapid increase in the natural greenhouse effect. An increase in the number of GHGs has increased the prevalence and effects of meteorological events, such as severe hurricanes, floods, and droughts. It has also raised sea and ocean levels and caused the melting of snow and icebergs (Başoğlu, 2014).

It is foreseen that global policies and regulation will increase GHGs, and by the end of the twenty-first century, these are expected to have caused an overall 3.0 °C increase in global climate. In the absence of appropriate policies, this rise could exceed 4.1 °C–4.8 °C. According to an optimistic policies scenario of December 2019, there is a 66% probability of an overheating of about 2.8 °C when ongoing planned programs and policies, which have yet to be implemented, are combined with the commitments and targets that governments have already made (United Nations Environment Programme, 2020).

Climate change still has serious effects on the daily lives of people by generating environmental, social, political, and economic multi-directional changes. It is crucial to know what can be done to positively respond to climate change. This research, based on the explanations above, studies climate change within the framework of economic growth. It explores the adaptation process to climate change on the basis of entrepreneurship and innovation in the axis of the Schumpeterian Economic Growth Model.

A large part of the literature on this topic evaluates issues of innovation, entrepreneurship, and environmental load separately. This study aims to combine the three elements by studying them concurrently. Specifically, the chapter contributes to the available literature by adding entrepreneurship and innovation factors to the production function in order to calculate the environmental load that reflects an economic value.

We present our research as follows. In Sect. 2, which follows the introduction, we first focus on the extent of climate change, and in Sect. 3, we explain the relationship between economic growth and climate change. We review related literature in Sect. 4, and information regarding case studies is presented in the Sect. 5. We conclude by presenting the results of our study and exploring their future implications.

2 Extent of Climate Change

The root causes of climate change within the last fifty years are human activity and fossil fuels. According to data collected in 2017, the amount of human-induced GHGs equals 50,820 million metric tons of carbon dioxide (CO_2). This is a record amount in humanity's history and has caused unprecedented concentrations of atmospheric CO_2, methane, and nitrous oxide over the past 800,000 years (United Nations Environment Programme, 2020; United States Global Change Research Program, 2017).

We are witness to the warmest period in the history of modern civilization. As can be seen in Fig. 9.1, global annual average temperatures increased by an additional 0.65 °C in the 1986–2016 period compared to 1901–1960. Global temperature increased by approximately 1.0 °C between the years 1901 and 2016. The human contribution to the increase in global average temperature of the 1951–2010 period is estimated as being 0.6 °C–0.8 °C; the central estimate of 0.65 ° C of observed global warming is at this range. The ratio of the human contribution to climate change in the 1951–2010 period is 92%–123% (IPCC, 2014; USGCRP, 2017). Data from the National Aeronautics and Space Administration (NASA) in 2020 shows that nineteen of the hottest twenty years occurred after 2001, with the exception of 1984, which preceded this period. The year 2016 was the hottest on record. Global average sea levels have risen by 7–8 inches since 1900, with almost half of

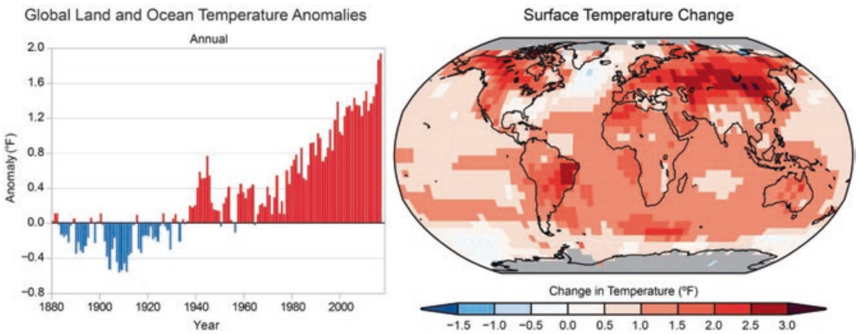

Fig. 9.1 Global average temperature anomalies and surface temperature change: 1880–2020. (Source: USGCRP, 2017)

this increase occurring after 1993. Sea levels will continue to rise by a few inches in the next fifteen years and by 1–4 inches by 2100 (NASA, 2020).

The extent of climate change beyond the next few decades will be based on the amount of GHGs produced (especially CO_2) and the sensitivity of climate to related emissions. The annual average global temperature increase can be limited to 2 °C or less with significant decreases in GHG emissions. However, it is foreseen that increases in annual average global warming will exceed 5 °C by the end of the twenty-first century if emissions are not greatly reduced (USGCRP, 2018).

Figure 9.2 illustrates the observed monthly global mean surface temperature change and estimated human-induced global warming. The orange dashed arrow and horizontal orange error bar, respectively, show the central estimate and possible time range when reaching 1.5 °C in the case of a continuing available warm-up speed. The gray area on the right represents the possible range of warming reactions that are computed by a simple climate model, based on stylized pathways, where CO_2 emissions reach zero by falling to a straight line in 2055 from 2020. The radiation stress (forcing) without CO_2 increases until 2030 and then decreases. We can see in the blue area that faster CO_2 emissions reductions decrease cumulative CO_2 emissions, which reach zero by 2040. The purple area shows that CO_2 emissions are at zero in 2055 and that forcing without CO_2 remains stable after 2030. Lines at the right of the figure represent the possible ranges of vertical error bars.

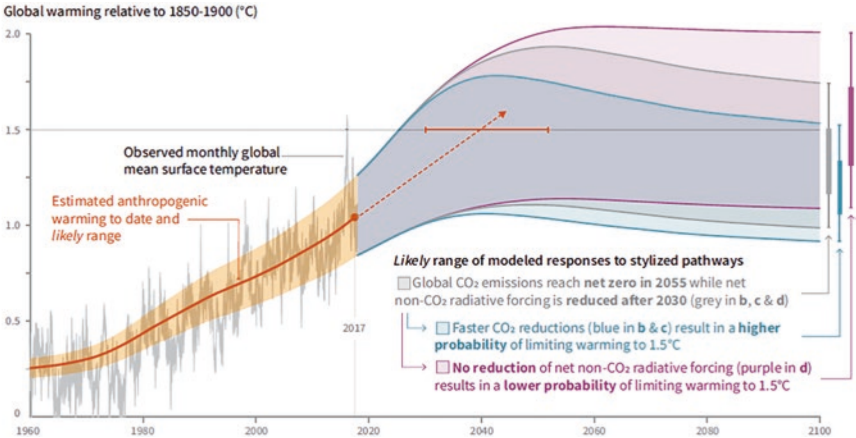

Fig. 9.2 Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways. (Source: IPCC, 2018) (Color figure online)

Climate-related risks for people and natural systems are based on the size and ratio of global warming, geographical position, development and vulnerability levels, choice of adaptation and mitigation options, and their respective implementation. The potential effects and related risks that are created by a change in the range of 1.5 °C and 1.5 °C–2 °C in global climate are as follows (IPCC, 2018):

- Remarkable differences, such as changes in average temperatures in many land and ocean regions and other regional climate characteristics, extreme temperatures in many residential areas, heavy rain in a few areas, and drought and rainfall probability in certain areas will be observed.
- The global average increase in sea level will be about 0.1 meters higher by the year 2100.
- Biological diversity will decrease as a result of the extinction of land and sea species, the effects of which will be significant to ecosystems.
- The acidity of oceans will increase, and a decrease in oxygen levels will bottom out along with temperature increases in the oceans.

- Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth will increase.
- The adaptation capacity for people and natural systems and the losses associated with it will be greater.
- The effects of climate change on sustainable development, poverty eradication, and reduction of inequalities will be more pronounced.

According to the United Nations Intergovernmental Panel on Climate Change's (IPCC) 2018 report, green areas between one-fifth and one-twelfth of the planet will become deserts, 99% of coral will be destroyed, 450 million people will be affected by increased temperatures, and hundreds of millions of people will fall below the poverty line as a result of a 2 °C increase in global temperature. Moreover, there will be food and water shortage crises due to rising sea levels polluting agricultural land and water resources. There will also be desertification in areas where global warming is more significantly pronounced (IPCC, 2018).

3 Economic Growth and Climate Change

Environmental and economic values are evaluated as contradictory to each other in discussions regarding climate change. It is thought that there is a need to make a choice between providing economic growth and protecting nature, and that fewer emissions entail higher costs (Doganova & Karnøe, 2015). According to environmental economics, environmental degradation is caused by a market failure, while the entrepreneurship literature argues that opportunity lies in the nature of the failure (Dean & McMullen, 2007). Efforts to reconcile environmental and economic values are the result of these contradictions.

3.1 The Schumpeterian Economic Growth Model

Joseph Schumpeter (1942) examines innovation and technology based on Marx's Plus Value Hypothesis within the frame of creative destruction thesis. The creative destruction process is defined as those companies that use new products, new production structures, and new technology, and which outcompete companies that use old products, old production structures, and old technologies. This relational process emerges as innovation meets the market. The engines of economic development are research and development (R&D) and innovation. It is possible for companies to organize production activities and profit sustainably by adaptiveness (Çelik, 2020; Genç & Tandoğan, 2020; Lundvall, 2007).

Schumpeter, in his entrepreneurship theory, defines capitalism as a production flow that is completely stable and which reproduces itself within a circular flow which never changes or increases in its wealth creation. Profit emerges when this flow is interrupted and diverges from the route of a static economy. A change in technological and organizational innovation involved in the flow can cause its deviation. In other words, innovation is directed by monopoly profit expectation, and profit can be achieved by reducing the cost of producing a product or if a new product can be created. In this way, an income flow is independent of the contribution of labor and capital owners (Acemoglu, 2009; Büyükılgaz, 2020).

3.2 Economic Effects of Climate Change

There are two risks in determining the cost of natural disasters in climate change analysis models. The first is underestimating the immediate effects of losing assets from disasters on the economic output flow in the aggregate production function. The other is that the capital stock in the production function causes the rebuilding capacity of output impact of natural disasters (as a critical determinant of welfare losses) to be ignored, which also causes a decrease in the estimation of the output impact of natural disasters (Hallegatte & Vogt-Schilb, 2016).

As can be seen in Fig. 9.3, the repercussions of climate change include fluctuating temperature increases and precipitation regimes. This situation causes huge economic losses by increasing the frequency and severity of climate-related natural disasters, such as extreme droughts, floods, and storms. Almost 87% of recorded natural disasters in the 1980–2012 period are climate related. Of these disasters 44% were storm, 41% were floods, and 15% were droughts. The economic losses associated with

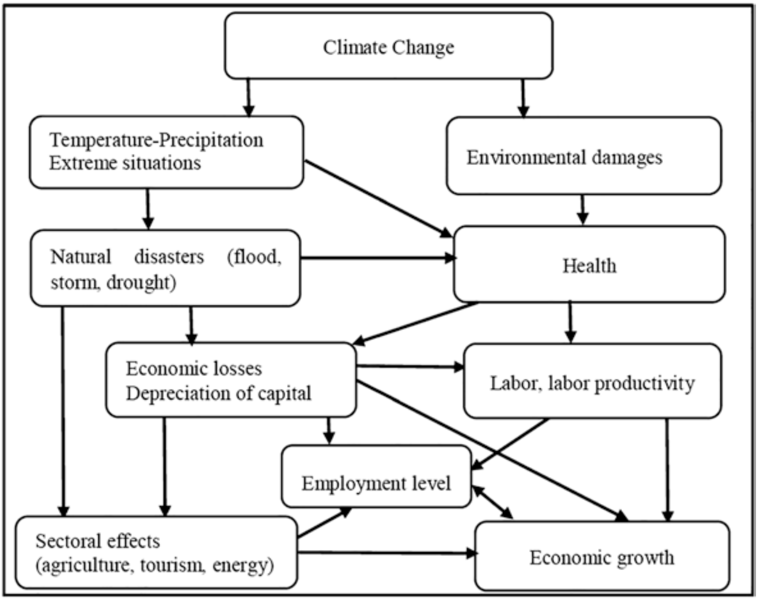

Fig. 9.3 Economic effects of climate change. (Note. The original version of the text in the figure is in Turkish. Source: Başoğlu, 2014)

these disasters, in the related period, reached 2.8 trillion US$ (Başoğlu, 2014). The average estimated global flood losses in 2005 were approximately 6 billion US$. This estimation increases to 52 billion US$ when socio-economic change is considered. This number, along with other damages caused by climate change, is assumed to be the 1 trillion US$ or more per year (Hallegatte et al., 2013).

Climate change is expected to be the stochastic shock that trickles into the productivity of labor, energy efficiency, and company inventories. Accordingly, the Dystopian Schumpeter meeting Keynes (DSK) model shows comprehensive micro- and macroempirical regularities regarding both economic and climatic dynamics (see Fig. 9.4). The model explains frequent and mild climate shocks with low probability, but with extreme climatic events. There are technical changes in both the manufacturing and energy sectors. Innovation determines the cost of the energy that is generated by dirty and clean technologies, the status of which impacts

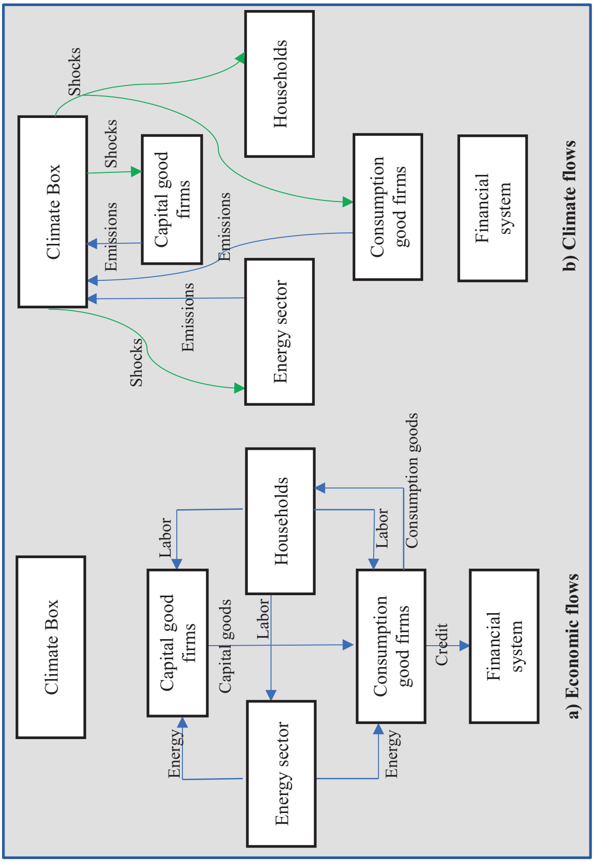

Fig. 9.4 A stylized representation of the DSK model. (Source: Lamperti et al., 2018)

the energy technology production mix and the amount of CO_2 emissions. Structural changes in the economy are closely associated to climatic dynamics. Moreover, climatic shocks affect economic growth, duty cycles, technical change trajectories, GHGs, and global temperatures (Lamperti et al., 2018, 2020). There is an observable cyclical relationship between economic growth and climate.

The annual economic value of world terrestrial ecosystem services equals the annual amount of global GDP. According to World Bank estimations, air pollution causes 5 trillion US$ of lost revenue in health and 225 billion US$ in welfare costs per year. It is foreseen that climate change will decelerate economic growth, complicate the reduction of poverty, further erode food security, prolong current poverty traps, and create new traps in hunger zones, especially in urban areas (UNEP, 2020).

4 Literature Review

The roles of innovation and international information dissemination during economic growth and development processes are inclusively analyzed in Schumpeterian research. Another comprehensive research area is one that scrutinizes the Schumpeterian Innovation and Growth Models. This research focuses considerably on the comparative dimension of the economic growth process across countries in the Schumpeterian literature (Castellacci & Natera, 2016). Studies on climate change are less common in the literature.

There has been a growing interest (e.g., Cohen & Winn, 2007; Dean & McMullen 2007; Riti et al., 2015) in environmental entrepreneurship that pursues profit opportunities that deliver environmental benefits besides the ability (e.g., Dean & McMullen, 2007; Riti et al., 2015) for entrepreneurs to take advantage of opportunities inherent in environmentally relevant market failures. Studies that analyze the effects of entrepreneurial activities on the environment need to consider that related effects vary according to the economic growth levels of the countries in question. Acs et al. (1994) consider entrepreneurship levels, which are generally explained by economic development stages, in situations particular to different countries and periods. Omri (2018) explains that results are responsive to different income groups and sectoral analyses.

A vast majority of studies focusing on the relationship between governmental regulations and strict environmental policies notice a positive correlation between variables. Albrecht (2002) emphasizes that the environmental policy area that strongly increases governmental regulation aims to correct market failure and, accordingly, affects market forces. Albrizio et al. (2017) survey the effects of changes in the frequency of environmental policy in Organisation for Economic Co-operation and Development (OECD) countries on productivity growth at the industrial and company level. They conclude that pressures on environmental policy are associated with a short-term increase in productivity growth in most technologically advanced countries at the industrial level. Chen and Wang (2017) analyze the effect of consumer demand preferences and environmental policies on the environmental investment decision-making processes of companies and the development of environmentally friendly technologies. Their results show that consumers prefer the product price. Indeed, a market-based tool combined with an information-driven tool can promote the development of environmentally friendly technologies, while a market-based tool implemented alone decreases environmental investment. Cohen and Winn (2007) claim that market failure causes environmental degradation and that it also provides significant opportunities to create radical technology and innovative business models. According to Doganova and Karnøe (2015), policymakers and entrepreneurs rely on a combination of technological innovation and market mechanisms to reconcile environmental and economic value on the agricultural sector; they have, however, already attempted various methods of reconciliation. Filatova (2020) summarizes the developmental aspects of legislation governing environmental and entrepreneurial relations in Russia. In this case, there is no legal regulation of environmental entrepreneurship for the regulator. There is a need to consider the priority of environmental organization of economic activities. Low-level development of legislation acts as an external factor which constrains environmental entrepreneurship. Kasim and Mohd Nor (2015) emphasize that company executives and entrepreneurs should apply environmental management practices, such as recycling, water-saving, and energy efficiency management systems to solve environmental problems. Meireles et al. (2016) develop a dynamic general balance growth model by establishing technological change based on inner skills to review the contributions of environmental policies for ecological goods. In the model, the dynamics of the transition are analyzed and it is shown that when green firms and green research are supported by policy and/or dirty activities are taxed, technological progress leads to more ecological product production and improvements in environmental quality.

We see in the existing literature that the majority of studies emphasize a positive relationship between entrepreneurship and environmental quality. In this context, Dean and McMullen (2007) focus on the issue of how entrepreneurial activities can be a solution for environmental problems in global socio-economic systems, and they find that entrepreneurial activities lighten market failures. Demir Uslu et al. (2015) claim that more profit targets and industrialization cause climate change in the developing global economy and that green entrepreneurship provides opportunities for economic agents that are affected by this change. Kimmel and Hull (2012) analyze ecological entrepreneurship as an integrated conservation strategy in terms of both environmental and economic targets. According to them, ecological entrepreneurship supports local economies as much as the environment; in other words, this type of entrepreneurship promotes sustainable development. Lenox and York (2011) pose that environmental entrepreneurship theory has gone beyond the business/environment dilemma and reuses market forces as a solution for environmental degradation. Nakamura and Managi (2020) conclude that there is a U-shaped relationship between entrepreneurship and the marginal cost of CO_2 emissions in economic development; a so-called developed country such as Japan has median marginal CO_2 cost, while countries such as China, with low CO_2 reduction levels, have higher entrepreneurship ratios. They also emphasize the entrepreneurship process, which discusses the central issues of environmental concerns. Shepherd and Patzelt (2011) conclude that increasing entrepreneurial activity does not always increase environmental degradation, as it can also protect ecosystems and be a solution for climate change. York and Venkataraman (2010) offer entrepreneurship as a solution to environmental degradation. According to their research, entrepreneurs contribute to the solution of environmental problems by establishing new products, firms, markets, information resources, and institutions that are more environmentally sustainable.

Offering an example of entrepreneurial activities that increase environmental degradation, Koe et al. (2014) conclude that, since entrepreneurial activities are an accepted reason for environmental degradation, entrepreneurs need to play a part in the management of sustainability issues. Riti et al. (2015) research the causal relationship between entrepreneurship and the environment. Their results show the presence of an environmental Kuznets curve and a long-term relationship between CO_2 emissions per person and entrepreneurship. They observe that entrepreneurship has a negative impact on environmental sustainability. Omri (2018) explains that the contribution of entrepreneurial activities to environmental degradation in the long term is low for high-income countries. Entrepreneurial activities in these countries increase environmental pollution to begin with; however, related activities reduce environmental pollution after a certain period of time. Omri and Afi (2020) explain that types of entrepreneurship increase carbon emissions. Mandatory and informal entrepreneurship, compared to opportunity and formal entrepreneurship, create the biggest contribution to carbon emissions, where government expenditure reduces carbon emissions in models concerned with opportunity and mandatory entrepreneurship. Vivarelli (2013) argues that increasing entrepreneurship can create a perverse effect in both the environment and the economy. Youssef et al. (2018) highlight that formal and informal entrepreneurship decrease the environmental quality in seventeen African countries; however, informal entrepreneurship increases environmental degradation more than formal entrepreneurship. The conclusion to draw from these studies is the significant role of innovation in reaching sustainability.

Ang (2009), who focuses on the innovation factor in environmental degradation, explains that CO_2 emissions in China are negatively associated with technology transfer, research intensity, and the economy's capacity to absorb foreign technology. According to Busch et al. (2018), there is a need for the promotion of innovation in low-carbon technologies, business models, and applications in order to create a low-carbon industrial strategy. There is also a need for activities to manage energy supply as well as energy demand. They offer a strategic target to provide elasticity for systematic change. Corradini et al. (2014) review investment decisions regarding innovation and emissions reduction. Their results reveal that innovative efforts are positively associated with several dissemination effects, which include a reduction of emissions in the sector. They also explain different reactivity powers as well as the special role of technological and economic complementarity. Deleidi et al. (2019) focus on the effects of government expenditure on innovation, innovation on economic growth and the ecosystem, ecological feedback on economic growth, and the expenditure efficiency of government. They observe that the government can succeed in supporting innovation and growth while simultaneously decelerating depletion rates of material and energy reserves, and also by struggling with climate change. Hickel and Kallis (2019) state that despite major technological changes and their increasing impact, revenue growth is not separated from resource demands or emissions generation at a global level.

In their study on environmental degradation's role as an economic output, Althouse et al. (2020) suggest green growth strategies that promote more productive types of economic growth, proposing that there is a need for pricing mechanisms and a demand for Keynesian management applications to solve environmental problems. Hornborg (2009) highlights that, as climate change and environmental degradation worsen, the possibility of additional calls for sustainable investment and green growth to create a zero-sum game is higher, rather than a progressive march toward sustainability and development. Lamperti et al. (2018) report much greater climate damage compared to estimates in computable general equilibrium integrated assessment models. In a recent study, they use a mediator-based integrated assessment model to review the possibility of transitioning to green and sustainable growth in the case of climatic damage (Lamperti et al., 2020). Results show that the economy has a sustainable growth path balance characterized by better macroeconomic performance with a carbon-intensive lock-in. Monasterolo et al. (2019) not only explain climate effects on socio-economic systems, but also explain the need for a new model that includes uncertainty and complexity arising from their reaction. Pollin (2019) confirms that economic growth is an acceptable and desired method of increasing environmental sustainability.

5 Case Study

The model in this study is established within Equation (9.1), by discussing the climate change problem within the framework of the Schumpeterian Economic Growth Model.

5.1 Data and Model

The sample set is composed of countries which emit the most CO_2[1] since it is the dominant factor of the climate change, based on data from 2018 (see Appendix) relating to GHGs. We analyze the output of entrepreneurship and innovation parameters regarding emissions by panel statistics for the 2002–2018 period, in the sample of the US, Germany, Russia, China, India, Japan, and South Korea. We review the model from a perspective that highlights the role of innovation and entrepreneurial activities based on the Schumpeterian type of growth model.

The model below is formulated with reference to studies from Costantini and Monni (2008), Deleidi et al. (2019), Nakamura and Managi (2020), Omri and Afi (2020), Prieger et al. (2016), Youssef et al. (2018):

$$\begin{aligned} CO_{2it} = \partial_0 + \partial_1 GDP_{it} + \partial_2 FCI_{it} + \partial_3 GE_{it} + \partial_4 GS_{it} \\ + \partial_5 TEA_{it} + \partial_6 RD_{it} + \partial_7 PA_{it} + \mu_{it} \end{aligned} \quad (9.1)$$

CO_2, GDP, FCI, GE, GS, TEA, RD, and PA in the model represent the following, respectively: carbon dioxide emissions (million tons), gross domestic product (per capita, PPP, current international $), fixed capital investment (gross, current US$), government expenditure (current US$), genuine savings (GS; adjusted, including particulate emission

[1] The main reason for taking CO_2 data in this research, which focuses on the climate change adaptation process, is that CO_2 emissions are responsible for approximately three quarters of global warming. Atmospheric CO_2 concentration, which is the largest contributor to human-induced global warming, has increased by about 40% during the industrial age. This change has caused increases in global surface temperatures by intensifying the natural GHG effect of the atmosphere and has also caused other widespread changes in the world's climate unprecedented in the history of modern civilization (UNEP, 2020).

damage, current US$), entrepreneurial activities (total early-stage entrepreneurial activity), research-development (transfer), and patent applications (residents). The *RD and PA* variables represent innovation. All the variables are included in the model by logarithmic (*ln*) structure. ∂_0 is the constant parameter, $\partial_1 \ldots\ldots \partial_7$ is the slope parameter, and μ is the error term. The sub-symbol *i* shows the units, and *t* is the time interval of 2002–2018. The CO_2, *GDP*, *FCI*, *GE*, *GS*, *and PA* data is from the World Bank's World Development Indicators (World Bank, 2020), and the *TEA and RD* data is accessed from the Global Entrepreneurship Monitor (2020a, b).

The research hypotheses within the scope of available literature are as follows:

- Hypothesis 1: We expect, within the Schumpeterian Growth Model, that entrepreneurial activity and innovation will improve environmental quality by reducing CO_2 emissions in the long term. Studies conducted by Dean and McMullen (2007), Demir Uslu et al. (2015), Kimmel and Hull (2012), Lenox and York (2011), Nakamura and Managi (2020), Shepherd and Patzelt (2011), and York and Venkataraman (2010) support this hypothesis.
- Hypothesis 2: We estimate that economic growth, fixed capital investment, and public expenditure will decrease environmental degradation by reducing CO_2 emissions in the long term. Studies by Albrecht (2002), Albrizio et al. (2017), Althouse et al. (2020), Busch et al. (2018), Chen and Wang (2017), Cohen and Winn (2007), Corradini et al. (2014), Deleidi et al. (2019), Doganova and Karnøe (2015), Filatova (2020), Hickel and Kallis (2019), Kasim and Mohd Nor (2015), Meireles et al. (2016), and Pollin (2019) provide support for this hypothesis.
- Hypothesis 3: We posit that for estimates, genuine savings have a direct negative impact on CO_2 emissions. Costantini and Monni's methodology (2008) for the GS variable explains that GS is the only macroeconomic sustainability indicator that is computed for a wide range of countries and for a consistent time series.
- Hypothesis 4: We assume that there is a causality relationship that confirms the feedback hypothesis between dependent and independent variables. The study by Riti et al. (2015) produces similar results.

5.2 Empirical Strategy

Estimation procedures of the model within Equation (9.1) are conducted for co-integration and causality analyses in a panel time series. We then perform a two-step empirical methodology toward statistical reliability of the tests in analyses. We then conduct a correlation test between the units in the first stage and apply unit root tests in the second stage.

5.2.1 Cross-sectional Dependence and Panel Unit Root Tests

We use the CD Lagrange multiplier (LM) test, which was developed by Breusch and Pagan (1980), in a matrix with 119 observations ($N = T \times n$) when the time dimension is greater than the number of cross sections ($T > n$). Breusch-Pagan CD_{LM} test findings in Table 9.1 in Appendix show a correlation between units by denying the H_0 hypothesis. There is therefore a need to choose the second-generation panel unit root tests that are used in the case of correlation between units.

The Harris and Tzavalis (1999) and Breitung (2000) panel unit root tests were applied to series with differences from cross-section means to reduce the correlation effect between units. According to stationarity findings in Table 9.1, the CO_2, *GDP*, *FCI*, *GE*, *and PA* variables are taken into the first difference and the *GS*, *TEA*, *and RD* variables are taken into the co-integration model at level values.

5.2.2 Panel Co-integration Test and Long-Term Estimates

We then perform a co-integration analysis for the presence of possible long-term equilibrium relationships between variables after cross-sectional dependence and apply unit root tests. The Westerlund (2007) panel co-integration analysis findings in Table 9.2 in Appendix show that there is a long-term co-integration relationship between variables, based on group (Gt-Ga) and panel (Pt-Pa) average statistics by denying the H_0 hypothesis. In this context, we observe that there is a long-term relationship between CO_2, growth, fixed capital investment, government expenditure, genuine savings, entrepreneurship, R&D, and patent applications.

The Panel Fully Modified Least Squares (FMOLS) heterogeneous parameter findings, in a long-term relationship within a co-integration model (see Table 9.3 in Appendix), confirm that growth, fixed capital investment, R&D, and patent applications increase emissions under statistical significance, which means genuine savings reduce emissions. Entrepreneurial activities are statistically insignificant.

Equation (9.2) is obtained by rearranging the model in Equation (9.1) based on long-term slope parameters:

$$\begin{aligned} CO_{2it} = 0.44GDP_{it} + 0.11FCI_{it} - 0.16GE_{it} \\ - 0.01GS_{it} + 0.03RD_{it} + 0.05PA_{it} \end{aligned} \tag{9.2}$$

According to the estimation findings, while a 1% increase in GDP increases emissions by 0.44%, a 1% increase in fixed capital investment increases emissions by 0.11% and a 1% increase in innovation (R&D and patent applications) increases emissions by 0.08%. A 1% increase in government expenditure reduces emissions by 0.16% and a 1% increase in genuine savings reduces emissions by 0.01%. Within this context, GDP (%0.44) is the variable with greatest impact on emissions, while the variable with least impact is the genuine savings (%0.01). Therefore, for the purpose of adapting to climate change by reducing the CO_2 emissions level, it is thought that it is necessary to focus especially on economic growth in the long term.

5.2.3 Panel Causality Test

The Heterogeneous Panel Causality Test, developed by Dumitrescu and Hurlin (2012), results in the findings in Table 9.4 in Appendix, which show the feedback relationship between emissions and growth, fixed capital investment, government expenditure, genuine savings, and patent applications. We also find there is a one-way causality relationship from R&D and entrepreneurial activities to CO_2 emissions. Therefore, for the purpose of adapting to climate change, considering that the growth, fixed capital investment, government expenditure, genuine savings, entrepreneurial activity, and innovation variables are the cause of CO_2 emissions, policy recommendations regarding the specified parameters should be determined.

6 Conclusion

Schumpeter's opinions on growth are explained by innovation and technological competition concepts. As the entrepreneur is a production factor, it has an important role in the development of the capitalist system. Within this context, as the most important factor in the system, the application of technical advances to production by entrepreneurs is based on the expectation of monopoly profit, so technical progress can be seen.

Promoting entrepreneurship is accepted as a solution for environmental degradation and climate change today, because entrepreneurs evaluate their environmentally friendly goods and services to create a remarkable market potential. Even if green goods and services endeavor to capture demand with high margins at the beginning, it is expected they will increase market share. This assumption is based on the innovation that the focal point of entrepreneurial activity is to take correct market opportunities. Therefore, entrepreneurs who try to develop their market share and domestic market using sustainable production methods to create a positive impact on the environmental load can offer a solution for climate change.

In this study, we analyze the climate change problem within the framework of the Schumpeterian Economic Growth Model for the US, Germany, Russia, China, India, Japan, and South Korea, for the 2002–2018 period. Based on the co-integration results, there is a long-term balance relationship between the variables. As the economic growth, fixed capital investment, and emissions of innovation increase, government expenditure and genuine savings reduce emissions. The causality test results confirm the feedback hypothesis between emissions with economic growth, fixed capital investment, government expenditure, genuine savings, and patent applications. We also find a one-way causality relationship from R&D and entrepreneurial activities to emissions.

Therefore, when we evaluate the climate change adaptation process of the countries in the sample cluster, we conclude that these countries should focus their efforts on a reduction of emissions relative to growth, fixed capital investment, and innovation. Considering that the causality results also confirm the co-integration results in terms of variables, we can see that the efforts of these countries are insufficient for adaptation to climate change in the current situation. The results obtained confirm our third and fourth hypotheses. Our results also show that fixed capital investment and government expenditure, which were included in the second hypothesis, increase environmental quality.

Regarding policy perspective, we propose that countries in the sample set implement efficient policies that support production arrangements related to innovation efforts toward growth in order to reduce CO_2 emissions. Consideration must be given to the fact that parameters regarding innovation for economic growth purposes of related countries increase environmental degradation as a response to climate change. The confirmed feedback hypothesis indicates that environmental quality and economic growth, fixed capital investment, government expenditure, genuine savings, and patent applications should be reviewed together. Since entrepreneurial activities and research and development are the principal causes of emissions, the demand for green goods and services ought to be increased. We also emphasize the importance of forming public opinion on this issue.

Conflict of Interest We have no known conflict of interest to disclose.

Appendix

Table 9.1 Cross-sectional dependence and unit root tests

Cross-sectional dependence test		Unit root tests	
Variable	Statistic	Harris-Tzavalis	Breitung
$\ln CO_2$	163.3962 (0.0000)*	1.9041 (0.8622)	4.1065 (1.000)
$\Delta \ln CO_2$		0.1299 (0.0000)*	–3.1058 (0.0009)*
lnGDP	340.2257 (0.0000)*	0.8905 (0.8109)	4.3272 (1.000)
ΔlnGDP		0.2554 (0.0000)*	–4.4293 (0.0000)*
lnFCI	219.6238 (0.0000)*	0.8739 (0.7340)	2.4826 (0.9935)

(*continued*)

Table 9.1 (continued)

Cross-sectional dependence test		Unit root tests	
Variable	Statistic	Harris-Tzavalis	Breitung
ΔlnFCI		0.2366 (0.0000)*	–5.1100 (0.0000)*
lnGE	264.4116 (0.0000)*	0.9177 (0.0931)	2.8934 (0.9981)
ΔlnGE		0.2688 (0.0000)*	–3.7708 (0.0001)*
lnGS	149.9767 (0.0000)*	0.6582 (0.0035)*	–0.6123 (0.2702)
ΔlnGS		–0.0106 (0.0000)*	–6.1273 (0.0000)*
lnTEA	43.08109 (0.0031)*	0.6204 (0.0005)*	–1.4631 (0.0717)**
ΔlnTEA		–0.1709 (0.0000)*	–6.0749 (0.0000)*
lnRD	47.75574 (0.0007)*	0.7227 (0.0442)*	–1.5500 (0.0606)**
ΔlnRD		–0.0678 (0.0000)*	–5.2865 (0.0000)*
lnPA	173.3340 (0.0000)*	0.9520 (0.9662)	5.2321 (1.000)
ΔlnPA		–0.1591 (0.0000)*	–3.5968 (0.0000)*

Note. The Δ notation is the difference processor, *p*-values are in parentheses, and * and ** are 1% and 10% statistical significance levels, respectively

Table 9.2 Panel co-integration test

Model	Test	Value of test	*z*-value	Model	Test	Value of test	*z*-value
$\Delta lnCO_2$ = f(ΔlnGDP)	Gt	–2.608	–4.150 (0.000)	$\Delta lnCO_2$ = f(lnTEA)	Gt	–3.694	–5.656 (0.000)
	Ga	–8.992	–3.019 (0.001)		Ga	–36.599	–14.352 (0.000)
	Pt	–5.854	–3.858 (0.000)		Pt	–7.407	–3.461 (0.000)
	Pa	–7.533	–5.946 (0.000)		Pa	–14.579	–5.895 (0.000)
$\Delta lnCO_2$ = f(ΔlnFCI)	Gt	–3.693	–5.654 (0.000)	$\Delta lnCO_2$ = f(lnRD)	Gt	–3.733	–5.774 (0.000)
	Ga	–25.731	–9.046 (0.000)		Ga	–22.779	–7.605 (0.000)
	Pt	–7.625	–3.675 (0.000)		Pt	–8.709	–4.745 (0.000)
	Pa	–14.651	–5.937 (0.000)		Pa	–20.227	–9.151 (0.000)
$\Delta lnCO_2$ = f(ΔlnGE)	Gt	–3.392	–4.758 (0.000)	$\Delta lnCO_2$ = f(ΔlnPA)	Gt	–3.263	–4.375 (0.000)
	Ga	–26.392	–9.369 (0.000)		Ga	–21.147	–6.808 (0.000)
	Pt	–8.071	–4.116 (0.000)		Pt	–7.514	–3.567 (0.000)
	Pa	–14.918	–6.090 (0.000)		Pa	–12.796	–4.867 (0.000)
$\Delta lnCO_2$ = f(lnGS)	Gt	–4.558	–8.229 (0.000)				
	Ga	–22.365	–7.403 (0.000)				
	Pt	–7.552	–3.604 (0.000)				
	Pa	–15.799	–6.598 (0.000)				

Notes: The *p*-values are in parentheses, the model has a constant term but no trend, according to the Akaike information criterion, and the lag length is in the range of 1–2

Table 9.3 Panel fully modified least squares (FMOLS) long-run elasticity estimates

Variables	Coefficient	*t*-Statistic	Prob.
ΔlnGDP	0.441074*	9.080713	(0.0000)
ΔlnFCI	0.107715*	4.052736	(0.0001)
ΔlnGE	−0.162775*	−6.148147	(0.0000)
lnGS	−0.007143**	−2.732500	(0.0076)
lnTEA	−0.000416	−0.087704	(0.9303)
lnRD	0.031128*	3.170660	(0.0021)
ΔlnPA	0.053047**	2.629114	(0.0100)

Note. The *p*-values are in parentheses, and * and ** are 1% and 5% statistical significance levels, respectively

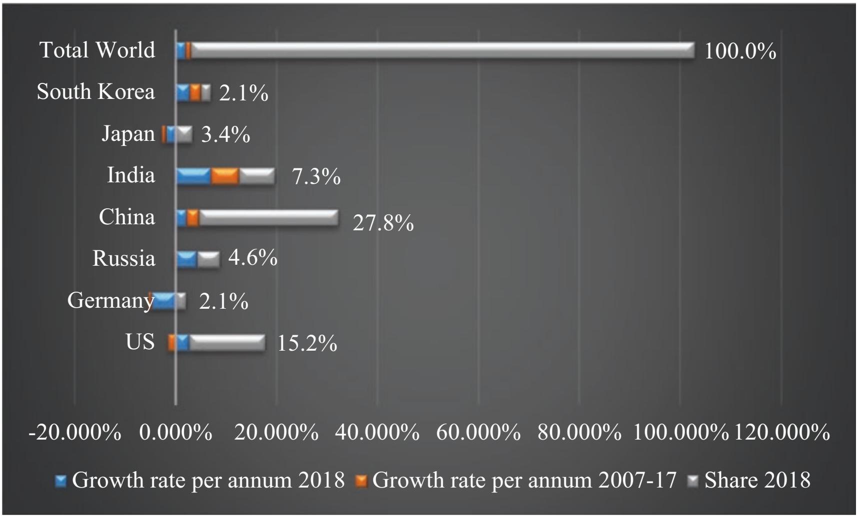

Fig. 9.5 CO_2 emissions (million tons CO_2 emissions). (Source: This was created by the researchers using data from the British Petroleum Energy Outlook Report (2019))

Table 9.4 Granger causality test

	$lnCO_2$	lnGDP	lnFCI	lnGE	lnGS	lnTEA	lnRD	lnPA
$lnCO_2$	–	6.4534 (0.0000)*	3.6715 (0.0002)*	5.8990 (0.0000)*	1.9022 (0.0571)***	0.3107 (0.7560)	–0.6172 (0.5371)	2.1876 (0.0287)**
lnGDP	2.0462 (0.0407)**	Direction of causality: $lnCO_2 \Leftrightarrow lnGDP$						
lnFCI	3.9448 (0.0001)*	Direction of causality: $lnCO_2 \Leftrightarrow lnFCI$						
lnGE	2.0575 (0.0396)**	Direction of causality: $lnCO_2 \Leftrightarrow lnGE$						
lnGS	2.1030 (0.0355)**	Direction of causality: $lnCO_2 \Leftrightarrow lnGS$						
lnTEA	5.1578 (0.0000)*	Direction of causality: $lnTEA \Rightarrow ln\ CO_2$						
lnRD	7.4611 (0.0000)*	Direction of causality: $lnRD \Rightarrow ln\ CO_2$						
lnPA	11.1947 (0.0000)*	Direction of causality: $lnCO_2 \Leftrightarrow lnPA$						

Note. The *p*-values are in parentheses, and *, ** and *** are 1%, 5% and 10% statistical significance levels, respectively

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10

Culture, Economics, and Climate Change Adaptation

Madhavi Venkatesan

1 Introduction

The discipline of economics evaluates human behavior relative to wants, needs, and resources within a natural environment. Per this definition, the discipline encompasses the study of other life forms and the assessment of resource use. The operation of an economic system is ultimately based on its goal. Under the assumption of an indefinite termination, an efficient economic framework implicitly includes the conditions necessary to maintain both human life and environmental regeneration. Given that the cultural foundation of an economic framework incorporates non-human elements in decision-making, an economic system should arguably include an understanding of the holistic interdependence of living and non-living elements. From this perspective, culture is a significant contributor to the perception of value; it is also noted by the United

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Nations Educational, Scientific and Cultural Organization (UNESCO) as a determining parameter in resource allocation within a society (Mokyr, 2017; UNESCO, 2019).

Culture is a learned behavior; it can therefore either promote or diminish any given society's understanding of the interconnectedness of human and planetary life, thereby determining the extent of the anthropocentric perspective of the culture in question. UNESCO defines culture as a significant tool in attaining global sustainability and advocates for its inclusion:

> Placing culture at the heart of development policy constitutes an essential investment in the world's future and a pre-condition to successful globalization processes that take into account the principles of cultural diversity… As demonstrated by the failure of certain projects underway since the 1970s, development is not synonymous with economic growth alone. It is a means to achieve a more satisfactory intellectual, emotional, moral[,] and spiritual existence. As such, development is inseparable from culture. (UNESCO, 2017, paras. 1–2)

Both the inputs and outputs of economic systems are dependent on the value structures implicit in culture. To the extent that economics explain observable phenomena and propose optimal outcomes, the discipline can, at once, be responsible for the maintenance of a cultural framework and the catalyst for its change. Economic assumptions, in essence, mimic and shape the values of the participants in an economic system.

The role of culture in economics is presently significantly limited by the perception that the current economic system is the outcome of natural evolution. As Zein-Elabdin (2009) notes:

> [t]he assumption that modern European achievements represent a natural or historical norm—as in [Adam] Smith's (1976, p. 405) 'natural course of things'—leads to disavowal of culture. As the cultural framework is taken for granted, the realm of economy, or what is perceived to be economic tendency, is disembodied from culture; in other words, the materiality of life, habits of provisioning or accumulation are seen as supracultural. (p. 1156)

At the time of Smith's writing, Christianity and its evolving Protestant forms espoused a Christian-defined moral perspective. Independent of such implicit and morally based cultural norms, an economic system developed. Arguably, the adoption of "otherness"—in practice, the stigmatizing of perceived difference—allowed for differentiation with respect to the implementation of ethics in practice, which eventually required and legitimized regulation to substitute for morality. Notwithstanding the role of culture in promoting a commonalty of societal values, the practice of economics eliminated the explicit evaluation of moral and ethical parameters in decision-making. In so doing, economics in both teaching and practice promoted a new cultural orientation, consistent with its assumptions (Hardin, 2009). However, the reliance on market value in determining the optimal use of resources has created an environmental and human health conundrum, as market values, rather than qualitative impacts, are used to determine optimal production and consumption. As McCloskey (1996) notes:

> [t]o the extent that cultural attributions incorporate individual moral responsibility and community ethics, the focus on self-interest alone may have promoted economic outcomes devoid of moral orientation. But I believe now that neglecting the culture—for example, neglecting ethics—will make the economic analysis wrong. By this I mean "wrong" *in terms that economists themselves would recognize as relevant.* I believe now that an economics that wants to get the economy right has to know about ethics. And an economy that wants to get its business right has to practice ethics. (p. 188)

McCloskey reaffirms the significance of Smith's impartial spectator, with an embedded assumption that the spectator is directed by an innate conscience. Indeed, as Smith states:

> We can never survey our own sentiments and motives, we can never form any judgment concerning them; unless we remove ourselves, as it were, from our own natural station, and endeavor to view them as at a certain distance from us. (Smith, 1869, 99)

This chapter discusses the role of culture in enabling climate change adaptation. Specifically, I address the relationship between common global cultural norms that result from the adoption of GDP, the relationship between GDP and climate change, and the cultural changes required to transform the economic framework so that it might be consistent with climate change adaptation; for the latter, I highlight the role of grassroot movements. This chapter argues that understanding the need for change requires stakeholder engagement in order to promote cultural transformation and to facilitate adaptation, which in turn will impact the economic system.

2 GDP, Culture, and Climate Change

The discipline of economics assesses how resources are used to meet human needs and, potentially, wants. At the center of this is thus the perception of a resource. If a resource is for human use, then its value to other living beings and to the functioning of the environment itself may be overlooked. However, if the perception is that the environment has an intrinsic value that may not be completely understood through the prism of human needs and wants, then this may promote a recognized symbiosis between the thriving of the human species and the thriving of the environment. In either case, there is a cultural predisposition toward the role and value of the environment; in the first, it is domination, and in the second, it is stewardship.

Since the era of the first colonial settlements, the United States (US) has been dominated by a hegemonic perspective that aligns with the Christian worldview of its colonizers and settlers. As conveyed in the Bible's book of Genesis, man is regarded as the "special" being of God's creation. He is assigned the task of controlling nature, the Earth's resources, and all its living creatures. This worldview affects cultural norms and embeds itself within the economic framework. White Jr.(1967) emphasizes that "[W]e shall continue to have a worsening ecologic crisis until we reject the Christian axiom that nature has no reason for existence save to serve man" (p. 1207). Indeed, it is the justification of man's dominion of nature, as legitimized by the interpretation of such

Biblical verses, that may be tied to anthropogenic issues, defining the existential threats to life on the planet (Ballantyne, 2011).

2.1 What Is the Gross Domestic Product (GDP)?

The Gross Domestic Product, created and first applied in the US, is characterized as an achievement of the twentieth century by the US Department of Commerce. The GDP measures final purchases by households, businesses, and governments. The components of the expenditure calculation of GDP include consumption (C), investment (I), government (G), and net exports (X − M), which are equal to the sum of exports minus that of imports. The GDP represents the sum of these values as follows: GDP = C + I + G + (X − M). The primary driver of GDP in the US is consumer spending, which accounts for more than 65 percent of the country's GDP.

Credited to the efforts of Nobel Laureate Simon Kuznets, the indicator's first iteration as the Gross National Product (GNP) was an outcome of the modern system of national income accounting. In the 1930s, national income accounting was developed in the context of the Great Depression as a way to measure economic productivity. This was done in an effort to better assess aggregate economic activity. Use of the indicator as a gross measure of economic activity gained traction in the post-World War II era in an effort to stabilize the global economy.

In 1944, the Bretton Woods Conference, which was attended by representatives from 44 countries, established the International Monetary Fund and International Bank for Reconstruction and Development (now part of the World Bank) to provide access to funds and establish policies to facilitate trade and global economic growth and stability. Given the strength of the post-war US economy, the country dominated both institutions. As a result of US influence, and following its transition from GNP to GDP in the 1990s, the latter became the standard for measuring economic growth within a country, as well as a ranking metric across countries.

The GDP measures the market value of all final (gross) goods and services (product) produced within a country (domestic) at a specific point in time. In doing so, the GDP provides an aggregate value, but no details with respect to the distribution of goods and services, the quality, or the standard of living of a country's inhabitants. However, given the relationship between employment, income, and consumption, there is an implied connection between employment growth and GDP. An increase in employment is assumed to increase consumption, which in turn affects GDP growth. As a result, employment is routinely evaluated as an economic indicator.

On the surface, the relationship between GDP and employment may not appear to be problematic; after all, income determines how much can be purchased and, consequently, the ability to satisfy needs and wants. This is one of the reasons why GDP is considered synonymous to standard of living, quality of life, and societal well-being, not to mention the "wealth of a nation". These definitions are consistent in situations where a formal market mechanism exists, in other words, in which monetary exchange is the basis for meeting needs and wants. However, not all goods and services are traded through a formal market channel, and this condition may be more prevalent with specific occupations and differ significantly across nations. By relying on monetary values, GDP has unintentionally led to the evaluation of all economic activities in monetary terms. As a result, unpaid work, though it may be highly productive, not only may be uncounted in GDP, which depresses the perception of country's productivity, but also impacts an undervaluing of occupations that do not generate monetary income. The informal sector is an example of the former and can include trade and subsistence agriculture, which respectively promote access to goods and provide for caloric needs. Parenting is an example of the latter (Philipsen, 2015).

By validating formal market-based consumption, the standardization of the measurement of a country's economy to GDP affects its nation's culture. The definition of GDP values only income; as a result, unpaid labor is not economically valuable and remains uncounted, and paid employment and production for consumption are the only focus of economic measurement. Though GDP increase is tied to consumption, so too is resource use, which normalizes environmental degradation and results in ecosystem and biodiversity losses as well as poverty. Market values are determined by the relative strength of the relationship between suppliers and the demand for their resources. The net result is the continued and vicious cycle of the exploitation of the most vulnerable: the environment and people in low-income financial situations (Anielski, 2002).

2.2 How Has GDP Affected Cultural Norms?

GDP has transformed cultural norms by establishing the acceptability of excess which has come to replace the frugality that characterized society at the indicator's inception. The transition to consumerism has been both facilitated and maintained by government action (Toossi, 2002). Tax reductions and financial transfers are used to boost consumption when it slows. Similarly, central banks target interest rates to promote GDP growth and lower rates to incentivize debt funded consumption.

Need does not determine the supply of a good or service; rather, advertising and marketing are the basis of creating demand for products. Planned and perceived obsolescence, in turn, induce a requirement for replacement resulting from use or appearance respectively. Given the economic system's legitimized preoccupation with consumption, resource use in production and the impact of disposal remain largely unnoticed (Szasz, 2016). The latter attribution mirrors the self-gratification and convenience that have become the expected characteristics of consumer products.

A tangible example of how GDP affects daily transactions is found in the planned obsolescence of convenience consumption, most easily typified by plastic bottled water. In the US, single-use plastic bottled water represents over 50 percent of the beverage market; estimates claim that nearly 70 million bottles are consumed per day (Franklin, n.d.). The growth in this market is largely attributable to marketing, which has promoted health centric aspects of drinking bottled water *in lieu* of tap water (Gleik, 2010).

The average retail cost of a 12-ounce single-use plastic water bottle is \$1.10, and its wholesale price is approximately \$0.10; the \$1.00 difference marks the retailer's profit (Sustainable Practices, 2020). The wholesale price reflects the low to nonexistent cost of the water in the bottle and the commodity value of the plastic used to make the bottle. What it does not reflect is the environmental impact of petroleum extraction for petroleum-based plastics or the monoculture impact of bioplastic material. Also excluded are the human health impacts resulting from the ingestion of chemical leachate from the plastic into the water it contains. Plastic leachate has been linked to obesity, infertility, ADHD, cancer, heart disease, autoimmune disease, and endocrine disruption (Bao et al., 2020; Borrell, 2010; Borrelle & Rochman, 2019; Hinterthuer, 2008). Perhaps even more significant, from a time and uncertainty perspective, is that the price does not account for the disposal of the plastic.

Presently, the majority of plastic is landfilled where it may thermodegrade, release methane, break down into microplastics, or remain intact. A smaller yet increasing proportion is incinerated, releasing toxic chemicals into the air, and the smallest percent is recycled. As of 2015, of the 8.3 billion metric tons of plastic that have been produced, 6.3 billion metric tons have become plastic waste (Geyer et al., 2017). Of these, only 9 percent have been recycled. However, 12 percent were incinerated, and 79 percent have accumulated in landfills or the natural environment. If current production and waste management trends continue, roughly 12,000 Mt of plastic waste will be in landfills or in the natural environment by 2050 (Geyer et al., 2017).

Based on the chemical properties of plastic, recycling still requires "virgin" plastic to strengthen the recycled product. Recycled plastic is typically used in the manufacturing of an alternative to the initial product. This is essentially waste diversion, which requires both new bottles to be made and yields more plastic in the environment (Monroe, 2014; The Berkley Ecology Center, 1996). Given that plastic will not biodegrade, the convenience benefit of the $1.10 single-use product is insignificant in comparison to the qualitative impacts of its life cycle from production to disposal. In other words, if assigned monetary value, the adverse impacts of single-use plastic water bottles significantly surpass those of its financial returns. Certain communities lose their access to water as a result of commercial bottling operations; this only magnifies the imbalance in light of global water scarcity issues. However, in spite of the costs, the monetized benefit of the product along with its routine obsolescence makes single-use plastic water bottles well aligned to a GDP framework (Gregory, 1947; Guiltinan, 2009).

Single-use plastic water bottles are one of many examples of planned obsolescence, which also underpins the production of many other consumer products such as clothing and cellphones. These products are essentially designed to be replaced, which is the growth driver for a consumer-based GDP. This ties back to the relationship between GDP and the exploitation of the environment and the vulnerable. Looking specifically at clothing, for example, reveals that an estimated 713 gallons (2700 liters) of water are required to grow cotton for a single cotton t-shirt (World Wildlife Fund, 2013). If the human average daily water consumption is 0.5 gallons, then the production of one t-shirt equates to almost 4 years of water consumption. The t-shirt's price does not factor the ecosystem damage related to a monoculture cotton plantation or the chemical impact of bleaching and coloring (Claudio, 2007). Emissions from transportation and the end-of-life impact of the t-shirt are also not considered. These two attributes are also true for cellphones; they vary in that the environmental impact of cellphones also includes mining, and their social impact includes the use of child labor. Children as young as seven have been found mining for cobalt in the Congo in unsafe and abusive conditions (International Labour Organization, 2019).

From a global perspective, the most significant environmental impact attributed to GDP-based growth is the increased acceleration of climate change as a result of fossil fuel-based energy production. Per Figs. 10.1 and 10.2, CO_2 emissions are directly correlated with global GDP growth. However, there exists a conundrum: GDP growth is energy dependent. Without a zero emissions infrastructure to substitute for fossil fuels, GDP will contract. It is therefore the very use of the metric to rank economic progress that has become the hurdle to enabling policies that promote sustainable economic growth.

2.3 Are There Other Economic Measures that Better Align to Social Well-Being?

Using the limitations that Simon Kuznets identifies as a starting point and considering what is accepted within the economics profession presently, the need for an alternative to GDP as an indicator of well-being has

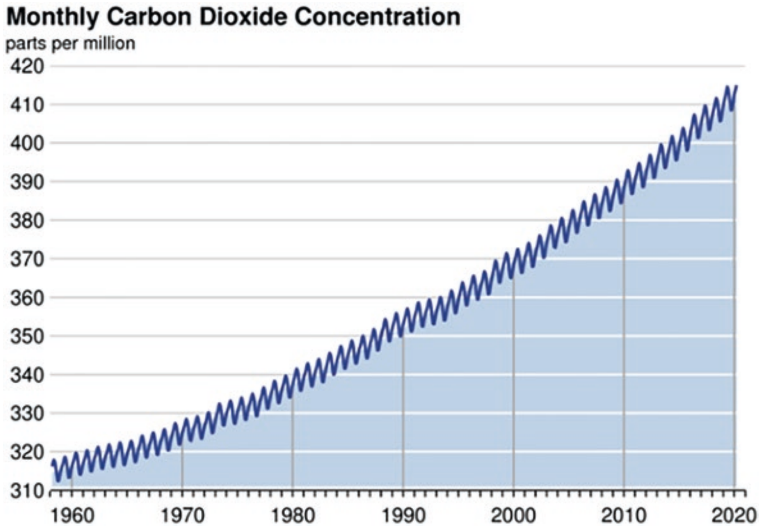

Fig. 10.1 Atmospheric carbon dioxide concentration: 1960–2018. (Source: The Keeling Curve, CO2 Concentration at Mauna Loa Observatory, Hawaii. Retrieved from http://scrippsco2.ucsd.edu)

been increasingly a point of discussion in academic discourse. Actions related to modifying the perception of economic growth to align with, rather than as a proxy for well-being, have been limited in spite of public appeals from government leaders, from American politician Robert Kennedy in the 1960s and to the UK prime minister David Cameron during his term in office from 2010 to 1016. In her 2018 addresses to the United Nations, activist Greta Thunberg also questioned how GDP-defined economic growth can be valuable if in its achievement, the long-term sustainability of planetary life is compromised.

Identifying how to get beyond GDP indeed appears to be an important task of the present period. Alternative indicators have been developed, including the Gross National Happiness Index (GNHI) and the United Nations Human Development Index. However, GDP remains the dominant measure.

GDP is reflective of the values of society, as social values change to align to sustainability criteria, the rationale, and responsibility inherent in consumption will potentially redefine GDP. In this manner, a cultural shift will guide the development of the purpose of the economy from

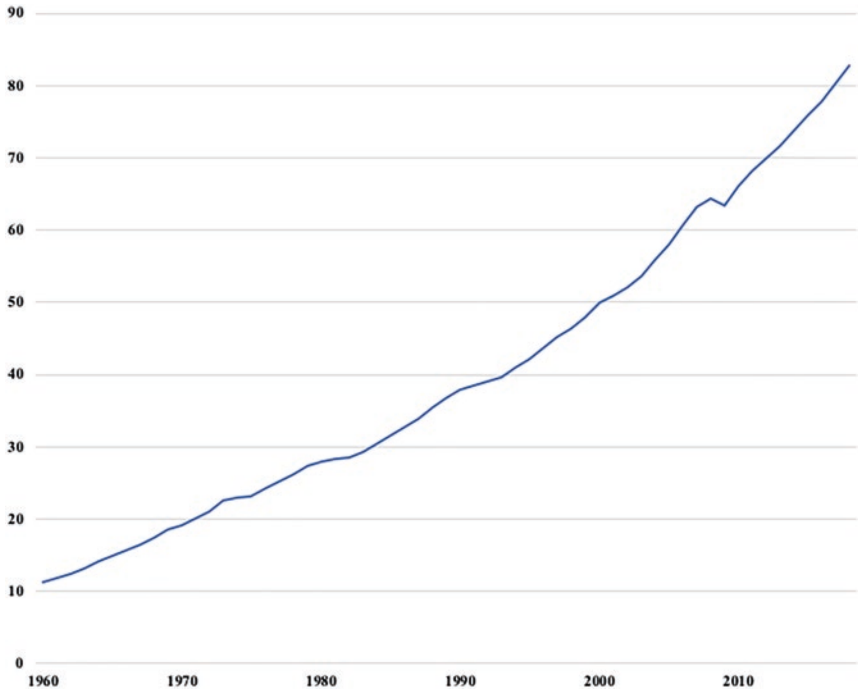

Fig. 10.2 Global GDP (constant 2010 US dollars; trillions). (Source: World Bank national accounts data, and OECD National Accounts data files. Retrieved from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD?end=2017&start=1960&view=chart)

resource use to conservation. As a result, GDP may provide a metric to quantify resource use. A lower GDP value may then be indicative of the amount of reuse in an economy, given that GDP considers newly produced goods and services.

3 Adaptation, Grassroots Movements, and Cultural Change

Mitigation is closely tied to a systemic change in an economy and, as most readily noted in the Paris Agreement, in the active pursuit of emissions reduction. Specific to global CO_2 levels, mitigation refers to changes in the manner of energy production as a means to significantly reduce or eliminate CO_2 emissions. However, given that CO_2 in the atmosphere will continue to impact climate change for hundreds of years even with a complete cessation in release, mitigation is not sufficient. Adaptation acknowledges that mitigation is necessary but not sufficient and seeks to address the changes that are observed and forthcoming with localized adjustments. Both mitigation and adaptation are needed; while these are complementary strategies, they are also distinct. With respect to CO_2 emissions, mitigation references a global interconnection and a need to embark on a common mutually reinforcing strategy, while adaptation recognizes the need to prepare for upcoming changes and can be implemented at a local level. In addition, mitigation requires a change in detrimental behaviors that will lessen the impacts of current and past actions. For example, the benefits reaped from the abatement of a ton of carbon are experienced irrespective of where the ton was abated. Conversely, adaptation accepts the adverse outcomes expected from existing behavior and seeks to live with them.

The cost of reduction in activity can be high in the present, as can be the infrastructure requirements for adaptation. This commonalty highlights the equity inherent in mitigation and adaptation, as countries that have the resources for these actions are the very same that are responsible for that fact that they are needed, while those who are the most vulnerable to climate change tend to be those who have been exploited for resources and have the least amount of resources available in working toward adaptation. This concern is addressed in the Paris Agreement under the concept "common but differentiated responsibilities".

Adaptation entails measures implemented locally whose benefits advantage primarily the local communities targeted. The global public good nature of emissions reduction creates the incentive to free ride; in other words, a country can benefit through the mitigation of others. This is one of the biggest problems in reaching a large and sustainable international mitigation agreement (Bosello et al., 2012; Bosetti et al. 2009); it is also what maintains the present viability of GDP as a production and consumption focused indicator.

3.1 What Is Adaptation?

Adaptation to climate change offers us both a universal need and a localized opportunity for a revision in the relationship between the human system and the environmental system, which can be the catalyst for a reframing of the economic system. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation in its Third Assessment Report as any "adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli, and their effects or impacts. This term refers to changes in processes, practices or structures to moderate or offset potential damages or to take advantages of opportunities associated with changes in climate" (McCarthy et al., 2001). Building on this, Bosello et al. (2012) identify three dimensions of climate change adaptation: (i) the subject of adaptation (who or what adapts), (ii) the object of adaptation (to what they adapt), and (iii) the way in which adaptation takes place (how they adapt). The combination of the three dimensions addresses aspects of prevailing cultural norms, with the last dimension specifically related to what resources are used, when and how they are used, and with which results (Bosello et al., 2012).

The IPCC Third Assessment Report defines autonomous adaptation as one that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems (McCarthy et al., 2001). Planned adaptation is defined as one that is the result of a deliberate policy decision based on an awareness that conditions have changed or are about to change, and that action is required to return to, maintain, or achieve a desired state (McCarthy et al., 2001). From this perspective, planned adaptation is reflective of a proactive cultural reorientation toward the environment and other peoples, while autonomous adaptation will force a modification in cultural orientation toward the environment stemming from the environment itself. The local action required in planned adaptation provides grassroots activism with a natural opportunity to promote local engagement. This may be the catalyst to eliminating the free rider problem inherent to mitigation.

3.2 Grassroots Movements

Participation in a grassroots movements is based on a shared experience and/or perspective that has both individual and communal consequences. The actions of grassroots movements relate to the power and authority they grant themselves to "solve the problem they are facing or create the future that they desire" (Richardson, 2009).

Grassroots movements begin with the identification of an issue by an individual and grow as a result of individual communication. Typically, the formation of a small group of individuals follows, and both a plan of action and a goal are developed. All individuals involved are volunteers, though there may be a leader. In general, the motivation for involvement is the addressing of a common issue. Given the size of the group relative to the issue, both intra-group and extra-group communications are vital. Specific to the latter, because resources are limited to those donated by group members, different forms of media (i.e., newspapers, local television, radio, and more particularly social media, i.e., Facebook, Instagram, Twitter) are a primary vehicle for marketing. Typically, the focus of communications is education to promote broader public interest in the issue as well as to increase the perception of the group's influence and representation within its community.

As public interest and support for their goal increase, grassroots movements embody the democratic process and promote collective action (Loh, 2003; Poulos, 2015). In the US, there have been numerous examples such activism, from the abolition of slavery, to women's suffrage, to the fight for universal civil rights. These movements have also included more localized actions such as Love Canal (Gibbs & Livesey, 2003) and the protection of the Grand Canyon (Wyss, 2016). These actions all focus on specific local issues and their remediation. It is important to note that mitigation can also be fostered by grassroots activism, but given its global nature, it does not provide local remedies as is the case with adaptation. The best-known recent grassroots movement for mitigation was started by Greta Thunberg in 2018. Greta, a 15-year-old schoolgirl, left school in order to advocate for climate action. Though her strike began alone, she was eventually joined by other students and inspired global mobilization to address climate change, #Fridays4Future (Fridays for the Future, 2021).

All grassroots actions identify a failure to protect or provide acceptable standards as determined by an individual and/or the community that is affected. Further, all depend on the use of communication and media to create widespread awareness. This awareness leads to knowledge which inspires collective interest to support the change, as demonstrated by the action of government, which is, arguably, in a democratic system the reflection of society (Ferguson & Hirt, 2018; Freudenberg & Steinsapir, 1991).

McNeeley and Lazrus (2014) note that cultural differences underpin the barriers related to promoting adaptation strategies. Specifically addressing planned adaptation, the authors state that the building of adaptive capacity to reduce climate change impacts has been undermined, in large part, by social barriers found in politics, economics, regulation, and divergent risk perceptions, among others. Given the relationship between social structures and culture, McNeeley and Lazrus (2014) address the need for adaptation through the lens of the Cultural Theory of Risk (CTR) and conclude that adaptation strategies hinge on two factors: "1) an understanding of people's cultural worldviews about social organization and nature, which determines how they see the climate system "working"; and 2) participatory, community-based approaches to analysis to understand the nuances of the relationship between culture, climate change, and adaptation strategies" (p. 517). Their discussion highlights the significance of stakeholder engagement in grassroots action and the relationship between grassroots activism and transformative cultural change.

3.3 Stakeholder Engagement for Adaptation

Grassroots movements begin with a small number of participants, but in order to grow and to promote action, they need to engage a variety of stakeholders. Venkatesan et al. (2020) outline the determination of stakeholder groups as a defining element of the engagement process; it requires both an identification and a stratification of stakeholders (Freeman, 1984; Freeman et al., 2007; Mitchell et al., 1997), as Fig. 10.3 depicts.

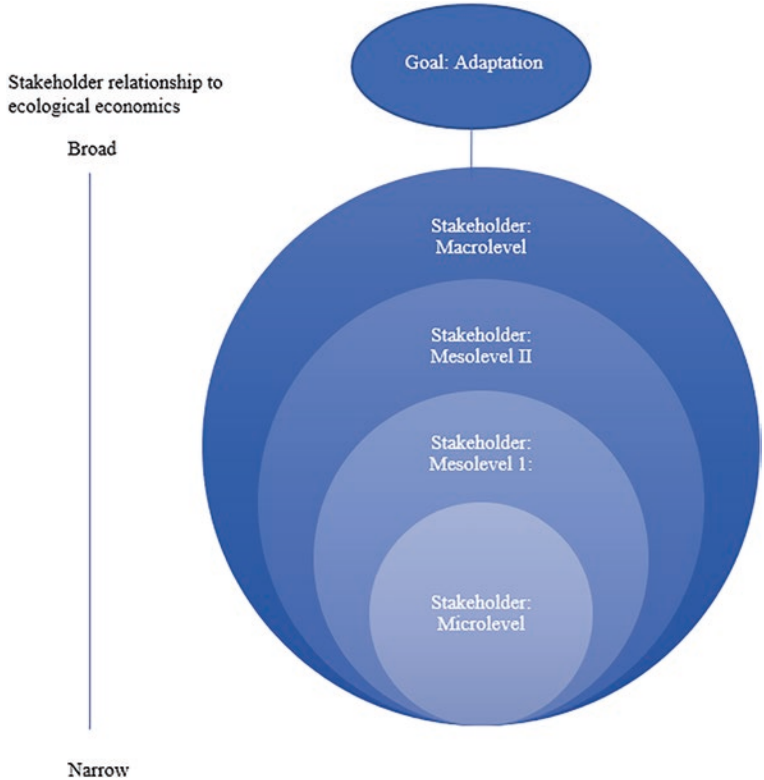

Fig. 10.3 Stakeholder identification and communication process. (Source: Venkatesan et al. (2020))

Micro-level stakeholders are those individuals and organizations most affected by the issue, while meso-level stakeholders are implicated, but not as directly impacted. For macro-level stakeholders, the impact may be even smaller, but the significance of the issue remains relevant. Communicating with each stakeholder group conveys the common goal and must also align with the specific stakeholder's incentive.

Ideally, communication should meet the needs of the broadest stakeholders given that other stakeholder groups are subsets of the broadest grouping. A better understanding of differences in stakeholder incentives can help tailor communications to address the sensitivities of individual stakeholders. Communications among stakeholders, in recognition of their differing incentives, could then be facilitated with a process for conflict resolution that provides procedures for constructive criticism and feedback as well as the adjustment of the goal as information is shared across groups. The latter, referenced as an emergence of new ideas by Pade-Khene et al. (2013), allows the process of engagement to have value independent of the goal itself. Engagement becomes, in this manner, an opportunity to formalize a common foundation. Table 10.1 provides an example of a set of principles for stakeholder engagement.

Research on stakeholder relationships in different environments and on common goods highlights that local users who collaborate with one another find ways to make better collective decisions than those who have regulations imposed by outsiders (Ostrom, 1998). Further, incorporating diverse values and community priorities (as identified through CTR analysis) can improve the social relevance and community compliance of local adaptation efforts and policies (McNeeley & Lazrus, 2014).

Attention to direct, broad, and diverse stakeholder engagement fosters discussions by its very implementation, which provides a foundation for

Table 10.1 Principles of stakeholder engagement

1. Identification of a goal.
2. Determination and stratification of stakeholders based on their relationship to the goal.
3. Determination of stakeholder incentives for action.
4. Determination of stakeholder-specific communication and incentivization of the identified goal.
5. Communication of the goal across stakeholder groups using education to promote the alignment of stakeholder interests with the intent of the goal.
6. Facilitation of communication across stakeholder groups to ensure that there is alignment with respect to the common goal.
7. Consultation of stakeholders for ideas and suggestions, providing flexibility, so as to augment the engagement process and the goal as new information surfaces.
8. Maintenance of communication channels and facilitation of communication between groups even after the goal is reached to ensure continuous improvement and the long-term viability of the intention of the initial goal.

Source: Venkatesan et al. (2020)

dialogue and knowledge exchange between invested groups. As such, stakeholder engagement creates an opportunity to not only address adaptation issues but also affect social perception and cultural norms related to the environment in an efficient and time-sensitive manner.

4 Final Comments

In acknowledging the relationship between culture, economics, and adaptation, it becomes evident that regulation may not be sufficient to promote societal change. Understanding an issue at a local level, fostered by stakeholder engagement, offers the opportunity to align impacted individuals, groups, and institutions to work together, thus eliminating the free rider issue in pursuit of a common goal. In the case of climate change adaptation, local action is needed to enable mobilization for localized events; this condition may in itself facilitate collective action as each individual benefits from and is harmed by the impact of their action or inaction related to the adaptation goal. As a result, regulation's success may be attributed to localized change in perception, preceding the regulation itself.

The outcome expected from stakeholder engagement which relates to climate change adaptation is a change in the common perception of a local system toward both the environment and the exploitation of other peoples. As information transparency lifts the market veil that obscures supply chain impact, information is expected to align consumption and production to a more intrinsic and moral worldview. Sustainability encompasses concerns not only for ecological integrity but also for social and economic justice and for nonviolence, democracy, and peace (Tucker, 2008). Further, "sustainable culture is a socially and economically just culture, recognizing that wealth is never an individual or corporate accomplishment" (Holthaus, 2008, 123). As what is valued changes, the expectation is that the same will be mirrored in the economic system.

However, the challenge to adaptation may also be in prevailing cultural norms which limit the perception of and/or interest in an alternative economic framework. The use of GDP establishes resource-based consumption and gratification as the purpose of an economy. In essence, the pursuit of GDP growth implicitly establishes cultural norms related to the environment and other peoples, the foundation of which may arguably be based in religion. Climate change adaptation that is achieved by prompting localized action provides an opportunity for transparency and collective action that can transform the basis for an organized economy. As local systems work independently, there is the potential for localized sustainability action geared toward establishing a global system based on common principles but supported by locally specific methods, ultimately aligning to and fostering global sustainability. Though this may appear straightforward, heterogeneity in beliefs unrelated or tangential to the economic system may be problematic. For example, religious beliefs may contribute to a worldview that aligns to environmental degradation and even human economic stratification. Bradley (2009) finds that fundamentalist Christian beliefs, due to fixed perceptions (i.e., human dominion, binary sexuality), are less likely to engender a relational empathic response to fostering sustainability (Ives & Kidwell, 2019). Further research is required to determine the extent to which religious beliefs affect adaptation responses. Such scholarship might then develop stakeholder engagement strategies in response to worldviews that may not necessarily be shaped by economic framework-induced cultural norms.

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11

Investors' Adaptation to Climate Change: A Temporal Portfolio Choice Model with Diminishing Climate Duration Hazard

Hany Fahmy

1 Introduction

There is no denying that earth's climate is changing. This shift has prompted organizations as well as governments around the globe to take action toward climate change mitigation and adaptation. According to the Intergovernmental Panel on Climate Change (IPCC), "climate change mitigation" is the term used to describe the efforts aimed at reducing carbon emissions and greenhouse gases, whereas "climate change adaptation" refers to adjustments in natural or human systems in response to actual stimuli or expected stimuli and their effects (IPCC, 2001); the latter moderates harm or exploits beneficial opportunities.

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In financial markets, climate adaptation can be thought of as a temporal process that describes the progress in investors' awareness of current climate change risks as well as their beliefs and perceptions about future risks. This is consistent with the aspect of human adjustment in the IPCC definition. As a temporal process, climate adaptation can be characterized by two key features: time (duration) and risk (climate uncertainty). So, a successful adaptation plan should entail both an increase in investors' awareness and portfolio strategies that guarantee a perception that climate risks are decreasing over time.

This chapter proposes an asset pricing model that describes uncertainty (financial and climate risks) in investment decision-making as a temporal process over the duration of financial portfolios. The premise of modern portfolio theory (Markowitz, 1952, 1959) and Fahmy's (2020) recent extension of this theory are the foundation for this study's proposed framework. The novelty of the approach lies in describing investors' adaptation to climate change as a temporal process, in which investors' perception of climate hazards shapes their preferences and decisions over the duration of their financial portfolios. The proposed model has several advantages. First, the optimal solution of the model provides a parametric formula of climate duration hazard risk, which can be easily estimated empirically. Second, the model is flexible enough to be used by practitioners when projecting various climate risk scenarios and factoring climate risks into their portfolios. Third, the analytical results of the model yield a set of recommendations for a sustainable climate adaptation process. These recommendations are important to participants, regulators, and policy makers alike; such recommendations hopefully present a step forward toward winning the battle against climate change.

The chapter is organized as follows. Section 2 describes climate adaptation as a temporal process. Section 3 discusses investors' behavior over time and their perception regarding future climate risks. Section 4 introduces the model in question and discusses the main results. Section 5 demonstrates the empirical applicability of the model. Finally, Section 6 concludes and provides policy recommendations in line with the proposed framework.

2 Adaptation as a Temporal Process

Winning the battle against climate change is a monumental task that requires global collaboration. Stern (2007) offers an estimate of the financing needed to mitigate the effects of climate change in the range of US$200 billion and US$1000 billion. A report by the World Bank Group in 2008 echoes Stern's findings by suggesting that at least tens of billions of dollars are needed every year to finance the cost of adaptation to global warming. Raising this staggering amount of funds is clearly beyond the means of governments' limited budgets. Therefore, private investment in climate mitigation and adaptation projects is urgently needed, and on a large scale, this mobilization of funds can be achieved only through global financial markets with innovative solutions across asset classes (Reichelt, 2010). Although some organizations have already provided creative solutions that have attracted investors' interest in climate-related investments and have caused a rapid growth in green markets, investors are still unenthusiastic about investing in green instruments. This lack of enthusiasm is mainly attributed to investors' lack of knowledge about the potential impact of climate change on various asset classes (Shen et al., 2019) and/or investors' belief that green investment is more of a moral choice than a reward (Riedl & Smeets, 2017; Walley & Whitehead, 1994).

There is, however, evidence indicating a rise in the awareness of climate change amid climate-related events. For instance, Fahmy (2022) shows that admitting clean energy as an asset class on its own in portfolio construction is rewarding especially after the Paris Agreement. Choi et al. (2020) examine the impact of abnormally high temperature on investors' beliefs about climate change. The authors document a rise in the awareness of climate change at the time of those events. By further examining trading volume and stock markets' returns during the times of these events, the authors report that retail investors tend to overreact to climate events by selling carbon-intensive stocks, and carbon-intensive firms are perceived to under-perform firms with low emissions. Alok et al. (2019) find that institutional investors overreact to large climatic disasters that happen close to them. Moreover, in a recent survey on global institutional investors' perceptions of climate risks, Krueger et al. (2020) find that investors regard these risks to be important despite ranking them below financial, operational, and other types of risks.

Much of the extant literature suggests that investors' awareness, especially after the Paris Agreement (Fahmy, 2022) and the increased occurrence of climate crises around the globe, is on the rise. Climate awareness, however, is not enough to win the battle against climate change. Investors need assurance that green investments are rewarding and that temporal climate risks in green portfolios (i.e., portfolios that contain green instruments) are decreasing over time. Achieving the former objective is more related to mitigation, whereas the latter objective relates to adaptation. Although this analysis focuses on the second objective, it is worth noting that there is a natural risk/reward interconnection between the two objectives. Successful mitigation policies that stimulate investments in clean energy must have the potential to make investors perceive lower future or expected climate risks. On the other hand, successful adaptation policies that have the potential to alter investors' perception regarding future climate risks will, over time, enhance awareness and attract more green investments.

3 Investors' Temporal Behavior

In financial markets, processes known as asset allocation and portfolio construction form the basis of investment decisions. These processes are founded on Harry Markowitz's (1952, 1959) seminal work on portfolio theory. It postulates that, given a target expected rate of return (mean) on a financial portfolio, a risk-averse investor, who is facing a choice set X that consists of n risky assets, allocates their wealth over n assets to minimize the risk (variance) of the portfolio. Markowitz's mean-variance (MV) portfolio theory yields a vector of optimal asset weights that minimizes the risk of a portfolio of n assets.

The previous MV optimization, or some variant of it, for example, Black and Litterman (1992) model, is the process that is commonly used by fund and portfolio managers in the asset allocation phase in the portfolio management process (PMP).[1] In this phase, subject to the investment strategy of the fund, the total wealth of all investors in the fund is allocated on a number of asset classes (e.g., fixed income, domestic equity, foreign equity, commodities, real estate, and derivatives). Once the optimal investment weight in each class is determined, a process of security selection begins within each individual asset class such that the expected rate of return on the portfolio is maximized or the risk is minimized.

It is worth noting that the above-mentioned MV optimization is static in the sense that it is executed on the set X at a reference point in time. This reference point is equivalent to a trading time $t = 0$, that is, the time of constructing the portfolio before the actual trading takes place. As time progresses from point $t = 0$, investors' reactions to various types of uncertainty (e.g., global events, financial news, and other cognitive and behavioral biases) impact their temporal allocations and choices. This, in turn, could cause some investors to revisit their portfolios sooner than later for rebalancing. This dynamic process of continuously rebalancing or revisiting the portfolio over time is known as the dynamic portfolio duration problem. Fahmy (2020) provides a solution to this problem (i.e., an optimal time to revise/rebalance a portfolio under the assumption of uncertainty) via their time extension of the MV portfolio theory. In particular, by adding a time-choice set T to the set of monetary outcomes X and by modeling the investor's choice over the extended set $X \times T$, the author extends the MV portfolio theory and derives an analytical expression in which optimal portfolio duration is explicitly expressed as a function of different types of uncertainty. This explicit connection between time and uncertainty is what distinguishes Fahmy's (2020) model from other studies on portfolio selection under uncertain time-horizon (e.g., Blanchet-Scalliet et al., 2008; Brennan, 1998; Hakansson, 1969, 1971; Martellini & Urošević, 2006; Merton, 1971; Richard, 1975; Yaari, 1965).

The present chapter uses a modified generalization of Fahmy's (2020) model, in which duration hazard of climate change is added as an

[1] The PMP consists of three stages: planning, allocation, and performance evaluation. Asset allocation and portfolio construction take place in the second stage of the PMP.

additional source of uncertainty in the portfolio duration problem. The focus is on applying this generalized framework to climate adaptation. This framework is particularly suitable here since it yields analytical results that quantify the hazard of climate duration. The following section introduces the model and deduces the main results.

4 A Simple Two-Period, Risk and Reward Asset Pricing Model with Climate Duration Hazard

This section proposes a simple two-period, risk and reward asset pricing model that accounts for time and uncertainty. The proposed model, founded on Markowitz's MV portfolio theory (1952, 1959) and a generalization of Fahmy's (2020) MV-time extension, makes the distinction between the present and the future by separating the portfolio/investment decision into two sequential optimal decisions: an allocation decision on the space of monetary outcomes, X, and a duration decision on the time space, T. At time $t = 0$ (i.e., before trading takes place), the investor chooses an optimal allocation of assets on X that minimizes the variance (risk) of the portfolio. As time progresses from zero (i.e., as $t > 0$), the chosen allocation is subject to different types of uncertainty (including climate hazard). The investor chooses an optimal portfolio duration such that a utility of time function that represents the investor's preference, $U(t)$, is maximized. It is worth noting that the allocation decision executed on X at time $t = 0$ represents the certainty of the present. On the other hand, the optimal time to revise, rebalance, or even exit the market after trading represents the future uncertainty. A decision to exit the market amid an unexpected event with global implications, such as the recent COVID-19 pandemic, is due to the investor's perception that the portfolio duration hazard is increasing over time. This perception, which is usually fueled by intensive news coverage of the event, is what prompts rational investors to make irrational exit decisions amid global events or financial crises. Focusing on climate change, this chapter posits that if one can alter investors' beliefs to perceive a decreasing climate duration hazard in their financial portfolios, then a successful adaptation policy is guaranteed.

4.1 The Portfolio Allocation Problem on *X*

Consider constructing a portfolio p that consists of a number of n assets, which includes green securities. Let the time of constructing p be $t = 0$; in other words, assume that the time dimension T is absent for now. Denote the weight of asset i in portfolio p by w_i and the investor's level of wealth at time t by y_t. Therefore, y_0 is the initial level of wealth that the investor wishes to allocate on the n assets forming portfolio p.[2] Assume two periods: period 0 representing the present and period 1 representing the future. Notice that, in the previous setup, the choice set X is a set of monetary outcomes. At time $t = 0$, the monetary outcome y_0, which is an element of X, is an allocation of the initial wealth on a number n of risky assets such that the weight of asset i in this allocation is w_i and $\sum_i^n w_i = 1$. Following the premise of the MV portfolio theory, consider a risk-averse investor with a strictly concave utility of wealth function, $u(y)$, on X.[3] The investor's objective is to find the best allocation that maximizes the expected utility of future wealth. More formally, the investor solves the following problem:

$$\text{choose } w_1, \ldots, w_n \text{ in order to } \textit{maximize } Eu(y_1). \tag{1}$$

Let the price of asset i in period t be P_{it}, for $i = 1, 2, \ldots, n$, and $t = 0, 1$. Notice that P_{i0} is the price of asset i at period $t = 0$, that is, it is the current or known price of the asset. In practice, this price is the end-of-day closing price of an asset in a financial exchange. Notice also that P_{i1} is the

[2] An investor could be a retail trader or an institutional investor, that is, a fund or portfolio manager.

[3] This chapter follows the convention of treating wealth as a commodity with an increasing total utility but diminishing in value added utility, that is, the added utility per additional increase in wealth is diminishing. This is known as the law of diminishing marginal utility of wealth. Mathematically, this means that $u(y)$ is an increasing function in wealth y, that is, the first derivative $u' > 0$, and diminishing in value added, that is, the second derivative is strictly negative; $u'' < 0$. This is the mathematical condition that guarantees the strict concavity of the utility of wealth.

asset's price at the beginning of period 1, that is, the future uncertain price of the asset. The symbol "tilde" makes the distinction between known and uncertain variables through its placement above the variable, which indicates that it is random. Thus, the rate of return on asset i is

$$\tilde{r}_i = \frac{\tilde{P}_{i1} - P_{i0}}{P_{i0}},\ i = 1,\ldots,n. \tag{2}$$

The choice on the set X is described as follows. At time $t = 0$, the investor allocates their wealth y_0 over the n assets by purchasing a_i units of asset i at period 0 prices. Subsequently,

$$y_0 = a_1 P_{10} + a_2 P_{20} + \cdots + a_n P_{n0} = \sum_{i=1}^{n} a_i P_{i0}. \tag{3}$$

Notice that a negative (positive) a_i signifies selling (buying) some units of asset i. If the portfolio is constructed for the first time, then all the a_i terms will be positive. A rebalancing of an existing portfolio implies a mix of positive (long position) and negative (short position) a_i terms. Therefore, the weight of asset i, w_i, can be defined as

$$w_i = \frac{a_i P_{i0}}{y_0},\ i = 1,2,\ldots,n. \tag{4}$$

The rate of return on the portfolio p is, by definition, the weighted sum of the rates of return on the n assets forming it; that is,

$$\tilde{r}_p = w_1 \tilde{r}_1 + w_2 \tilde{r}_2 + \cdots + w_n \tilde{r}_n = \sum_{i=1}^{n} w_i \tilde{r}_i. \tag{5}$$

The mean of the portfolio, or the expected rate of return on portfolio p, denoted by μ_p, is the weighted sum of the expected returns of the individual assets forming the portfolio; that is,

$$\mu_p = E\tilde{r}_p = w_1 \times E\tilde{r}_1 + w_2 \times E\tilde{r}_2 + \cdots + w_n \times E\tilde{r}_n = \sum_{i=1}^{n} w_i \times E\tilde{r}_i. \tag{6}$$

The variance of portfolio p's return, denoted by $?_p^2$, is a weighted function of the individual variances of the n risky assets forming the portfolio and their pairwise covariances:

$$\sigma_p^2 = \text{var}\left(\tilde{r}_p\right) = w_1^2 \times \text{var}\left(\tilde{r}_1\right) + w_2^2 \times \text{var}\left(\tilde{r}_2\right) + \cdots + w_n^2 \times \text{var}\left(\tilde{r}_n\right) + 2w_i w_j \text{cov}\left(\tilde{r}_i, \tilde{r}_j\right), \tag{7}$$

for all $i \neq j$. The investor's wealth in the future, that is, in period 1, y_1, is the number of units per assets purchased times period 1's price; that is,

$$\tilde{y}_1 = a_1 \tilde{P}_{11} + a_1 \tilde{P}_{21} + \cdots + a_n \tilde{P}_{n1} = \sum_{i=1}^{n} a_i \tilde{P}_{i1}. \tag{8}$$

Equation (8) can be re-written as

$$\tilde{y}_1 = \sum\nolimits_{i=1}^{n} a_i \left(\tilde{P}_{i1} - P_{i0}\right) + \underbrace{\sum_{i=1}^{n} a_i P_{i0}}_{=y_0}, \tag{9}$$

where the second term on the right-hand side is the initial wealth in Eq. (3). Multiplying the first term on the right-hand side of Eq. (9) by $\frac{P_{i0}}{P_{i0}}$ gives

$$\tilde{y}_1 = \sum_{i=1}^{n} \frac{a_i P_{i0}}{1} \times \frac{\left(\tilde{P}_{i1} - P_{i0}\right)}{P_{i0}} + y_0 \tag{10}$$

$$= y_0 \left(1 + \sum_{i=1}^{n} \underbrace{\frac{a_i P_{i0}}{y_0}}_{=w_i \text{ from}(4)} \times \underbrace{\frac{\left(\tilde{P}_{i1} - P_{i0}\right)}{P_{i0}}}_{=\tilde{r}_i \text{ from}(2)} \right) = y_0 \left(1 + \underbrace{\sum_{i=1}^{n} w_i \times \tilde{r}}_{=\tilde{r}_p \text{ from}(5)} \right) = y_0 \left(1 + \tilde{r}_p \right).$$

Equation (10) states that the future uncertain level of wealth is the current wealth grown by the portfolio return. Applying the expectation operator and the variance operator to y_1 in Eq. (10) yields, respectively, the expected value (mean) and variance of the future uncertain level of wealth as functions of the mean and variance of the portfolio p; that is,

$$E\tilde{y}_1 = y_0 \left(1 + \underbrace{E\tilde{r}_p}_{=\mu_p} \right), \tag{11}$$

and

$$\begin{aligned} \operatorname{var}\left(\tilde{y}_1\right) &= \underbrace{\operatorname{var}\left(y_0\right)}_{=0} + \operatorname{var}\left(y_0 \tilde{r}_p\right) + \text{zero cross covariances} \\ &= y_0 \underbrace{\operatorname{var}\left(\tilde{r}_p\right)}_{=\sigma_p^2}. \end{aligned} \tag{12}$$

By taking a second-order Taylor approximation of u about $E\tilde{y}_1$, one can show that the investor problem in Eq. (1) is equivalent to minimizing the variance of the portfolio in Eq. (12). To demonstrate this, let G be the Taylor approximation and notice that

$$\begin{aligned} u\left(\tilde{y}_1\right) \approx G = u\left(E\tilde{y}_1\right) + u'\left(E\tilde{y}_1\right)\left(\tilde{y}_1 - E\tilde{y}_1\right) \\ + \frac{1}{2} u''\left(E\tilde{y}_1\right)\left(\tilde{y}_1 - E\tilde{y}_1\right)^2 + R, \end{aligned} \tag{13}$$

where $R = \sum_{i=3}^{\infty} \frac{1}{i!} u^i\left(E\tilde{y}_1\right)\left(\tilde{y}_1 - E\tilde{y}_1\right)^i$ is the remainder of the approximation. Applying the expectation operator on both sides of Eq. (13) yields

$$Eu(\tilde{y}_1) = u(E\tilde{y}_1) + \frac{1}{2}u''(E\tilde{y}_1) \times \underbrace{\text{var}(\tilde{y}_1)}_{=y_0\,\sigma_p^2\text{ from}(12)} + ER. \tag{14}$$

Equation (14) shows that the investor's expected utility of wealth is a function of $E\tilde{y}_1$ and $\text{var}(\tilde{y}_1)$, the mean and variance of period 1's wealth. As previously mentioned, from Eqs. (11) and (12), both $E\tilde{y}_1$ and $\text{var}(\tilde{y}_1)$ are, in turn, functions of the mean and variance of portfolio *p* respectively. In other words, Eq. (14) establishes the link between expected utility of wealth and the portfolio mean and variance. In particular, Levy and Markowitz (1979) show that, provided that *ER* goes to zero, a strictly concave utility of wealth function ($u'' < 0$) guarantees that maximizing the investor's objective in Eq. (1) is equivalent to minimizing the variance of the portfolio; that is,

$$\max Eu(\tilde{y}_1) \text{ if and only if} \min \sigma_p^2. \tag{15}$$

This is evident since $u'' < 0$ guarantees that the second term on the right-hand side of Eq. (14) is negative. Therefore, minimizing this term, that is, minimizing σ_p^2, is equivalent to maximizing $Eu(\tilde{y}_1)$. The assumption that the utility of wealth is strictly concave is sensible since the concavity of *u* implies risk aversion. The restriction that the remainder goes to zero in Eq. (14) to ensure the equivalence in Eq. (15), however, is not a simple one. A choice of a strictly concave utility function, for example, $u = \ln y$, might not ensure that *ER* goes to zero. It is worth noting that a quadratic utility function is increasing, concave, and has a zero remainder under Taylor's approximation. However, when entertaining this function, there will be a point of satiation beyond which utility decreases.[4]

Luckily, in the present model, the previous technical concerns will have no impact on the model and its analytical results. This is true since the proposed model focuses on the progress of the initial allocation over time regardless of the form of the utility of wealth function on *X*. In

[4] This concern led to the alternative of putting a distributional restriction on the rates of return to achieve the equivalence in Eq. (15).

particular, the present model assumes that at time $t = 0$, a risk-averse investor with a strictly concave utility of wealth function, $u(y)$, chooses optimal portfolio weights such that $?_p^2$ is minimized. The utility of the resulting allocation at time 0, that is, $u(y_0)$, is assumed to be constant:

$$u\left(y_0\right) = m, \tag{16}$$

where m is the level of satisfaction from owning the portfolio before the actual trading takes place.

4.2 The Portfolio Duration Problem on *T*

This section discusses the temporal progression of the initial allocation $u(y_0) = m$ over time. The assumption of a risk-averse investor with a strictly concave utility of wealth u still holds to ensure optimal initial allocation on X. In particular, given an initial allocation y_0 at time $t = 0$ that minimizes the variance (risk) of the constructed portfolio, the investor at $t > 0$ is solving the following problem: choosing an optimal portfolio duration, t^*, such that a utility of time function, $U(t)$, is maximized. Notice that the utility of time function $U(t)$ on the T space is different from the utility of wealth function $u(y)$ on the X space. The former corresponds to duration choices, whereas the latter corresponds to monetary/allocation choices. Per the previous sub-section, the investor has already solved the allocation problem at time $t = 0$. In order to solve the duration problem, one must define $U(t)$.

Under a set of conventional preference axioms, Fahmy (2020) shows the existence of a unique utility of time function that represents the investor preference over the portfolio duration that takes the following form:

$$U\left(t\right) = M + \left(m - M\right)e^{-\theta t}, \theta > 0, \tag{17}$$

where $m = u(y_0)$ is the lower bound of U, that is, it is the value derived from the allocation of the initial level of wealth at time $t = 0$. Notice that when $t = 0$ in Eq. (17),

$$U(0) = m = u(y_0). \tag{18}$$

That is, both functions, u and U, agree at time $t = 0$. The parameter M is an upper bound of U. It is the maximum amount of satisfaction that corresponds to a maximum portfolio duration time t. This assumption is imposed for the mathematical tractability of the function, and it has no impact on the results of the model. The utility level corresponding to that time is $U(t) = M$. Thus, the function in Eq. (17) is bounded from below by m and from above by M, as Fig. 11.1 shows, where $m = 2$, $M = 10$, and $\theta = 0.8$ (left panel) or $\theta = 2$ (right panel). Parameter θ is what governs the rate of decay of U. Notice that since $U(\tilde{t}) > U(t)$ for all $0 < t < \tilde{t}$, then dU/dt is strictly positive; that is, the marginal utility of duration is positive. Moreover, the second derivative with respect to time is negative, that is, the function is strictly concave. This means that the marginal utility of portfolio duration is diminishing over time. In other words, the marginal utility that is gained from an increase in portfolio duration by one period in the short-run is higher than the same increase in duration in the long-run. Since the magnitude of the additional increase in utility per additional period is governed by parameter θ, an investor with large θ derives higher value of one increment increase in time in the short-run and, subsequently, reaches maximum utility faster than an investor with a lower θ. These behaviors can be observed from the shape of the utility function in Eq. (17) under different parameterization of θ as Fig. 11.1 shows, where the left panel depicts a utility function with low $\theta = 0.8$ and the right panel corresponds to a larger $\theta = 2$. The behavior of the former

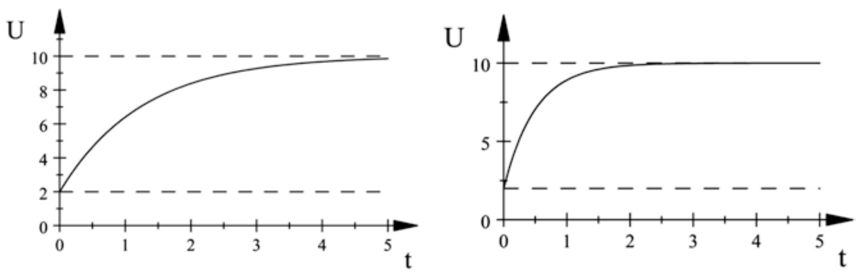

Fig. 11.1 The utility of time function

belongs to rational or institutional investors, who tend to react less to financial news and market events, whereas the latter belongs to irrational investors who tend to overreact.

The previous discussion suggests that parameter θ captures the degree of investors' overreaction to market conditions. By solving the investor duration problem, Fahmy (2020) shows that optimal portfolio duration is inversely related to the degree of overreaction. In particular, by taking a Taylor approximation of U about an expected duration time, Et, and solving for the optimal time, t^*, that maximizes this approximation, the author was able to derive the following optimal duration decision rule:

$$t^* = Et + \frac{1}{\theta}, \text{ or equivalently, } t^* - Et = \frac{1}{\theta}. \tag{19}$$

Figure 11.2 depicts the second-order Taylor approximations of the utility functions in Fig. 11.1 about an expected duration time $Et = 2$ weeks. Notice here that Et is the investor's own expectation regarding the time to revise or rebalance the portfolio. The distance between the optimal duration and this expectation is inversely related to parameter θ, which captures the degree of overreaction to market conditions. The rationale behind this inverse relation is that the lower the overreaction, the more likely that the investor will be to revise the portfolio in the long-run. This behavior is consistent with institutional investors, and it is well documented in the literature that long-term duration strategies are more profitable for rational investors under perfect information (Fahmy, 2020;

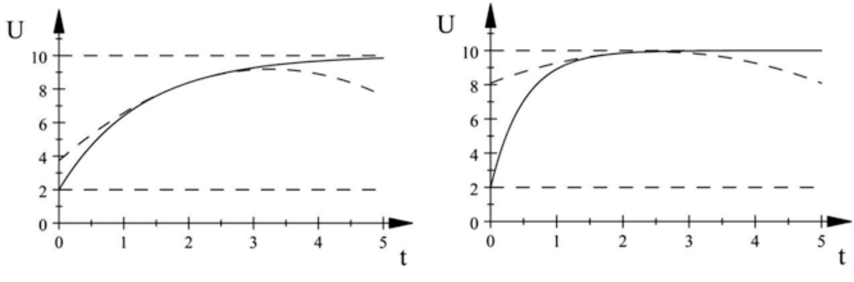

Fig. 11.2 Second-order Taylor approximations of the utility functions

Jegadeesh & Titman, 1993). On the other hand, irrational or retail investors with large θ who tend to overreact to financial news are more likely to revise/rebalance the portfolio in the short-run.

The result in Eq. (19) departs from most specifications in the literature on portfolio selection under uncertain time-horizon in its explicit treatment of the non-money attribute of the decision-making process, that is, Et (duration) and θ (uncertainty). That being said, two remarks regarding the empirical applicability of the result in Eq. (19) and how it fits in the present framework are in order: first, in practice, the investor's own expectation of portfolio duration, Et, is usually the investor or the fund manager's predetermined duration strategy, which could be short term (one or two weeks) or long term (twelve or more weeks). In an empirical analysis, it is sensible to assume a given expected duration a priori and to maximize $U(t)$ locally around it. Second, it is important to note that the degree of overreaction is intrinsic to the investor and is prone to cognitive and behavioral biases. In other words, it does not capture the risk of the event per se; rather, it captures the investor's attitude and reaction toward it. Most investors are risk averse. However, the degree of risk aversion and overreaction to financial news and events vary from one investor to another. In summation, although the result in Eq. (19) is useful in explaining various phenomena in financial markets (Fahmy, 2020), it does not capture climate uncertainty. The next sub-section shows how to modify this result to account for climate risk.

4.3 Climate Duration Hazard

I propose to match $U(t)$, the utility of time function in Eq. (17) over all possible values of t, with a posterior duration distribution $F(t|\text{ data})$ over future unknown states.[5] Since U is a monotonic increasing function in its argument (t in the present model), then a cumulative probability distribution function F may be convenient to describe utility.

If one entertains the frequentist approach in statistics and thinks of the portfolio duration problem as an experiment that is repeated in different

[5] This matching of utility with a distribution function is not new to the literature. The underlying theory of this matching approach is treated in Novick and Lindley (1979). An application of this theory on education is presented in a companion paper (Novick & Lindley, 1978).

states such that the trials of the experiment are the rebalancing/revising of the portfolio over time, then one could think of duration time as a random variable, denoted by *d*, with a density function *f*(*t*) and a distribution function *F*(*t*) over the set (0, *t*]. The reason the support of the distribution function *F* is a left-open right-closed set is to guarantee the right continuity of the distribution function *F*. This technical assumption is imposed to ensure that *F* is an adequate distribution function and that it will not impact the results of the model. In practice, two suitable distributions are commonly used to describe duration data: the exponential distribution, which is defined as

$$F(t) = 1 - \mathrm{e}^{-\theta t}, \tag{20}$$

and the Weibull distribution, defined as

$$F(t) = 1 - \mathrm{e}^{-\theta t^{\alpha}}. \tag{21}$$

The former distribution is characterized by parameter $\theta > 0$, whereas the latter is characterized by $\theta > 0$ and $\alpha > 0$.

The survival function, *S*(*t*), of the portfolio duration is the probability of its survival beyond time *t*; that is,

$$S(t) = \mathrm{Prob}(d \geq t) = 1 - F(t), \tag{22}$$

where *F*(*t*) is the portfolio duration distribution. The hazard function, *h*(*t*), is the likelihood that the portfolio revision/rebalancing or the market exit will be completed at time *t*, which is conditional on the portfolio surviving or lasting up till that time; that is,

$$h(t) = \frac{f(t)}{S(t)} = \frac{\frac{d}{dt}F(t)}{1 - F(t)}, \tag{23}$$

Per Eq. (23) and the definitions of F in (20) and (21), if portfolio duration, d, follows an exponential distribution, then the hazard function, h, is constant and equal to parameter θ. On the other hand, under the Weibull distribution, the hazard function exhibits duration dependence:

$$h(t) = \theta \alpha t^{\alpha - 1}, \tag{24}$$

for the Weibull distribution with parameters $\alpha > 0$ and $\theta > 0$. Notice that the hazard function of the Weibull distribution is increasing in duration if $\alpha > 1$, decreasing in duration if $\alpha < 1$, and constant (as well as equal to the exponential case) if $\alpha = 1$. The parameter α is known as the hazard rate parameter, and it governs the behavior of the hazard function in Eq. (24).

If the lower bound of U in Eq. (18) is zero, that is, $m = u(y_0) = U(0) = 0$, and the upper bound $M = U(t) = 1$, then the utility function $U(t) = M + (m - M)e^{-\theta t}$ becomes $U = 1 - e^{-\theta t}$. Together the previous two restrictions, with the monotonicity of U over the range $(0, t]$, guarantee that U satisfies the requirements of a distribution function in general and matches the exponential distribution function $F(t) = 1 - e^{-\theta t}$ in Eq. (20).[6] Moreover, since the Weibull distribution, $F(t) = 1 - e^{-\theta t^{\alpha}}$, is just a monotone transformation of the exponential distribution, $F(t) = 1 - e^{-\theta t}$, then it follows immediately that the function,

$$V = M + (m - M)e^{-\theta t^{\alpha}}, \alpha > 0, \theta > 0, \tag{25}$$

is a positive monotonic transformation of Fahmy's (2020) utility of time function $U = M + (m - M)e^{-\theta t}$, and V also represents the investor's preference over time.

Figure 11.3 plots the monotonic transformation function V in Eq. (25) for different values of the hazard rate parameter α using the same parameterization of U in Eq. (17), namely the upper bound $M = 10$, the lower bound $m = 2$, and the overreaction parameter $\theta = 0.8$. The thick bold line depicts V with a large hazard rate $\alpha = 8 > 1$. Notice how the

[6] The restrictions that the lower bound is 0 and the upper bound is 1 are not restrictive and can be thought of as rescaling of the utility function. Furthermore, this rescaling will not affect the analytical results of the model.

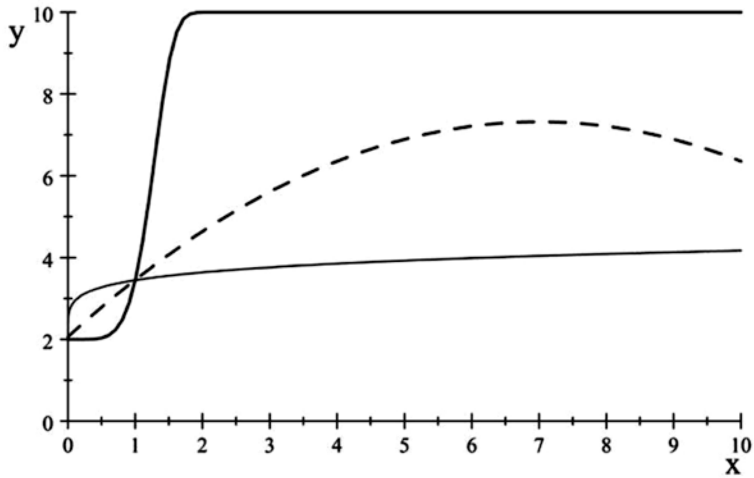

Fig. 11.3 A plot of the utility function *V, where the y-axis represents V(t) and the x-axis represents time t.*

trajectory of the function reaches its upper bound M. This swift swing over a short period of time is indicative of the high hazard rate perceived by the investor. This perception is what prompts the investor to re-visit the portfolio or even exit the market in the short-run during a global event. The dashed line in Fig. 11.3 corresponds to a utility function V with a neutral hazard rate $\alpha = 1$. This is in fact the exact same utility function that is plotted in Fig. 11.1 (left panel). Notice that when $\alpha = 1$, V is equivalent to the original utility function U that does not account for duration hazard. Finally, the thin solid line in Fig. 11.3 corresponds to the utility function V with a low hazard rate $0 < \alpha = 0.2 < 1$. Notice how this function progresses slowly to its upper bound. The "slow" pace is due to the fact that the investor perceives the diminishing duration hazard, which in turn prompts her to choose a long-term duration strategy rather than a short-term one.

The three versions of utility function V in Fig. 11.3 intersect at $t = 1$. Consider the possibility of a global climate event at time $t = 0$. The three curves in Fig. 11.3 depict three different scenarios in the short-run, that is, at a portfolio duration $0 < t < 1$, and in the long-run, at duration $t > 1$.

In the short-run, it is clear from integrating the area under each V curve that the total utility for investors who perceive climate hazard to be decreasing over time, that is, those investors with a utility of time function V with $0 < \alpha < 1$ (solid thin line in Fig. 11.3) is higher than others who believe that the hazard is neutral (dashed line) or increasing (solid thick line) over time. The same conclusion may apply to the long-run scenario, when $t > 1$. This is true since the utility functions with neutral and increasing hazard rates will reach the upper bound M faster than the decreasing duration hazard function (solid thin curve). The previous analysis reveals that a decreasing climate duration hazard perception is more rewarding for investors.[7] If policy makers, regulators, and key players in financial markets embrace the task of designing sound policies and strategies that guarantee a diminishing climate hazard over time, investors will be keener to hold green instruments. Moreover, this approach has the advantage of maintaining stability in financial markets by altering the attitude of investors who tend to panic and overreact in the short-run because of a climate event; this helps them to hold their positions rather than exiting the market. This preference reversal is crucial in reducing disruptions in financial markets that are mainly caused by retail investors. I illustrate this preference reversal in the following section.

To conclude this section, I solve the portfolio duration problem using the proposed monotonic transformation utility function V in Eq. (25) that accounts for climate duration hazard. Proceeding in the exact same way as in Sub-sect. 4.2, it is clear that taking a second-order Taylor approximation V about Et and solving for the optimal portfolio duration time that maximizes this approximation yield the following expression:

$$t^* = Et + \frac{ET}{\alpha\theta Et + (1-\alpha)}, \tag{26}$$

where α is the duration hazard rate and everything else is represented in Eq. (19). Equation (26) states that the optimal portfolio duration is a function of three types of uncertainty, namely, the investor's own expected

[7] Recall that the investor in the present framework is maximizing $U(t)$ around an expected duration time Et.

duration, *Et*; the investor's degree of overreaction to news, θ; and the hazard rate of duration, α, which may represent the climate duration hazard in the proposed model.

5 Empirical Analysis

Consider a risk-averse investor with an extremely low overreaction parameter $\theta = 0.02$. In practice, this could refer to institutional investors, mutual fund managers, or sovereign wealth managers. These types of investors usually prefer to adopt long-term duration strategies. Therefore, a reasonable mandate for these funds is to revisit the portfolio for rebalancing every two or three quarters. Ultimately, taking an average $Et = 32$ weeks target long-term duration is reasonable for parameterizing the problem. Consider an existing MV optimal portfolio that contains green instruments. Assume a major climate event at time $t = 0$. The investor's reaction to this event depends on the way they perceive its degree of hazard over time. If the investor believes that the climate duration hazard is increasing over time, that is, if $\alpha > 1$ in the utility of time function in Eq. (26), the likely reaction would be a revising/rebalancing of the portfolio sooner than later. When α is "high" or when its level is magnified by news coverage and social media, it is possible for the investor to exit the market in the short-run, that is, within days of the climate event. If many investors opt to exit, a major sell-off could significantly disrupt financial markets. The major sell-off that stock markets worldwide have recently witnessed amid the recent COVID-19 pandemic is a key example. It is easy to capture this behavior if one sets $\alpha = 5.6 > 1$ in Eq. (26). This results in

$$t^* = Et + \frac{ET}{\alpha\theta Et + (1-\alpha)} = 32 + \frac{32}{5.6 \times 0.02 \times 32 + (1 - 5.6)} \tag{27}$$
$$= 0.5 \text{ weeks.}$$

Ultimately, a rational investor with an expected long-term duration strategy $Et = 32$ weeks might exit the market within a few days of a major climate event due to the perception of increasing climate duration hazard.

On the other hand, if measures are taken to assure investors that the duration hazard of climate events is decreasing over time, then long-term (profitable) strategies are likely to be entertained. To see this, set $\alpha = 0.2$ in Eq. (27) and compute the optimal duration given the same intrinsic parameters, namely, expected time $Et = 32$ and overreaction $\theta = 0.02$. This gives a long-term duration strategy of 66 weeks instead of 0.5 weeks:

$$t^* = Et + \frac{ET}{\alpha\theta Et + (1-\alpha)} = 32 + \frac{32}{0.2 \times 0.02 \times 32 + (1-0.2)} \tag{28}$$
$$= 66 \text{ weeks.}$$

This analysis demonstrates that successful climate adaptation over time relies on enhancing investors' awareness of climate change risks and assuring them that these risks are diminishing over time. Therefore, per the following section, portfolio strategies and policies that guarantee a perception that climate risk is decreasing over time are essential for successful adaptation.

6 Concluding Remarks and Policy Recommendations

The temporal model that this chapter proposes provides a measure of climate duration hazard in the optimal solution of the portfolio duration problem. The analytical result of the proposed model (Eq. 26) reveals that investors exhibit increasing impatience and tend to revise, rebalance, or even exit the market in the short-run amid a major climate event due to the perception that climate hazard is increasing over time. This behavior has negative implications on financial markets in general as well as on climate mitigation and adaptation efforts in particular. Investors who believe that climate hazards are rising over time tend to be skeptical about investments in clean energy and/or mitigation or adaptation projects. Reversing this belief is, therefore, at the core of climate adaptation.

While altering investors' perceptions of climate risks is the key to sustainable climate adaptation, it is not an easy task. It requires the collective collaboration of politicians, policy makers, regulators, and practitioners in the finance industry. In particular, in order to achieve this incredible goal, politicians should put climate mitigation and adaptation policies at the top of their agenda. International organizations and governments around the world should increase their efforts toward implementing policies that stimulate investments in renewable clean energy that reduces the emissions of greenhouse gases, for example, feed-in tariff policies (Bürer & Wüstenhagen, 2009; Hofman & Huisman, 2012). Global institutions such as the World Bank are already working on creating more effective green solutions across asset classes. These solutions have been mainly focused on the fixed income class of assets, for example, green bonds, cool bonds, and eco notes (Reichelt, 2010). Innovative solutions that create more awareness in other asset classes are needed (Fahmy, 2022). Many investors are not aware of the carbon footprint and the climate impact of the companies in their portfolios. Few investors who hold oil and gas stocks in their portfolios are conscious of the risk they face with respect to those companies' stranded assets (Anderson et al., 2016). Despite the unanimous agreement on climate change following the Paris Agreement, climate risk remains unpriced by the market, and thus, future uncertainty about climate risk remains an increasingly important risk factor for investors—particularly long-term investors. CEOs of private companies should increase their efforts to reduce the carbon footprints of their products and, more importantly, to provide investors with clear signals and transparent rules with respect to how this reduction is to be achieved. Fund and portfolio managers should focus on factoring climate risks in their portfolios and design hedging policies that aim to lower the risk exposure to climate events without compromising the rewards of the portfolios.

In conclusion, the collective efforts of all of the above-mentioned players in financial markets will have the potential of inversely impacting the perception of increasing climate hazard over time. This preference reversal will, ultimately, lead to a successful climate adaptation and more sustainability over time.

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Part IV

Cities and Urban Areas

12

Mainstreaming Adaptation into Urban Planning: Projects and Changes in Regulatory Frameworks for Resilient Cities

Francisco García Sánchez

1 Introduction

All territories, and the urban areas within them, face new challenges imposed by climate change. In addition to mitigation measures to reduce greenhouse gas emissions (GHGs), adaptation strategies have been more favorably positioned on the political agenda (Rosenzweig et al., 2018; Taedong & Hughes, 2017). Climate change impacts are being addressed through different adaptation actions with changes made to spatial management models (Olazábal et al., 2018). Among them, urban planning has been recognized in scientific literature as one of the most effective tools for mainstreaming adaptation strategies. Efforts for integrating climate change adaptation with initiatives that go beyond sustainable urban development must consider a framework of flexible and experimental

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planning. The need to incorporate flexible planning strategies in line with climate variability is one of the main challenges faced by technicians and policy-makers responsible for urban planning (Runhaar et al., 2018).

This chapter will review the concept of adaptation, the mechanisms of its integration within urban planning, and its significance for managing climate change. Moreover, the chapter will also underscore experiences and good practices of mainstreaming adaptation into urban planning that reveal different lines of work within which cities are engaged.

2 Mitigation and Adaptation: Conceptual Framework

The concept of "adaptation" implies the will to take action for solving a problem. The array of definitions made by various authors (Schipper, 2007; Simonet, 2010) demonstrates its relevance within the context of climate change. According to the chronological review of this concept developed by the Intergovernmental Panel on Climate Change (IPCC), the difference between *mitigation* and *adaptation* to climate change has theoretically been recognized. The first official definition appears in the Second IPCC Assessment Report (SAR): "Adaptation is concerned with responses to both the adverse and positive effects of climate change. It refers to any adjustment—whether passive, reactive, or anticipatory—that can respond to anticipated or actual consequences associated with climate change" (IPCC, 1996, p. 831). The term mitigation is associated with the fight against climate change through efforts to reduce or limit GHG emissions. This differentiation will mark the field in which scientific literature will develop in the following years.

Urban planning, as a tool for the organization of land use and its development, has successfully integrated mitigation into its regulatory structures, both for the control of natural or man-made risks and for GHG emissions in urban environments (buildings and activities), as well as in the control of urban mobility.

However, in the context of climate change, adaptation can be recognized as the adjustment of a natural or man-made system that allows impacts to be reduced through active responses to adverse effects and through taking advantage of the opportunities offered by the early detection of system deficiencies. Consequently, the concept of resilience in the urban environment encompasses the capacity to face risks and to recover, taking into account adaptation actions.

Within the scientific literature, adaptation is structured around different concepts, such as the process, the intervening actors, and the space-time scale of the interventions. Park et al. (2012) state the importance of adaptation strategies based on the concept of transformation. In a study carried out on the Australian wine industry's management, two different concepts or ways of acting in the face of climate change were established: *incremental adaptation* and *transformational adaptation*. The first concept is characterized by a short-term, reactive, and current-conditions-focused management approach, aiming to keep the existing system operational. However, the second focuses on more profound and systemic long-term management, based on future uncertainty and questioning the effectiveness of actions taken throughout the process (Heikkinen et al., 2019; Park et al., 2012, p. 122).

Therefore, to manage the impacts in regions and cities, the transformation toward a comprehensive adaptation, in which short- and long-term measures converge, must be assessed. In this sense, the adaptation capacity is subject to opportunities for the public sector to provide knowledge of the impacts, creating an appropriate regulatory framework for adaptation and stimulating long-term incentives for decision-making (Heikkinen et al., 2019). However, in the case of transformational adaptation, the main actors in the process are public institutions that establish structural changes for the collective benefit. In contrast, in the case of incremental adaptation, the private sector has more weight and actions are aimed at enabling a person or community to maintain their functional goals in changing conditions (Wagner et al., 2014, p. 17). Nevertheless, it is necessary to combine actions from each of these theoretical concepts, since the ultimate goal is to carry out adaptive interventions when faced with the effects of climate change (both in the short and long terms). In summary, the aim is to achieve a high degree of adaptive capacity where knowledge of climate change is adequately managed with an appropriate regulatory framework supported by urban planning, as an essential tool when setting out adaptation actions (Birkmann et al., 2010; Carter et al., 2015; Göpfert et al., 2019; Runhaar et al., 2018).

Biagini et al. (2014) carried out an analysis of 92 projects financed through funds established by the United Nations Framework Convention on Climate Change in more than 70 countries. This analysis grouped the different interventions into five large categories: strengthening adaptive capacity, planning management, practical management of environmental resources, interventions of a technological nature, and interventions in the financial sphere (Table 12.1).

With a focus on planning management, the study detected the importance of the legislative framework and how the integration of climate change in planning should be a priority within public policies (Biagini et al., 2014). Urban planning must comprehensively manage the contents and requirements of land use and urban growth and its development in line with the demands imposed by climate change.

Despite the advances that have been made concerning adaptation to climate change, integration in urban and regional planning tools is still being called for from a transformational perspective, but with two additional characteristics: the possibility of developing incremental actions and the sufficient flexibility to adapt to the variability imposed by climate change.

Table 12.1 Actions detected for planning management

Category	Description	Actions
Management and Planning	Incorporation of scientific knowledge on climate change, its impacts, vulnerability, and risk within institutional management and planning	Developing adaptation plans, diversifying resources, planning directed toward droughts, coastal protection, adaptation based on ecosystem, and natural resources management
Policies	Generation of new flexible policies for adaptation to climate change	Monitoring of adaptation within the development of legislation, specific policies on land use, integration into existing regulations

Source: Compiled by the author based on Biagini et al. (2014, p. 104)

3 Mainstreaming Adaptation into Urban Planning

The significant changes caused by climate variables suggest that adaptation to climate change will continue to be an increasingly pressing problem for urban areas in the coming decades (Carter et al., 2015). Approaches to building adaptive capacity challenge traditional urban planning strategies. Traditional plans are too static for cities, especially fast-growing areas, where development comes in exposed areas with informal settlements unable to manage climate-related risks.

These issues highlight the role of planners in this process, raising questions concerning whether appropriate management structures exist that incorporate the development of effective adaptation responses. Therefore, it is necessary to position adaptation more favorably in its relationship with other areas within urban planning, such as the economy, health, or social inequality. Indeed, an adequate response to extreme events and greater flexibility in uncertain conditions can be guaranteed through correct urban planning at source which integrates adaptation.

Cities are gradually preparing themselves with urban planning tools, with codes and ordinances to support a possible integration of adaptation. However, this is not feasible without prior knowledge of the risks, provision for the integration of this knowledge, and the consideration of all the limitations and resources which may appear during the process of mainstreaming adaptation into urban planning.

3.1 Establishing the Risks of Climate Change for Cities

The imprecision of the IPCC itself in establishing the risks to be considered for adaptive strategies has conditioned the evolution of cities' regulatory framework. The urban question and its relation to climate in the IPCC assessment reports show a clear evolution toward increasingly complex interactions. In the first assessment report (FAR), the urban issue is considered only within the concept of "settlement", which encompasses all permanent modifications made by humans to their place of residence. The treatment given is far from the ultimate contemporary holistic vision, which incorporates all elements of the relationship between the urban phenomenon and its environment. However, the last report AR5 (IPCC, 2014) identifies the city as epicenter of the climate crisis.

There is inconsistency in the terminology employed across the five reports regarding the climate change risks. Only four risks are repeated across the five reports without discrepancies: sea-level rise, floods, droughts, and landslides (Table 12.2).

Droughts are difficult for cities to manage, as a resolution involves collaboration between supra-municipal institutions. On the other hand, landslides are risks that are directly associated with conditions of urban vulnerability and not only with regard to climate change. In the last four reports, heat waves are also considered revisiting the specific impact of

Table 12.2 Risks identified for cities and settlements in the Intergovernmental Panel on Climate Change (IPCC) assessment reports

	FAR	SAR	TAR	AR4	AR5
Sea-level rise	X	X	X	X	X
Salinity due to marine intrusion				X	
Storm surge and similar phenomena		X		X	X
Wind action	X	X	X		
Tropical cyclones			X	X	
Extreme rainfall				X	X
Flooding	X	X	X	X	X
Continental and coastal floods					X
Droughts	X	X	X	X	X
Loss of biomass	X				X
Loss of permafrost	X		X		
Landslides	X	X	X	X	X
Health/air pollution/water quality	X	X	X		X
Heat waves		X	X	X	X
Urban heat islands (UHI)			X		X
Cold waves		X	X	X	
Wildfires		X	X		
Agricultural/forest/fishing productivity reduction			X		
Frost risk			X		

Source: Compiled by the author

Notes: FAR (IPCC, 1990); SAR (IPCC, 1996); TAR (IPCC, 2001); AR4 (IPCC, 2007); AR5 (IPCC, 2014) urban heat islands (UHI) in AR5. In Working Group II's sixth report (AR6), which is currently being drawn up, the report's agreed outline highlights the inclusion of the urban dimension of adaptation with a specific chapter entitled "Cities, settlements and key infrastructure". The aspects to be discussed are related to the relationships between climate change and the sustainability criteria consistent with the development objectives approved at the Quito Habitat III United Nations Conference on Housing and Sustainable Urban Development.[1]

Although droughts and landslides must be managed with a broader perspective than that specifically focusing on climate change, it is possible to specify the three main threats caused by climate change that must be considered within urban planning: urban heat islands resulting from rising temperatures; floods, especially those derived from extreme storm events where surface runoff poses a direct risk to the population and economic assets; and the impacts for coastal cities derived from exposure to rising sea levels.

3.2 Integrating Adaptation and Risk

Cities are using different urban planning management strategies to integrate risks in their regulatory structures, either with qualitative methodologies projecting the end result of an urban fabric that reflects the risks or with those that are quantitative in nature, such as reducing buildable ratios in vulnerable areas. Likewise, the use of risk visualization or modeling tools and their degree of exposure allows the achievements made through adaptation actions to be monitored and evaluated. With regard to the latter, the generation of urban scenarios based on climate scenarios is a revealing aspect of new action strategies (Byrd et al., 2015; Kim & Newman, 2019; Rosentrater, 2010).

In an analysis of the adaptive planning strategies of 401 cities across the world, Araos et al. (2016) establish a classification of cities based on

[1] Chapter Outline of the Working Group II Contribution to the IPCC Sixth Assessment Report (AR6):

https://www.ipcc.ch/site/assets/uploads/2018/03/AR6_WGII_outlines_P46.pdf (Accessed 26 October 2020).

their progress in incorporating adaptation into their regulatory structures. Only 15% of cities reported an initiative to integrate climate change risks into their regulatory framework, and 18% indicated that adaptation actions within their regulations were in the introductory phase. Hence, the vast majority of cities surveyed either are in the very early stage of the adaptive process or have simply not made any progress.

An analysis of several case studies by Hamin et al. (2014, pp. 111–112) determined that, in the integration of the climate issue, planning was generally in one of three stages:

- Municipalities maintain official planning with an updated risk control that, without solving the different situations generated by climate change, recognizes vulnerable areas and allows adequate adaptation strategies to be implemented in the future.
- Municipalities integrate the climate issue into planning, with changes in technical specifications and regulations that reflect projected climate conditions, but where a complete planning process has not been undertaken.
- Municipalities incorporate specific climate criteria in planning in order to prepare for various scenarios and possibilities.

Scientific literature has shown that adaptation planning has been introduced into urban policy in addition to mitigation planning (Reckien et al., 2019). The municipalities that have undertaken urban adaptation policies mostly established strategies that combine mitigation and adaptation actions. In a mere few cases has there been a specific adaptation policy (Aylett, 2015). In this sense, the integration of the risk derived from climate change in urban planning represents a significant difference in comparison with sectoral adaptation planning.

3.3 Limitations and Resources

Undoubtedly, there are limiting factors in the integration of climate change adaptation into urban planning. The existence of conflicts of scale in the regulatory framework has been detected, where state legislation prevents coherent planning at the municipal level (Abel et al., 2011; Shi et al., 2015). The lack of flexibility of the state regulatory framework limits the possibility of experimentation in urban planning. Experimentation represents the practical dimension of adaptation, as focusing on adaptation rather than management makes city planning commitments inevitably experimental, applied, and local (Evans, 2011, p. 230). Flexibility in urban and regional planning is a key characteristic in adapting to climate change due to the nature of this phenomenon. In this regard, various authors state the current urban planning and management model's inefficiency, as it does not favor flexibility and innovation in planning (Roberts & O'Donoghue, 2013, p. 304; Rosenzweig & Solecki, 2014).

However, other conditions prevent progress in the integration of adaptation, with the ability to analyze the phenomenon and action approaches at times being limited by a low perception of climate risk or since the cumulative impacts of climate change are not taken into account (Abel et al., 2011). On the other hand, planning professionals are unaware of the importance of development tools in managing climate change and seem to be either secondary actors in or even absent from the development processes of this type of planning that integrates adaptation (Göpfert et al., 2019). Along with the absence of clear and effective leadership in decision-making at the regional and local level, the lack of economic and technical resources and the inappropiate information on the possible consequences caused by climate change (Hamin et al., 2014) are very relevant aspects that condition regulatory integration.

Recognizing the need to combine criteria that define risks and focus policies toward the integration of adaptation in urban planning, it is cities that have made progress in their attempts to solve the existing limitations (Caprotti et al., 2017; García et al., 2018; Rosenzweig et al., 2018). One of the key elements that some cities have been recognizing in their planning tools is establishing climate-sensitive land use and proper management based on the opportunities offered by the environment, especially ecosystem services (McPhearson et al., 2015; McVittie et al., 2018). Urban ecosystem services have not been adequately incorporated into urban governance and resilience planning, although the quality, quantity, and diversity of these resources influence the degree of urban sustainability. The transition toward more sustainable and resilient cities requires incorporating ecosystem services' organization strategies in urban planning, which is significant in climate change adaptation (Galderisi & Treccozzi, 2017; García, 2019). The modifications made in municipal ordinances and codes try to take advantage of all the urban environment resources, where green infrastructure is a basic asset for adaptation.

Regardless of the resources available concerning urban environment conditions, planning tools are able to define appropriate ecosystem services based on urban growth scenarios designed under climate projections. Without an adequate regulatory framework that establishes the adaptation guidelines integrated into the organization of land uses, urban planning's climatic dimension will be very weak. Some cities have taken great steps toward the integration of adaptation, which paves the way toward a new horizon in which exposure and vulnerability to climate change threats are a fundamental part of urban development.

4 International Experiences in Mainstreaming Adaptation

In regions with a long tradition in urban planning, there are some experiences in mainstreaming adaptation into urban planning that could serve as models in developing new regional and urban management tools. As it has been verified, the main impacts of climate change in cities (that must be managed through urban planning) have already been assembled in the different IPCC assessment reports. Some recent examples of normative integration of adaptation include specific actions for the following main risks: urban heat islands, floods due to extreme storm events, or sea-level rise. This chapter presents the cases of Vienna (Austria), Toronto (Canada), Lisbon (Portugal), and the United States, Florida, and New York. These examples show how updating risk maps and changes in the legal framework, regulations, and ordinances are basic strategies in developing a new method of managing climate change within urban planning.

4.1 Integrating Urban Heat Islands in Planning

The increase in surface temperatures in Vienna (Austria) is posing a public health problem with effects on economic and environmental sustainability. Urban heat islands (UHI) have been identified in urban planning, and specific regulations have been organized in order to adapt the city to this phenomenon. Strategic actions for climate-sensitive urban planning include city-wide actions to reduce urban heat islands.

The Municipality of Vienna has implemented the existing regulations with green infrastructure standards aimed at better managing the problem and introducing construction regulations that minimize the use of air conditioning in buildings. Some actions have a city-wide impact, such as new standards for green and open spaces, while others have a small-scale effect on the inner-city, such as greening the façades of the Municipal Department 48 headquarters on Margaretengürtel Street. Similarly, policies that restrict motor vehicles' movement on hot and windless days are promoted in all areas identified as heat islands.

The *Urban Heat Island Strategy* (City of Vienna, 2018) has strong implications for the city planning process. Four phases make up the planning process for any part of the city. The initial first phase sets out the basic information to be collected from an urban climate perspective, which will help contrive local climate models. Based on the exposure, sensitivity, and adaptive capacity, the city analyzes each municipal district, and an UHI Vulnerability map is generated that allows to continue with the next phases of the planning process (Fig. 12.1).

The second phase establishes urban planning and urban structure requirements, which could actively create or prevent UHI. The third consolidation phase implements technical standards and conducts a strategic environmental impact assessment to reduce the impact of urban heat islands. The final phase specifies actions, in the process of implementation, within a wide range of solutions.

Among the actions considered are various groups of guidelines that must be included, such as increasing urban green and shading open spaces and footpaths, greening and cooling buildings, increasing the city's blue infrastructure, and finally, cooling public transportation. Urban

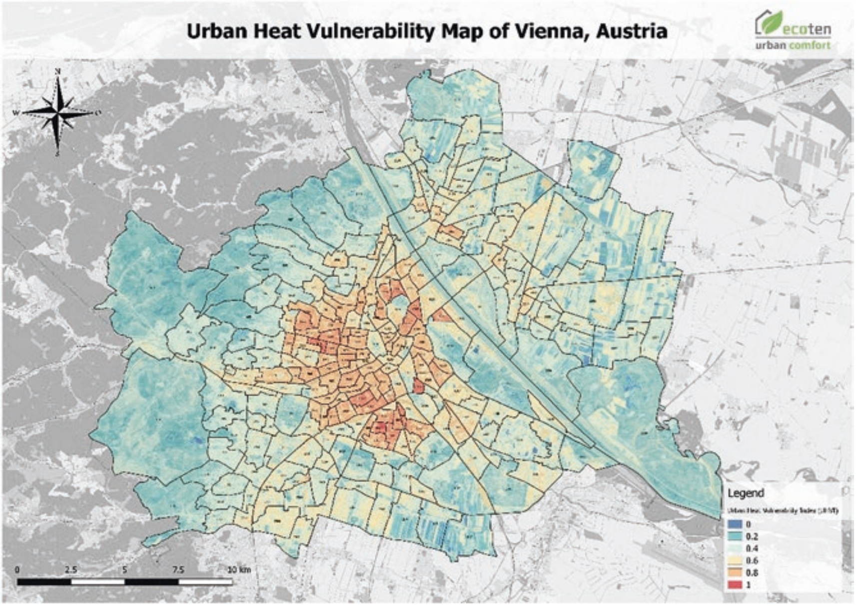

Fig. 12.1 Urban heat islands (UHI) Vulnerability Index Map. (Source: Ecoten urban comfort s.r.o. and Stadt Wien)

planning proposals ought to adequately justify the inclusion of these guidelines. However, combining strategic guidelines and the planning process phases leads to long-term development involving multiple stakeholders. Nevertheless, the Viennese strategy favors planning consistent with the possible environmental, social, and economic impacts of heat islands in the city.

Another example related to UHI is the *Toronto Green Standard* (City of Toronto, 2019), which is a set of measures with guidelines for new developments. Its purpose is to promote sustainable designs that address Toronto's environmental pressures: air quality, climate change and energy efficiency, water quality and efficiency, and ecology and solid waste.

The Toronto Green Standard is part of the City Planning Division's documentation for the Official Plan that is intended to ensure that the city improves the relationship between land use development and the environment. It is a key approach in order to achieve Toronto's ambitious climate action strategy (TransformTO), an aggressive environmental framework aimed at reducing greenhouse gas emissions by 80 percent by 2050. The measures will help meet this goal while setting standards to adapt the city to the climate, which makes them of particular interest within this chapter. Toronto's climate change framework and city-wide GHG reduction targets have been undertaken to address extreme weather regarding new buildings, neighborhoods, and infrastructure.

There are two versions of the Toronto Green Standard, each related to different types of development, one for *low-rise residential* and the other for *mid- and high-rise residential* (four stories and higher) and *non-residential*, such as industrial, commercial, and institutional developments. Each version contains two types of performance measures based on the degree of obligation conferred on them: Tier 1 (mandatory as determined by municipal planning) and Tier 2 (voluntary). If Tier 2 is satisfied, certified projects may be eligible for refunds for development costs paid to the city.

These standards, unlike classical planning, incorporate the climatic component in their specifications. Urban heat islands are included in the AQ2 (low-rise residential) and AQ4 (other developments) standards under the concept of improving urban air quality. The strategy requires the use of high-albedo materials, an increase in permeable pavement surfaces, and an increase in shadow areas. It also promotes the construction of green and/or cold roofs to reduce surface temperatures. The mandatory strategies are perfectly defined with action margins that allow sufficient flexibility for urban design teams.

4.2 Flooding due to Extreme Precipitation

For decades Lisbon has been affected by floods due to extreme weather events. However, the increase in recurrent flooding events, attributed to climate change, has motivated a revision of the *Lisbon Municipal Master Plan* of 2012 (Matos, 2016), generating new cartography, along with new norms and planning guidelines. The modifications carried out in 2020 introduce the concept of resilience in the contents and requirements of land use and urban growth. The idea behind the regulatory changes is to take advantage of public areas and municipal ecological structures to reduce flooding risk. Thus, the main strategy is based on the design of urban green spaces. This should promote an increase in their resilience, preferably through permeable pavements, the urban landscape modeling to allow in situ infiltration, and a vegetation structure adapted to the edaphoclimatic conditions.

To achieve these objectives, articles 49 and 63 of the Master Plan have been modified (PDM Lisboa, 2020), with a clear focus aimed at counteracting the impacts caused by climate change. Likewise, updating the risk mapping ensures better problem management. In Portugal's case, the integration of adaptation is supported by a resilient vision of the city based on the changing role of public spaces, especially green infrastructure. With this aim, Lisbon has mapped its municipality's ecological structure to take advantage of this resource within its flood control strategy (Fig. 12.2).

Actions such as guaranteeing ecological connectivity or increasing permeable urban surfaces in open spaces represent a tactical change in the city's climate management. The introduction of the concept of resilience within the regulatory framework is undoubtedly a declaration of their intent to plan in accordance with the variability imposed by climate change.

Another example for integrating flooding due to extreme precipitation in urban planning has been developed in the state of Florida. In 2015, strongly threatened by climatic factors, Florida promoted Senate Bill 1094, entitled *Peril of Flood*. This law includes the obligation to identify vulnerable coastal areas and specific elements of coastal management in Municipal Government Comprehensive Plans across the state. Florida had previously approved the Community Planning Act in 2001, allowing municipalities to deal with the risks and potential impacts of sea-level rise within their master plans.

One of the substantial elements of the paradigm shift is the creation of *Adaptation Action Areas* (AAAs). This concept, integrated into the local plans, identifies one or more areas that experience coastal flooding due to extreme high tides and storm surges and are vulnerable to the related impacts of sea-level rise. The aim is to prioritize funding for infrastructure needs and adaptation planning. AAAs are a mechanism for

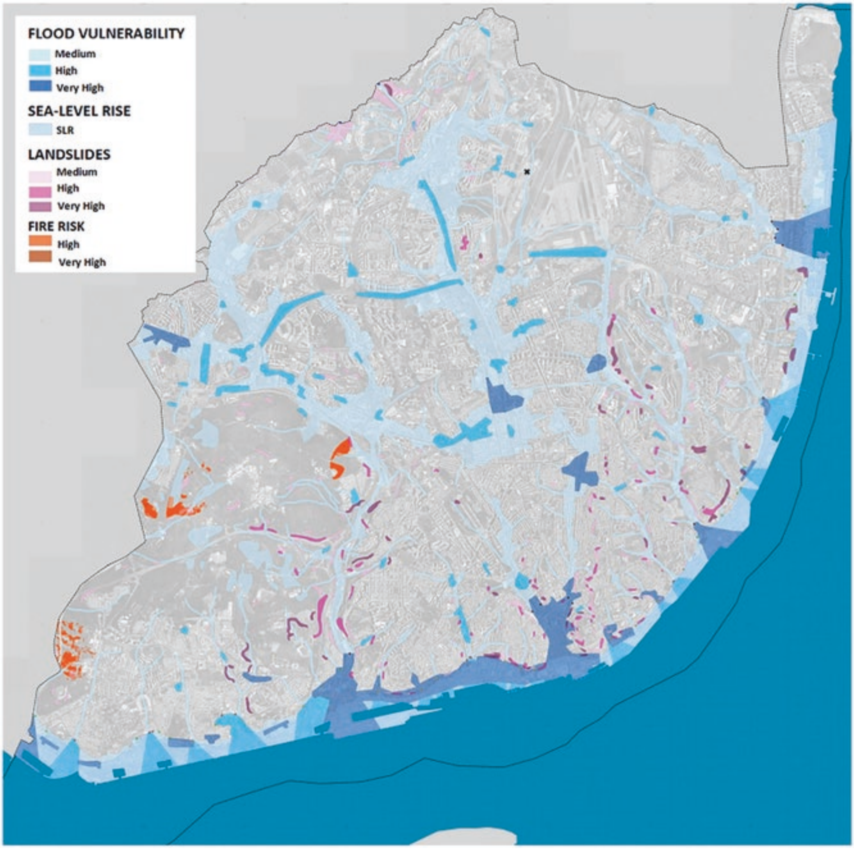

Fig. 12.2 Natural and anthropic risks, City of Lisbon Municipal Master Plan. (Source: Adapted from PDM Lisboa, 2020)

identifying neighborhoods at risk and for improving their climate resilience (Fig. 12.3).

One of the most active municipalities in the normative integration of Adaptation Action Areas has been Fort Lauderdale, which has adapted this resource as a tool that contributes to improving urban resilience (City of Fort Lauderdale, 2015). The city has incorporated the AAAs into the annual action plans and has introduced them into urban planning. This is evident in the city's Community Investment Plan for up until

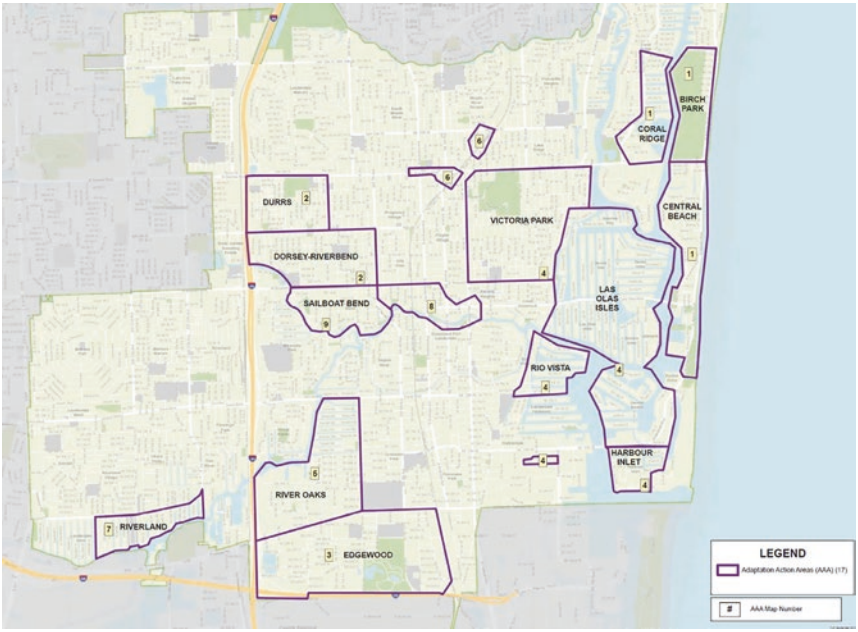

Fig. 12.3 Designated adaptation action areas, fiscal year 2020–2024. (Source: Adapted from City of Fort Lauderdale)

2024, including 17 AAAs with 43 projects identified for funding.[2] As a result of the adaptation areas, concrete actions within civil infrastructure are established, allowing the municipality to better mitigate and face possible climatic impacts.

4.3 Facing Sea-Level Rise

With the same protection strategy against rising sea levels, New York City has developed various policies and programs for managing adaptation to climate change. Of particular interest are the specific normative modifications for the control of coastal floods, "Flood Resiliency Zoning Text

[2] City of Fort Lauderdale, FL | Fiscal Years 2020-2024 Adopted Community Investment Plan. Available at: https://www.fortlauderdale.gov/home/showdocument?id=42638 (Accessed: 24 April 2021).

Amendment", that conform to FEMA's requirements, the Federal Emergency Management Agency. FEMA establishes the national cartography of floodplains in the United States, which is currently being revised in accordance with the new climatic projections for sea-level rise. The classification of flood zones based on their exposure is decisive for landowners since they must provide a specific insurance policy for flooding for homeowners.

The change in the initial exposure conditions due to climate change has also led to a readjustment of urban regulations. Until Hurricane Sandy, the New York regulatory framework did not take into account the variable of climate change when dealing with spatial planning. In 2013, the first rule incorporating the FEMA classification for floodplains was issued (City of New York, 2013). The strict FEMA regulations meant that homeowners with affected homes in flood zones had to add new insurance premiums to repair costs, premiums that were very high because these regulations did not allow buildings to be adapted to the new conditions concerning rising sea levels. Though, the 2013 regulation tried to relax these conditions, which were brought about by the devastating consequences of Hurricane Sandy.

The city is currently working on a new urban regulation in areas affected by rising sea levels in order to make the 2013 regulation more flexible—creating new specific zoning that accepts the uncertainty of the phenomenon and affects almost 800,000 people and more than 120,000 buildings located in flood zones (City of New York, 2019).

Among the main modifications to the urban regulations established in 2013 is the reconversion of disused port areas for their transformation into open spaces, where green infrastructure plays a decisive role. In addition, a set of rules has been implemented with the aim of generating greater resilience within buildings. Ground floors affected by flooding are granted the status of non-residential spaces. It is clear that this implies a loss of floor area ratio which the standard tries to resolve with new strategies such as admitting modifications in the building envelope,[3] reducing

[3] Building envelope: A three-dimensional space, shaped by height, setback, lot coverage, and yard controls that define the maximum volume within which a structure can be built on a zoning lot (City of New York, 2019, p. 2).

lateral setbacks, or allowing the relocation of commercial activity on floors situated above the maximum flood level. On ground floors, only the first nine meters (30 feet) from the façade line is allowed to be considered when calculating the floor area ratio, with subsequent variations in real estate taxes and a remaining buildable area that could be used in the event of rehabilitation. This also offers additional flexibility to facilitate mechanical, electrical, and plumbing equipment to be placed on the roof or in a separate structure within the plot (Fig. 12.4).

In summary, the flexibility of the rules in New York allows homeowners to rehabilitate and build their homes by greatly reducing insurance premiums, intelligently reorganizing the building area, and adapting to climate change demands. New York accepts uncertainty and sets clear risk control objectives, involving the community through regulations adapted to risk areas in order to create greater resilience.

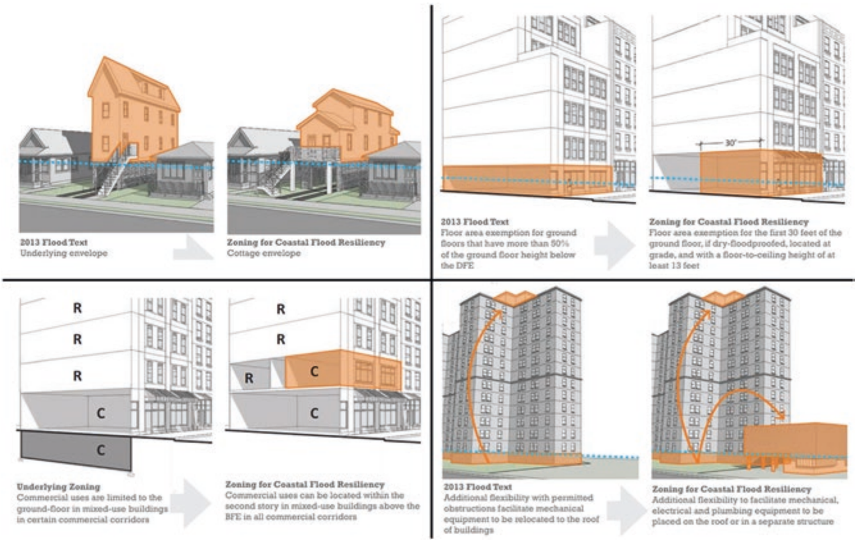

Fig. 12.4 Examples of the Flood Resiliency Zoning Text Amendment, making regulatory requirements more flexible. (Source: Adapted from City of New York, 2019)

5 Discussion

The distribution and management of land uses through climate-sensitive urban planning is one of the great challenges that cities face. Exposure to the main impacts defined by the IPCC (heat waves, extreme rainfall, or rising sea levels) is not usually incorporated into urban planning tools. However, some relevant cases point out the way toward resilient planning adapted to the future climate by including these studies in the planning process.

From the examples presented, some characteristics that should be considered within urban planning for mainstreaming climate change adaptation can be ascertained. First, once the threats have been identified and the vulnerability has been assessed, cities must set out adequate adaptation protocols for the detection of areas for intervention regarding the problem of climate change, as has been seen in the cases of Vienna and New York. Regulations are therefore in compliance with the threats, and cities modify or expand their regulatory framework to consider risk in land use management, as could be deduced from the case of Toronto or Lisbon. Second, cities embrace the uncertainty of climate variability's adverse phenomenon and promote long-term regulatory changes, but with enough flexibility to respond and to review actions as needed. An obvious example of this is Lisbon's case, with the recent changes to the Master Plan and the updating of its flood cartography, or New York, where the regulatory modifications cover areas based on a cartography that is sensitive to uncertainty. Finally, the integration of adaptation to climate change within urban planning is specified in the definition of adaptation areas, as in Fort Lauderdale's case, with the formulation of ordinances that allow for the resilient management of new urban growth.

As we have seen, one of the main actions against climate change is the recovery of green and blue infrastructure as a strategic resource for urban resilience. In the cases of Vienna or Toronto, an orderly planning of areas affected by heat waves is possible through the use of revegetation strategies and the promotion of ecosystem interconnectivity inside planning. This is also the case in Lisbon and Fort Lauderdale, where the protection of floodplains has required regulatory changes to protect open spaces.

New York has also developed a specific strategy for the protection of the coastline, in which open green spaces are conceived as a resource for climate change adaptation. These examples show the need to define planning toward urban environmental sustainability models, in line with the criteria promoted in the IPCC AR6 Assessment Report.

Finally, there is a relevant issue, oftentimes overlooked, which acts as a limiting factor for resilient urban planning, "capacity building". This planning tool enables urban planners and decision-makers to control the climatic response of cities and settlements. Also, the uncertainty surrounding the consequences on future unknown climate changes has been found to trigger a poor adaptive response. Land use management tools can only adequately integrate climate change if this concept is previously understood by planning staffs. The success of climate-resilient urban planning in the five cases analyzed in the chapter has only been possible through specific training of urban planners and decision-makers.

Urban planning should, therefore, explore new experimental formulas in the definition of land uses, where climatic exposure and vulnerability must be integrated in a holistic way. For an adequate response to climate impacts, the five cities have developed cartographies of impacts and vulnerability. These analysis resources imply a change of model concerning risk planning. Urban planning will be consistent with climate change only when new methodologies for interdisciplinary collaboration between climate scientist and urban planners are developed. Flexible planning, including norms and ordinances adaptable to changing future climate conditions, must be based on the use of climate scenarios, integrate uncertainty, and promote preventive action in decision-making.

6 Concluding Remarks

The demand which has been made to incorporate adaptation into urban and regional planning conflicts with planning models trapped in classic land use management systems. Experimenting with new planning tools in the face of climate change inevitably requires the modification of the regulatory framework. The need to incorporate flexible planning strategies in line with climate variability is one of the main challenges of regional and urban planning.

Mitigation measures focused on controlling GHG emissions within urban planning must be reciprocally complemented by adaptation strategies aimed at risk control. Sea-level rise, extreme rainfall and floods, and rising temperatures and urban heat islands are critical threats that must be integrated into urban planning from the initial phases of the master plan design or during its implementation. The cases presented are examples of the various options for integrating adaptation through regulatory changes that cities are developing. The new regulations have to embrace the uncertainty which exists, trying to incorporate greater flexibility into the ordinances and establishing specific norms adapted to the new conditions derived from climate change.

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13

Path-Dependency as a Potential Cause for the Disjunction Between Theory and Tools in the Modeled Reality of Sustainable Architecture

Maxime Leblanc and Aurélien Catros

1 Introduction

Every year, the American Institute of Architects (AIA) publishes a report on architectural firms in the US. The report surveys more than 19,000 member-owned firms to analyze trends and offer projections on the future of the industry. For over a decade, sustainability and resilience continue to be among the main topics addressed by these reports. In 2019, over half of the firms (51%) reported using energy-modeling software in their projects either in-house or through external consultants,

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and 13% of firms plan to integrate energy modeling in the near future (American Institute of Architects et al., 2020). Despite that these figures seem to indicate that most firms are doing their part in minimizing energy consumption, carbon emissions from the building sector keep increasing every year.

According to the United Nations Environment Programme (UNEP), “the building sector contributes up to 30% of global annual green house gas emissions and consumes up to 40% of all energy” (UNEP SBCI, 2009, p. 3). These numbers, taken more than a decade ago, are likely to increase given global industrialization and urban migration tendencies observed since the industrial revolution (International Energy Agency (IEA), 2019). The building sector is a significant contributor to our current climate crisis and should therefore be closely analyzed to help reduce the environmental impact caused by the extraction and production of building resources. In recent years, scholars and practitioners have spent considerable resources developing and promoting sustainable building solutions, mainly through energy-modeling software, which have become important tools for architects. Thus, when designing greener buildings, architects and engineers mainly focus on improving energy efficiency as dictated by such software, but more rarely take into account the environmental impact of the materials used.

2 How Do We Build Sustainably?

Since the computerization of the architectural profession some 50 years ago, most of a building’s design is shaped through software. Today, 2D and 3D Computer Aided Design (CAD) programs, like Autodesk’s AutoCAD, are used for smaller-scale projects by smaller firms, while large-scale endeavors are usually designed using the more recent Building Information Modeling (BIM) software (American Institute of Architects et al., 2020).

What we refer to as BIM software (Autodesk’s Revit and BIM360, Graphisoft’s ArchiCAD, and Nemetschek’s Vectorworks among the most used) are 3D modeling platforms that facilitate collaboration between architects, engineers, and construction professionals (AEC). While the main advantage of BIM is its collaborative and interactive possibilities, its secondary purpose is to track aspects such as cost, life cycle, and maintenance of buildings. According to the AIA's 2019 annual report, BIM software has become indispensable to the building sector: 100% of large firms, 88% of mid-sized firms, and 37% of small firms used it in 2019 (American Institute of Architects et al., 2020).

Among the vast number of features offered by such software, AEC professionals tend to focus only on a few of them. Indeed, the vast majority of firms use BIM for its visualization capabilities (84%) rather than its potential to analyze and assess energy consumption/production and building performance (26%) (American Institute of Architects et al., 2020) (Figs. 13.1–13.2).

Although the latter statistic might appear low, it still represents approximately a quarter of firms using BIM for its environmental analysis proficiencies. It justifies the apparition of dedicated plugins and tools to tackle the current environmental crisis. Thus, they are expected to

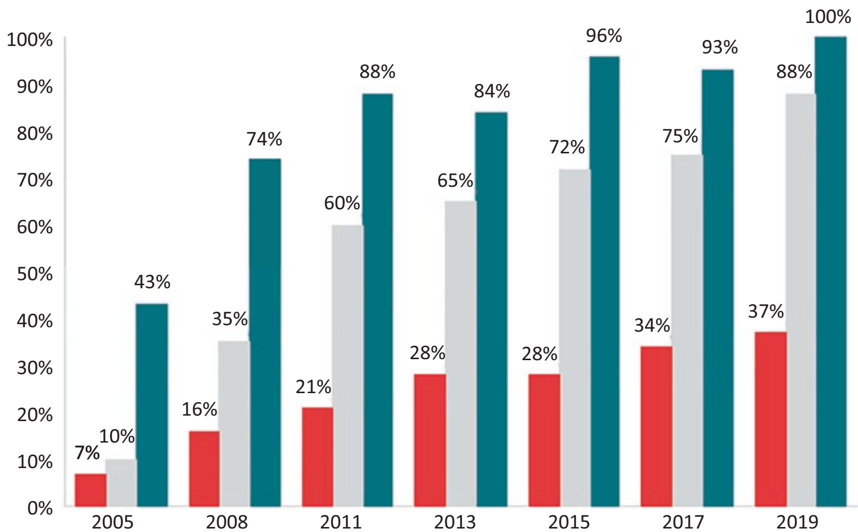


Fig. 13.1 Share of firms using Building Information Modeling (BIM) for billable projects. (Source: AIA, 2020 AIA Firm Survey Report, www.aia.org/firmsurvey)

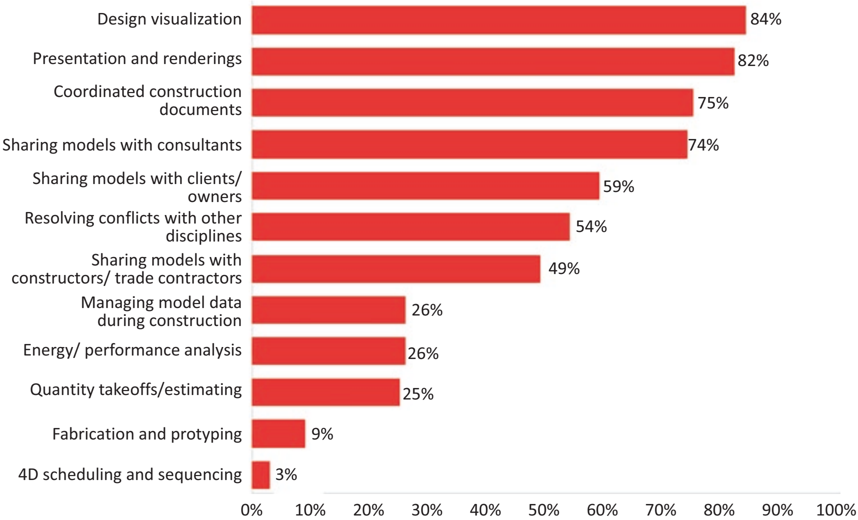


Fig. 13.2 How firms are using Building Information Modeling (BIM) for billable hours. (Source: AIA, 2020 AIA Firm Survey Report, www.aia.org/firmsurvey)

provide architects with the necessary tools to combat global warming beyond the 2°C threshold.

Autodesk's Revit is one of the most widely used BIM software in the world. With over 4.3 million subscriptions, Revit is a key software for plugin developers (*Autodesk Quarter Results*, 2019). According to the most recent edition of the *BIM Handbook*, there is a growing pressure to provide "much more energy-efficient buildings that use recyclable materials, which means that more accurate and extensive analyses [through software] will be needed" (Eastman et al., 2018, p. 393). Given that integrating energy analysis directly within a workflow constitutes the most cost-efficient way to reach all of a firm's goals, the need for Revit-compatible plugins (third-party software extensions) became evident. Autodesk's Revit Store offers over 1400 plugins that can simplify, complexify, or analyze almost every aspect of the work performed by AEC professionals. With the desire to produce more energy-efficient, net-zero energy, or even regenerative projects on the rise, an increasing number of sustainability-centered plugins are being developed and released. As of December 2020, according to Autodesk's Revit Store filtering system, Tally (developed by KT Innovations) is at the top of the list for most downloaded building performance analysis plugin.

Tally is a Life Cycle Assessment (LCA) tool, which "allows architects and engineers to quantify the environmental impact of building materials for whole building analysis as well as comparative analyses of design options" (*Tally: Overview*, 2020, para. 1). LCA is a standardized assessment method whose goal is to quantify and compare the environmental impacts of a system throughout its life cycle—from the extraction of the raw materials necessary for its manufacturing to its end-of-life treatment (landfill, recycling, etc.), and through its phases of use, maintenance, and transport. By identifying avenues for eco-design or improvement in the system's environmental balance, LCA allows architects to compare two systems that have the same function in terms of their environmental impact. LCA helps predict certain pollution transfers and assesses which elements of a product cycle contribute the most to this phenomenon. This outcome is achieved through a series of standardized steps as well as a mathematical model of transformations that make it possible to match flows to their environmental impacts, and thus contributes to a more informed design process.

However, LCA does have inherent limitations. First, it is almost impossible to obtain all the information regarding flows used for a particular product. This might prompt some users to opt for whatever is available and call upon generic or simplified data, which lacks precision. Even today's most powerful companies struggle to track the origins of the materials involved in their own products (Crawford & Joler, 2018, section XI). In current iterations of LCA software, processes are generally regionalized but not all regions of the world are represented for the same type of process. It is therefore often difficult, if not impossible, to carry out a life-cycle analysis that takes full account of the particularities and context of each area. The results are questionable depending on the methodological choices made. Therefore, the values obtained can hardly be used by the public and must be studied in detail beforehand.

In addition to Tally, other popular plugins like One Click LCA (developed by Bionova Ltd.) also provide insight on certification compliance for most major certification standards, including LEED, BREEAM, DGNB, and HQE, as well as LCA reports. Developed by the US Green

Building Council (USGBC) in 1993, the Leadership in Energy and Environmental Design (LEED) standard provides a framework for implementing measurable green building design solutions. LEED is the most widely used green building rating system in the world with over 80,000 participating projects, including over 32,000 certified commercial projects worldwide (Tufts, 2016). Since the development of LEED, clients have begun demanding buildings to be designed above minimum code requirements (American Institute of Architects et al., 2020). Although this process shows that the client spends additional money to build above standard buildings, LEED has become less about environmental sustainability and more about ensuring profitability for those willing to get certified. On the USGBC's own website in December 2020, under the rubric "why LEED?" the economic benefits are cited well before the environmental ones, the latter relegated to the third point out of three. Among the economic benefits, we find that "61% of corporate leaders believe that sustainability leads to market differentiation and improved financial performance" and that "LEED-certified buildings command the highest rents, while lease-up rates typically range from average to 20% above average" (*Why LEED Certification*, 2020, section 2). Making a profit off greener buildings is not necessarily nefarious when it appears to be win-win. However, this works only if buildings designed through LEED actually create greener buildings; this prompts the question: do they?

Among the many critiques of LEED as a sustainability tool, a recurring issue is that "its points for energy conservation are based on a computer model showing how much energy the building should save, if certain features are implemented, and not on actual post-occupancy energy use" (Barth, 2018, para. 29). Indeed, only 14% of firms performed post-occupancy evaluations (POE) in 2019 (American Institute of Architects et al., 2020), meaning that once buildings are certified and constructed, their actual energy-saving potential is rarely assessed despite the fact that strong methodologies exist to perform such a task (Elzeyadi, 2018). Already in 2013, John Scofield published an article in which he examined the energy consumption, greenhouse gas emission, and ENERGY STAR Energy Performance Rating (EPR) data for 953 office buildings in New York City (NYC) according to Law 84, which required certified building owners to annually measure their energy and water consumption (Scofield, 2013). Scofield's findings indicated that:

> *Collectively, the LEED buildings use the same amount of source energy and emit the same amount of GHG as do other NYC office buildings. LEED Gold buildings show a 20% reduction in source energy consumption and GHG emission than other buildings, but these savings are offset by the fact that LEED buildings at the Certified and Silver level actually use more energy and emit more GHG than other NYC office buildings. Looking at [Silver or higher] LEED buildings […] we find their GHG emission and source energy consumption to be insignificantly different from non-LEED NYC buildings.* (Scofield, 2013, p. 523)

Scofield concludes his paper by saying that "LEED building certification is not moving NYC toward its goal of climate neutrality" (Scofield, 2013, p. 524), which, in hindsight, should have been taken more seriously. Recent studies obtain similar results from comparing LEED buildings to their non-LEED counterparts in NYC (Saldanha & O'Brien, 2016). We now know that LEED certification does not produce substantially greener buildings compared to non-certified buildings in cities like NYC. The system currently in place simply does not work despite software and plugins working hand-in-hand with certification systems.

As it currently stands, architects, pressured by clients and socio-moral reasoning, strive to produce greener buildings, and these green buildings often require the seal of approval by organizations like the USGBC. To obtain these certifications, designers turn to plugins like Tally and One Click LCA to guide their decisions. The underlying problem is that certified buildings are not as green as they ought to be. Thus, arguably, the plugins used are calibrated to produce sub-par green buildings. Instead of rethinking what defines a green building and sustainable design, we turn to developing further software and patches to existing software; as a result, the cycle perpetuates in such a way that it is counter-productive to our efforts of reducing negative environmental impacts. In the end, can we even use these tools effectively, sustainably-speaking?

3 What Does Sustainable Architectural Theory Say?

Aware of the limits of simulation tools and plugins, scholars proposed different solutions to further analyze sustainability to avoid building architecture falsely touted as "sustainable." Often, such failures can be traced back to the universality of software and design tools that are sold as "one size fits all" solutions. Scholar Mahadev Raman argues that "there is no single architectural style or engineering solution that is efficient and appropriate for buildings in all climatic regions" (Raman, 2005, p. 43). Two theoretical trends are at the fore of debates surrounding sustainable design practices. Some advocates argue for the continuous updating of our most efficient methods (such as LCA) by integrating environmental impact and/or social factors into the algorithms. On the other hand, some scholars advocate for a redefinition of what constitutes sustainability and suggest a reassessment of our current quantitative approaches to green building. These contradicting views can be summarized as building through data and building by example, respectively.

Those who argue for increasingly up-to-date quantitative systems propose that we should build off of LCA; although it fails to account for crucial factors like the social impact of producing products and buildings, it still represents the best tools currently available. We have seen that LCA results are highly dependent on the varying parameters chosen for each project and the availability of data. Thus, comparative studies sometimes display contradictory results which tend to weaken LCA's reputation. Two successive evolutions of LCA arose in the last decade: environmental-LCA (E-LCA) and social-LCA (S-LCA), the latter a variant of E-LCA with some adaptations in accordance with specific ISO standards. Similar to the "classic" LCA, both techniques share the life-cycle perspective of materials from extraction, manufacturing, distribution, use, maintenance, and even recycling. Both E-LCA and S-LCA are improving on the classic LCA by attempting to model the real socio-environmental impact of each project. According to Elisabeth Ekener, the main difference between E and S-LCA relates to the impact on which they each focus, since "E-LCA addresses environmental impacts, whereas

S-LCA addresses social impacts, i.e. impacts on human beings and the society" (Ekener, 2013).

Published in 2020, a large-scale bibliometric analysis examined the literature on S-LCA from the last 15 years (2003–2018). Huertas-Valdivia et al. illustrate the evolution of S-LCA from a nascent to a standalone field of research with hundreds of publications appearing in specialized journals like the *International Journal of Life-Cycle Assessment*. According to this study, scholarly activity on the topic boomed after the publication of the United Nations Environmental Programme's (UNEP) Guidelines for Social Life Cycle Assessment of Products released in 2008 (Huertas-Valdivia et al., 2020). These guidelines provided a framework for assessing the socio-economic impacts of a product's life cycle and showcased some of the most common sources of data for assessing social impacts. Although S-LCA is promising in its ability to improve our understanding of product cycles' social impact, we still have a limited degree of knowledge when it comes to informing actual decision-making and communication (Lindkvist & Rydberg, 2020). Indeed, among the many critiques of S-LCA, the most common is the field's inability to reach a consensus on which social indicators to model:

> *Unlike environmental impact indicators, many social impact indicators are difficult to quantify. Due to the complexity of finding accurate and objective proxies for social indicators, no unanimity exists on what impact categories to include or how to measure some impacts. In fact, many authors supplement the impacts in the UNEP/SETAC Guidelines with additional ones.* (Huertas-Valdivia et al., 2020, p. 6)

While S-LCA is nonetheless likely to lead to the development of new tools and software in the coming years, some voices claim that such a way is tremendously limiting architects' perspective on sustainability. For example, scholar Kiel Moe proposed that these tools already:

> *Limit the practices of sustainability and preclude approaches that would engage architects in the much larger dynamics of sustainability. The shift in approach suggested here is not more statistics, checklists, or technologies but the development of deeper knowledge with regard to the actual context and technics of any architectural project.* (Moe, 2007, p. 28)

In other words, Moe suggests that we should stay away from our current performative models based on "green platitudes" which only serve to reinforce our "hegemonic pessimism of equilibrium-based notions of net-zero oriented, isolated systems" (Moe, 2018, p. 69). Methods such as LCA have contributed to opening up our understanding of systems boundaries in architecture, whereas prescriptive and performative models still consider buildings as closed systems, which intrinsically fail to consider the open-system nature of our world (Moe, 2017). Therefore, the critical assumption is that in order to truly build sustainably, we must admit to our lack of understanding of ecology and sustainability as they relate to the built environment and reorient our efforts toward developing methods for open-systems thinking.

Carmella Cucuzzella and Sherif Goubran echo Moe's concerns: "building sustainably [...] means moving the design and development focus beyond the measurement and reduction of damages and towards the aim of protecting the environment, promoting cultural development, encouraging local economic development, and addressing social challenges in our communities" (Cucuzzella & Goubran, 2020, pp. 3–4). Cucuzzella also suggests tackling sustainable architectural design inquiries using philosopher Jean-Paul Sartre's *in-self, for-itself,* and *for-others* existentialist split. The "in-self" corresponds to what she calls *facticity*, which relies on standards and performative thinking, while *potentiality* and *perception* correspond to Sartre's "for-itself" and "for-others," respectively. Potentiality encompasses the heuristic and anticipative way to think sustainably, that is, "what it [a building] has the possibility to become, for-itself" (Cucuzzella, 2020, p. 32), and perception is a matter of communication design in a semiotic way, that is, how the building is a signifier that conveys sustainability as a signified. For Cucuzzella, these last two aspects appear to be equally constitutive of what a sustainable architecture is, ontologically. Although both cannot be treated by any software, they should be considered in the design of any green building.

4 Why Such a Gap Between Theory and Tools?

We observe a major disjunction between what architects do when it comes to designing sustainably and what researchers claim architects should do. Even if a gap between theory and practice is usual in many fields, it is strange for researchers to pursue avenues such as S-LCA despite scientific objection regarding its validity as a quantitative tool. In the following section, we propose our own hypothesis as to why architectural design tools continue to be developed around contested theories of sustainable design practices, and how such a path does very little to prevent the building industry from shattering global warming's glass ceiling.

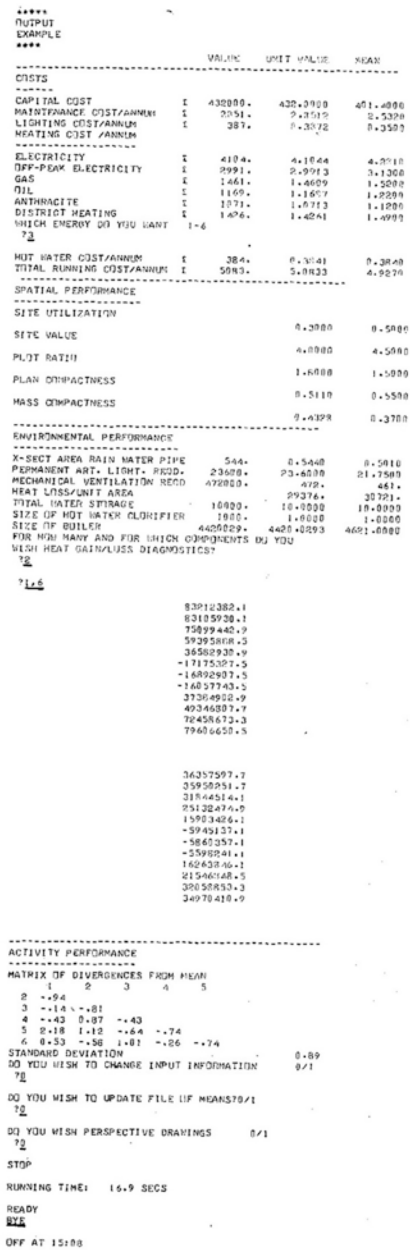
Based on the analysis of seemingly illogical evolutions of objects, *path dependence theory* claims that historical events and choices can have disproportionate effects on the development of a specific object or technology in the future. A notable example, which led to the conceptualization of this theory in 1985 by Paul David, is the ubiquitous QWERTY keyboard with its non-optimized letter positioning (Kay, 2013). This technological curiosity was initially devised as a way of preventing the jamming of the now-obsolete mechanical typewriter keys by separating commonly used letters. From this first example, a myriad of other cases emerged as examples of path-dependency theory in many other disciplines as Scott E. Page explains: "theoretical, historical, and empirical studies of path dependence run the gamut, covering topics ranging from the selection of institutions, to the formation of government policies, to the choice of technologies, to the location of cities, to pest control strategies, to the formation of languages and law" (Page, 2006, p. 88). Aside from providing novel ways of understanding product design evolution, path-dependency can serve as a framework for understanding shifting trends and explaining the current state of a given technology.

According to Page, path-dependency represents the entanglement of four separate yet connected effects that Bryan Arthur began describing in 1989: *increasing returns, self-reinforcement, positive feedbacks,* and *lock-in* (Page, 2006). Through the opposition of what Page calls *phat-dependence* (something which "depends on the set of approved proposals") and *path-dependence* (something which "depends on the order in which proposals were approved"), we argue that the disjunction between modeling tools and sustainable design theory could be partly understood through the order of apparition and approbation of tools and theory. In order to assess such an assumption, the following section discusses the early history of energetic analysis tools for sustainable design and how its development created a path-dependency that influences the tools we use today.

According to Kolarevic (2005), the very first architectural performance analysis and simulation tool was called PACE (Package for Architectural Computer Evaluation). PACE was developed by ABACUS (Architecture and Building Aids Computer Unit Strathclyde), a group of researchers led by Thomas Maver in the late 1960s and early 1970s (Kolarevic, 2005). Considered the ancestor of the performance analysis tools employed throughout the building industry today, PACE measured costs, spatial performance, environmental performance, and activity performance in order to assess and adapt the design of a building (Fig. 13.3).

Although, at face value, these characteristics appear to consider the essential components of a building, their descriptions lacked the specificity required to properly understand such complex and multi-faceted concepts. For example, according to Maver, spatial performance measures only the *plot ratio* and *mass compactness* of a site, while environmental performance was understood as the "plant sizes which [would] give adequate environmental conditions" (Maver, 1971, p. 208). Despite PACE's vague parameters, the tool provided a way for designers to augment their buildings in light of certain sustainable characteristics, giving rise to a new way of designing. We still use this sequential and iterative process in modern-day software and plugins, like Tally, which correspond precisely with the Kolarevic's description of PACE:

> *The program would instruct the designer how to change geometrical or constructional information, i.e. how to modify the design concept to improve performance and then submit the modified design for "re-appraisal." In the end, the "repetitive man/machine interaction" would lead to convergence of an "optimum design solution."* (Kolarevic, 2005, p. 196)



```
*****
OUTPUT
EXAMPLE
****
                                    VALUE      UNIT VALUE     MEAN
-------------------------------------------------------------------
COSTS
------
CAPITAL COST                  £    432000.     432.0000     401.4000
MAINTENANCE COST/ANNUM        £      2351.       2.3512       2.5320
LIGHTING COST/ANNUM           £       387.       0.3372       0.3500
HEATING COST /ANNUM
-------------------
ELECTRICITY                   £      4104.       4.1044       4.2210
OFF-PEAK ELECTRICITY          £      2991.       2.9913       3.1300
GAS                           £      1461.       1.4609       1.5200
OIL                           £      1169.       1.1697       1.2200
ANTHRACITE                    £      1071.       1.0713       1.1200
DISTRICT HEATING              £      1426.       1.4261       1.4900
WHICH ENERGY DO YOU WANT   1-6
 ?3

HOT WATER COST/ANNUM          £       384.       0.3841       0.3840
TOTAL RUNNING COST/ANNUM      £      5083.       5.0833       4.9270
 -----------------------------------------------------------
SPATIAL PERFORMANCE
--------------------
SITE UTILIZATION
                                                 0.3000       0.5000
SITE VALUE
                                                 4.0000       4.5000
PLOT RATIO
                                                 1.6000       1.5000
PLAN COMPACTNESS
                                                 0.5110       0.5500
MASS COMPACTNESS
                                                 0.4329       0.3700
---------------------------------------------------------
ENVIRONMENTAL PERFORMANCE
--------------------------
X-SECT AREA RAIN WATER PIPE       544.      0.5440       0.5010
PERMANENT ART. LIGHT. REQD.     23600.     23.6000      21.7500
MECHANICAL VENTILATION RECD    472000.        472.         461.
HEAT LOSS/UNIT AREA                          29376.       30721.
TOTAL WATER STORAGE             10000.     10.0000      10.0000
SIZE OF HOT WATER CLORIFIER      1000.      1.0000       1.0000
SIZE OF BOILER                4420029.   4420.0293    4621.0000
FOR HOW MANY AND FOR WHICH COMPONENTS DO YOU
WISH HEAT GAIN/LOSS DIAGNOSTICS?
 ?2

 ?1,6

                              83212382.1
                              83105930.1
                              75099442.9
                              59395808.5
                              36582930.9
                             -17175327.5
                             -16892907.5
                             -16057743.5
                              37384902.9
                              49346807.7
                              72458673.3
                              79606650.5


                              36357597.7
                              35950251.7
                              31844514.1
                              25132474.9
                              15903426.1
                              -5945137.1
                              -5860357.1
                              -5598241.1
                              16263846.1
                              21546148.5
                              32058853.3
                              34970410.9


-----------------------------------------------------------
ACTIVITY PERFORMANCE
--------------------
MATRIX OF DIVERGENCES FROM MEAN
        1      2      3      4      5
  2  -.94
  3  -.14   -.81
  4  -.43   0.87   -.43
  5  2.18   1.12   -.64   -.74
  6  0.53   -.56   1.01   -.26   -.74
STANDARD DEVIATION                                0.89
DO YOU WISH TO CHANGE INPUT INFORMATION           0/1
 ?0

DO YOU WISH TO UPDATE FILE OF MEANS?0/1
 ?0

DO YOU WISH PERSPECTIVE DRAWINGS       0/1
 ?0

STOP

RUNNING TIME:   16.9 SECS

READY
BYE

OFF AT 15:08
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Fig. 13.3 Visualization of the output format of Package for Architectural Computer Evaluation (PACE). (Extracted from: Maver, 1971)

This description is in line with the paradigm of *performative design thinking*, which posits that "building performance becomes a guiding design principle, considered on a par with or above form-making" (Kolarevic, 2005, p. 195). Driven by the desire to strive toward an "optimum," this approach (that became commonplace in sustainable architecture) recalls the notion of "increasing return," one of the characteristics of the path-dependency. Indeed, iterative processes lead to optimized solutions and increased return, pointing out that by using PACE, not only are buildings sustainably enriched but the software generating such solutions are improved upon as well.

In architecture, praise is prize. Nowadays, standards and certifications tend to be increasingly performance based, causing them to become dependent on the design tools capable of assessing a building's certification compliance. Here we find the second characteristic of path-dependency: positive feedbacks. Indeed, we have seen that certifications have become synonymous with green buildings, and more specifically "good" green buildings, as exemplified by the praise certified buildings are given through sustainability awards. While such feedback is typically more socially rewarding than environmentally effective, it is still highly advantageous for the architects upon whom such acclamations are bestowed and thus serve to strengthen path-dependency.

Another consequence of the proliferation of standards and awards can be observed in the *BIM Handbook* (2018), which proudly affirms that "all of these trends will put great pressure on developing better metrics for addressing the accuracy of energy and sustainability models" (Eastman et al., 2018, p. 394) without questioning the origin or relevance of such metrics. Such assumptions seem to recall path-dependency's third term, "self-reinforcement," in which the selected technology gains strength and thus weight over time. The more accurate our energy and sustainability models, the more difficult it becomes to question them and their conclusions. In turn, the less they are questioned, the more they are reinforced, perpetuating the vicious circle. Yet, so-called better metrics are still ignoring social factors; they will necessarily follow the path initiated by PACE some 50 years ago, leading to models increasingly disconnected with social reality. The final factor in path-dependency, "lock-in," could be explained by the following assumption stated by Cucuzzella and Goubran when considering sustainable practice as a whole:

> *Sustainability has been based on objective science and has perpetuated a mechanistic worldview, yet it is this very mechanistic worldview that has allowed us to identify current pressing environmental and social conditions. So, there is a reluctance to abandon such scientific knowledge when designing buildings for the future.* (Cucuzzella & Goubran, 2020, p. 6)

In architecture, the "lock-in" effect is even stronger since it becomes both a social and economic consequence of the three first aspects that we showed. Socially, architects who design sustainably but avoid performative design thinking are often be disregarded, if not subject to hostility, by the architectural community who adopts a vision of sustainability inherited from performativity. Such matters of fact make it extremely difficult to break away from this flawed perception and render any effort to do so potentially award-less. Economically, leaving the ubiquitous simulation tools behind to rethink new ones would entail massive upfront costs from firms. While such expenses would be easier for small firms than larger ones, since the latter have whole-heartedly adopted performative design thinking as we have seen in AIA reports, their impact is likely to be reduced since their visibility is dwarfed compared to that of *starchitect* offices. The overall result is less media attention, which accentuates the "lock-in" effect and leads us to wander aimlessly along the same path.

5 What Should the Practice Look Like in the Post-2C° Era?

The four effects of path-dependency discussed could be understood as expressions of what Maarten Hajer (1997) calls "a logic" defined as "a specific ensemble of ideas, concepts and categorizations that are produced, reproduced and transformed in a particular set of practices through which meaning is given to social and physical realities" (Hajer, 2005, p. 44). More specifically, Guy and Farmer (2001) call the path taken by analysis software an "eco-technic" logic, reworking Hajer's terminology (Guy & Farmer, 2001). According to Guy and Farmer, the eco-technic logic as it applies to sustainability in architecture concerns itself with a quantitative-led, high-tech approach focusing on "energy-efficient lighting, passive solar design and daylighting, the use of natural and mixed-mode ventilation, more efficient air conditioning and comfort cooling, combined with sophisticated energy management systems" (Guy & Farmer, 2001, p. 142). This logic is but one of six different logics they describe that define the environmental problem and suggest a design practice to answer it, the other five being eco-centric, eco-aesthetic, eco-cultural, eco-social, and eco-medical.

Each so-called logic is grounded in specific scientific fields and philosophical discourses which frame the way architects can understand ecology. Thereby, eco-centric logic, which relies on systemic ecology, sees any building as a "parasite"; this thinking urges architects to reduce their impact as much as possible, which ultimately can lead them to decide not to build. The eco-aesthetic logic postulates that the environmental crisis is in fact a consequence of the conflict between the utilitarian values of the modern era, and the formal, sensual, and aesthetic values which already exist in nature and that should inform building decisions. The eco-cultural and eco-social logics ground their ideas in people as inspiring sources for both architectural forms and design processes. While the eco-cultural logic touts that sustainable architectural approaches should surrender the idea of universality and technologism and focus on cultural specificity of different cultures, a notion highly linked with their environment, the eco-social logic states that we cannot think ecology and architecture apart from overall society, considering inhabitants of a community as designers and builders that contribute to a democratic architecture in which experts serve the collective good. Finally, the last logic identified by Guy and Farmer is called eco-medical. It sews together the field of medicine and ecology in order to propose building environments that prioritize human health and suggests that we should analyze and design our living spaces in order to create environments that consider and mitigate stress and foster mental wellness.

Guy and Farmer add that "the rhetoric of the ecotechnic approach tends to be overwhelmingly quantitative, [and that] success is expressed in the numerical reduction of building energy consumption, material-embodied energy, waste and resource-use reduction, and in concepts such as life-cycle flexibility and cost-benefit analysis" (Guy & Farmer, 2001, p. 142). Two decades later, it appears obvious that this insight was an augury. Indeed, this logic coupled with the development of computer simulation produced a social and technological environment which favors the eco-technic logic all the while disregarding other logics, as we have shown with the phenomenon of path-dependency.

In fact, only one of the four effects of path-dependency that we described vitiates the current state of the debate on green architecture. The "lock-in effect" described earlier implies that once a technological path is taken, it becomes harder to criticize it or consider alternative paths. Nonetheless, one should remember that these alternative paths exist and become necessary logics for adopting more inclusive adaptation strategies in this post-2 °C era, since the eco-technic logic alone is obviously not sufficient. This is not to say that we should disregard the eco-technic logic altogether, but rather, imagine such a logic within sets of parallel or opposing environmental logics. In other words, the blinders imposed by path-dependency's "lock-in effect" create conditions in which more efficient tools are thought to be the only way to tackle this environmental dilemma.

While the dominant eco-technic path has failed in its ability to mitigate the building sector's impact on the environment, many of the systems put in place through the refinement of the path provide fruitful schemes that we could integrate when developing our next sets of strategies. First, as we have seen, the creation of self-reinforcement labels, such as LEED, does lead to a renewed interest in building sustainably. While the performance results of LEED projects often fall short of expectations, this strategy does hint at how the industry can integrate various labels to create economic and political incentives to do better. For example, similar to fair-trade labels given to certain coffee roasters, one could imagine a LEED-like eco-social label which could be obtained by quantifying the social impact of a building prior to its construction or an eco-cultural label that promotes context-specific designs. Additionally, positive feedback through awards is also effective in encouraging AEC professionals to build toward a more sustainable goal. For example, we propose an eco-centric award which recognizes a firm's decision not to build a new building because of its potential negative impact on a site, a population, or the planet more broadly.

6 Conclusion

In this chapter, we have demonstrated how today's eco-technic logic, rooted in the four characteristics of path-dependency that Page surveys, began with performance analysis software like PACE (1960–1970) and has since evolved into more complex (yet similar) plugins like Tally and One Click LCA for BIM modeling software. Scholars advocate for better tools which take into account all aspects of sustainability (economic and social consequences of a product's life cycle) and even advocate for a complete rethinking of how we assess green buildings altogether. We argue that this lag between what experts say and what our tools actually do comprises our entrenchment in the current path. Path-dependency theory offers a way of looking at why we are where we are and where we come from while providing a framework for assessing how to break free from this treacherous path. Ultimately, AEC professionals and scholars must look toward different logics and instrumentalize non-dominant paths if we hope to one day see our industry mitigate, rather than contribute to, the environmental crisis.

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Part V

Global Perspectives

14

Addressing Climate Change and Waste Management Challenges Through the Development of the Waste-to-Energy Value Chain for Trinidad and Tobago

Don Charles

1 Introduction

Climate change, defined as the change in the long-term statistical distribution of weather patterns, increases the levels of anthropogenic carbon dioxide (CO_2) and greenhouse gases (GHGs) in the atmosphere (Davidson et al., 2007). These gases in turn are culpable for the rise in global temperatures and subsequent changes in weather patterns, including the intensification of tropical cyclones, the more frequent occurrence of storms and droughts, and sea-level rise. The international community has acknowledged the severity of these changes and, after decades of negotiations, has reached the most recent climate action treaty—the Paris Agreement in 2015. An achievement of the Paris Climate Agreement is that parties (both developed and developing countries) can voluntarily

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pursue climate change mitigation and adaptation action. These voluntary climate aspirations, also referred to as nationally determined contributions (NDCs), were introduced as an innovative way to break the climate change negotiations deadlock.

Trinidad and Tobago (T&T), a small island developing state (SIDS) in the Caribbean region, is a Party to the Paris Climate Agreement. The country deposited its instrument of ratification to the Paris Agreement in February 2018, and the Government of the Republic of Trinidad and Tobago (GORTT) agreed to reduce its cumulative greenhouse gas emissions by 15% from a business-as-usual baseline in industry, power generation, and the transport sector by 2030 (GORTT MPD, 2021). While the GORTT NDC plan highlighted the sectors in which it intended to act, the plan did not elaborate on exactly how to do so in practice; this was not unusual, as the other Country-Parties to the Paris Agreement also submitted vague plans.

The GORTT is in a fortunate position as the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) endorses the addressing of climate change with some of the other problems in an economy. One of the problems that T&T grapples with is the management of its municipal solid waste. Collectively, waste management problems generate concerns about public health and environmental degradation. Certainly, the problem of solid waste management could be partially addressed by recycling. There is a multitude of other opportunities for income generation and value creation from the recycling of solid waste. The present "collect and dump" system provides no incentives to support recycling or waste-to-resource (W2R) principles and practices from household to landfill. Any material recovery taking place is primarily the outcome of independent efforts.

The transformation of municipal solid waste into energy is an initiative that could address the waste management problem and contribute to T&T's NDCs. To provide a better understanding of the opportunities that can be derived from the solid waste value chain, I employ a value chain analysis. The objectives of this study are:

1. To examine the existing solid waste management cycle and potential waste-to-energy (WTE) value chain in Trinidad and Tobago.

2. To identify opportunities to generate business through the processing of waste.
3. To provide economically sound recommendations for the implementation of waste-to-energy in T&T.

This study is structured as follows. Section 2 reviews the waste management situation in T&T. Section 3 explores the opportunities in the waste-to-energy value chain. Section 4 proposes economically sound policy recommendations and concludes this study.

2 Local Solid Waste Industry in T&T

In T&T, the management of waste comprises the following steps: (i) waste generation, (ii) collection and transportation, and (iii) storage and disposal. However, there is the potential to add two additional steps: (i) waste handling, separation, and processing; and (ii) recycling.

Regional corporations are charged with the responsibility of collecting the solid waste. This municipal solid waste is the greatest source of solid waste in the country. The country's waste generation was estimated at 1.5 kilograms (kg)/capita/day, which is higher than the 1.1 kg/capita/day estimated for Latin America and Caribbean region (PRTT, 2019a).

According to the waste characterization study commissioned by the Ministry of Local Government in 2010, approximately 700,000 tons (t) of solid waste were recorded as reaching four landfill sites in Trinidad.[1] The Beetham Landfill is the largest of the landfills and receives most (45%) of the waste that is collected annually. For Tobago, it was reported that 7228 t were deposited at the Studley Park landfill, the island's sole landfill (CBCL Limited, 2010).

Organics, plastics, paper, and glass were identified as the main types of solid waste in the landfills. Organics make up 27.15% of the total solid waste, of which 70% (18.98% of the total waste) comprised food waste, while 30% (8.17% of the total waste) consisted of yard/gardening waste.

[1] The landfill sites in Trinidad under study were the Beetham, the Forres Park, the Guanapo, and the Guapo Landfills (CBCL Limited, 2010).

Plastics and paper accounted for approximately 38% of the total waste in Trinidad, and 51.7% of the total waste in Tobago. These materials are mainly from the packaging of various consumer goods. Glass accounted for approximately 10.15% of the waste in Trinidad, and 8.3% in Tobago; waste comprising this material was mainly from the packaging for various beverages and food products. Approximately 84% of the solid wastes were considered recyclable. Table 14.1 provides an overview.

Table 14.2 presents the forecasted waste volumes for the country. As can be seen from the table, the waste generated in T&T is expected to increase every year extending up to 2040.

The Environmental Management Authority (EMA) also notes that the landfills operating in T&T are not sanitary and have exceeded their stipulated lifespans (2012). Consequently, the sites pose a major health risk to the public, and there is an urgent need for measures to be implemented to sustainably manage the volume of solid domestic waste being deposited. The EMA also notes that solid waste enters the marine environment

Table 14.1 Solid waste at Trinidad and Tobago landfills

Trinidad		Tobago	
Material	Average percentage	Material	Average percentage
Recyclables		Paper	29.9
Organics	27.15	Glass	8.3
Plastics	19.17	Metals	3.0
Paper	18.77	Plastic	21.8
Glass	10.15	Textiles	9.6
Old, corrugated cardboard	3.83	Organics	25.7
Metals (ferrous)	2.33	Construction	0.1
Metals (non-ferrous)	1.41	Special care	0.2
Beverage containers	0.92	Other	1.4
Total recyclables	83.73	Total	100
Non-recyclable			
Textiles and clothing	7.82		
Household hazards	5.24		
Construction	0.50		
Other	2.71		
Total	100		

Source: CBCL Limited (2010)

Table 14.2 Waste forecast for Trinidad and Tobago

Year	Waste generation in T&T	Year	Waste generation in T&T	Year	Waste generation in T&T
2015	1911	2024	1992	2033	2070
2016	1921	2025	2001	2034	2078
2017	1930	2026	2010	2035	2086
2018	1939	2027	2019	2036	2094
2019	1948	2028	2028	2037	2103
2020	1957	2029	2036	2038	2111
2021	1966	2030	2045	2039	2119
2022	1975	2031	2053	2040	2127
2023	1984	2032	2062		

Source: PRTT (2019a)

in T&T (2012). However, due to the absence of a national data collection system for waste generation in T&T, the volume of the waste in the marine environment is not quantified.

2.1 Stakeholder Analysis and Mapping

There are several stakeholders involved in the management of waste in T&T. They include the municipal/regional corporations, the Ministry of Local Government, the Tobago House of Assembly (THA), the private waste collection contractors, the Community-based Environmental Protection and Enhancement Programme (CEPEP), the Trinidad and Tobago Solid Waste Management Company (SWMCOL), the Environmental Management Authority (EMA), and the ministry with the environment portfolio. Figure 14.1 maps the stakeholders of T&T's solid waste management industry.

2.1.1 Regional Corporations and the Ministry of Local Government

In Trinidad, the collection of domestic waste is the responsibility of the municipal corporations. There are 14 municipal corporations, and they all fall under the jurisdiction of the Ministry of Local Government. The

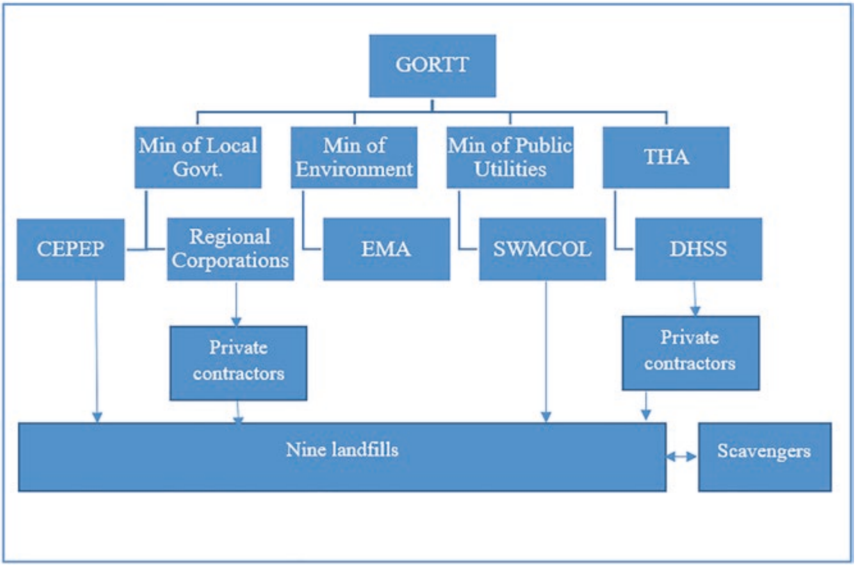

Fig. 14.1 Stakeholder mapping of solid waste management in Trinidad and Tobago

regional/municipal corporations all coordinate the collection of domestic waste within their boundaries. In Trinidad, waste is collected either three or four days a week in many of the residential and rural settlements, and it is collected seven days a week in urban areas. In comparison, in Tobago domestic waste is collected all seven days of the week.

2.1.2 Private Contractors

Approximately 90% of the domestic waste is collected by private contractors that have been hired by regional corporations. Public sector contracts typically focus their collection in urban settlements; however, regional corporations can use their daily-paid staff to collect waste based on a request by members of the public for a fee. The industrial waste generated by the private sector is not collected by the garbage collectors that are contracted by the regional corporations. Instead, the private sector must plan to dispose of its waste.

2.1.3 CEPEP

Apart from private contractors, solid waste collection is also performed by the CEPEP. CEPEP is a state-owned organization that reports to the Ministry of Local Government. Its official mandate is to (i) clean and enhance public green spaces daily, (ii) clean T&T's beaches, (iii) remove bulk solid waste to the landfills, and (iv) assist public authorities with the emergency removal of debris after natural disasters.

2.1.4 Landfill Management

As previously mentioned, the main method of disposal for solid waste in T&T is by landfilling. As a result, the domestic solid waste that has been collected is deposited at the landfills. There are nine landfills in operation in the country.[2] SWMCOL manages the waste at three of the main landfills (Beetham, Forres Park,[3] and Guanapo), which collectively receive 95% of Trinidad's solid waste. While the Government of the Republic of Trinidad and Tobago's (GORTT) initial intention was for SWMCOL to manage all the landfills in the country, legislation to designate SWMCOL as the national authority for waste management was never passed. The Point Fortin Borough Corporation subcontracts the management of its landfill at Guapo Village, Point Fortin. The Studley Park Landfill is managed by the THA. The remaining landfills are directly managed by their respective regional corporations.

2.1.5 Informal Waste Collectors and Scavengers

Many people venture into the landfills in T&T intending to extract useful products which they can either use themselves or sell in the domestic market. These individuals, also referred to as scavengers, informal waste

[2] The landfills in T&T are Beetham, Guanapo, Forres Park, Toco, Blanchisseuse, Guapo/Point Fortin, Cedros, Los Bajos, and Studley Park (the latter in Tobago).

[3] The Forres Park Landfill, located in Claxton Bay in Trinidad, is the country's only engineered sanitary landfill (i.e., constructed with a leachate collection system) (Singh et al., 2009).

collectors, or waste pickers, are characterized as being part of an operation that is small scale in size, labor intensive, uses little technology, and operates in an unregulated manner. Some of these informal waste collectors seek to extract scrap iron from landfills, while other collectors go from door-to-door collecting scrap iron and other recyclables from households.

2.1.6 The Environment Management Authority

The state-owned EMA is charged with the responsibility of regulating the environment in T&T. The EMA seeks to facilitate the sustainable management of the environment of T&T, therefore including the sustainable management of waste. The EMA utilizes its Environmental Police Unit to enforce environmental regulations under the Environment Management Act, the Litter Act, and the Public Health Act. The EMA also uses the Pesticides and Toxic Chemicals Control Act to regulate the manufacture, importation, transportation, sale, and use of pesticides and other toxic chemicals. The Occupational Safety and Health Act focuses on addressing the treatment of hazards and safety at the workplace (EMA, 2012).

2.1.7 The GORTT

The GORTT develops policies to help encourage the sustainable management of the environment in T&T. Notable policies and legislation developed by the GORTT to assist in the sustainable management of waste in T&T include:

- The Litter Act (1973)
- The Pesticides and Toxic Chemicals Act (1979)
- The Certificate of Environmental Clearance (CEC) Rules (2001)
- The Code of Practice for Biomedical Waste Management in Trinidad and Tobago (2005)
- The National Environmental Policy (2006; 2017)
- The Waste Management Rules:

- The Draft Waste Management Rules (2008)
- The Draft Waste Management (Hazardous Waste) Rules (2014)
- The Draft Solid Waste (Non-hazardous) Management Rules (2014)
- The Draft Waste Management (Registration and Permitting) Rules (2018)

- The Scrap Metal Policy for Trinidad and Tobago (2013)
- The National Integrated Waste Management Policy (2013)
- The Draft Beverage Container Bill (2012)
- The National Waste Recycling Policy (2015)
- The approved ban on the importation of polystyrene (2020)

2.1.8 The Tobago House of Assembly (THA)

THA is a unicameral autonomous legislative body that is responsible for Tobago. Initially, when the THA was formed in 1980 it had seven divisions, each representing a developmental concern. Presently, the THA has two main branches (the legislative branch and the executive branch) as well as ten divisions. The Office of the Chief Secretary is the division that oversees the remaining nine divisions. The Division of Health and Social Services (DHSS) is responsible for coordinating the collection of solid waste in Tobago. The Division hires private contractors, who in turn deposit the domestic solid waste at the Studley Park Landfill (L. Beckles, personal communication, May 23, 2018).

2.1.9 Multinational Treaties

T&T has entered several multilateral treaties that govern waste management. The notable agreements are:

1. The Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Disposal, which sets out international best practices to protect human health and the environment from the adverse effects of hazardous wastes (UNEP, 2011).

2. The Stockholm Convention on Persistent Organic Pollutants, which is a multilateral environmental agreement to protect human health and the environment from Persistent Organic Pollutants (POPs), that is, chemicals that can remain intact in the environment for long periods and can have adverse effects on human health and the environment (UNEP, 2019).
3. The Rotterdam Convention, which is a multilateral treaty that seeks to promote shared responsibilities in relation to the international trade of hazardous chemicals. Additionally, the Convention seeks to encourage the sound use of hazardous chemicals by facilitating exchange of information about their characteristics (UNEP, 2010).

T&T is also a signatory of two conventions that influence the management of waste. The conventions are:

1. The Protocol Concerning Pollution from Land-Based Sources and Activities, also referred to as the Land-Based Sources (LBS) Protocol, is an international convention that places a general obligation on signature countries to adopt laws and regulations to prevent, reduce, and control pollution of the marine environment from land-based sources.
2. The International Convention for the Prevention of Pollution from Ships (MARPOL) is an international convention developed by the International Maritime Organization (IMO), with the objective of preventing pollution from marine vessels caused by operational or accidental causes.

3 Waste-to-Energy as a Solution to T&T Waste Management Problem

Given that solid waste is generated by consumption, it is highly unlikely that a country will significantly reduce the amount of solid waste in its residential communities. However, countries can implement initiatives to improve their management of solid waste. The options include waste-to-energy, recycling, and sustainable landfilling. This study endorses the waste-to-energy option, which can be complemented by recycling and sustainable landfilling.

Energy can be commercially generated from solid waste by using several technologies. Popular technologies include (i) incineration, (ii) gasification, (iii) pyrolysis, (iv) mechanical biological treatment (MBT), and (v) anaerobic digestion. These terms are defined in the following sections.

3.1 Incineration

Municipal solid waste incineration is, essentially, the burning of solid waste to generate energy. In the incineration-based waste-to-energy process, the heat created from the burning of solid waste is used to transform water into steam. The steam then turns a turbine, which generates electricity. Incinerator-based waste-to-energy plants have electric efficiencies ranging between 14% and 28% (BREDL, 2009). As a result, emphasis has been placed on heat recovery to improve the municipal solid waste incineration (MSWI) plants' efficiency.

Incineration is advantageous as it reduces the volume of the original waste by approximately 96%, depending on the composition and degree of the material. The disadvantages of incineration include its tendency to pollute the environment which can cause harm to human health from the corresponding ash.

Moving grate incineration is the most used MSWI technology, and it has been applied in both developed and developing countries. The technology requires large amounts of solid waste, more than 300 t per day, to be economically viable. However, it is more appropriate for dry solid waste since its energy efficiency significantly drops in the presence of moisture (Makarichi et al., 2018).

3.2 Gasification

Gasification is a thermochemical process that transforms organic carbonaceous materials into gaseous products. The gasification process is composed of four stages:

1. The sorting and drying of the feed material.
2. The transformation of the carbonaceous material in the gasifier to producing syngas.
3. The processing of the syngas in the cleaning system to remove pollutants.
4. The application of an energy recovery system such as a gas engine (Seo et al., 2017).

Gasification is attractive relative to incineration, as the former presents more opportunities for recovering products from waste than the latter. When waste is incinerated the only practical product is energy; in contrast, when the gasification process takes place, it can produce combustible fuels and chemicals that can be used as feedstock for petrochemicals.

3.3 Pyrolysis

Pyrolysis is the thermal decomposition of materials at high temperatures in an inert atmosphere. When solid waste undergoes pyrolysis, it allows for the thermal degradation of the waste in the absence of air, which in turn produces recyclable products, including char, oil/wax, and combustible gases. In the pyrolysis of solid waste, energy can be extracted in a cleaner way than MSWI, as lower amounts of nitrogen oxides (NO_x) and sulfur oxides (SO_2) are produced as a consequence of the inert atmosphere (Chen et al., 2014).

Pyrolysis can be applied to sewage sludge, paper, wood, as well as industrial waste such as tires and plastics, to produce useful products. However, as previously mentioned, municipal solid waste is more heterogeneous in composition than tires, plastics, paper, wood, and sewage sludge (Chen et al., 2014). Another consideration is that pyrolysis decomposes material into solid, liquid, and gas states (Chen et al., 2014; Marzolf et al., 2015)[4]; ultimately, sorting and separating should be conducted before initiating pyrolysis.

[4] It is not ideal for the solid output to be mixed up with the liquid or gaseous output. Therefore, sorting and separation should be applied before pyrolysis.

3.4 Mechanical Biological Treatment

Mechanical biological treatment (MBT) integrates several mechanical processes commonly found in other waste management facilities (such as material recovery facilities (MRFs), composting, or anaerobic digestion plants) into the waste treatment process. A MET plant combines several mechanical and biological waste treatment processes to decompose the solid waste. MBT complements, but does not replace, other waste management practices as part of an integrated waste management system (UK DEFRA, 2013).

The operation of MET plants encourages the implementation of several changes to the waste management system. They include:

1. The pre-treatment of waste going to landfills
2. The sorting of solid waste into non-biodegradable and biodegradable
3. The drying of materials to produce a high calorific value
4. The conversion of carbonaceous material into combustible biogas for energy recovery

3.5 Anaerobic Digestion

Anaerobic digestion involves the breakdown of organic wastes by a community of anaerobic microorganisms producing useful products such as methane and carbon dioxide. Anaerobic digestion has attracted interest due to its potential for manure stabilization, sludge reduction, odor control, and energy production (Cantrell et al., 2008).

Anaerobic digestion occurs in three stages: hydrolysis, fermentation, and methanogenesis. In hydrolysis, the complex organic compounds are decomposed into soluble components. After this, they are mixed with fermentative bacteria. This allows the soluble organic waste to be converted into alcohols, acetic acid, other volatile fatty acids, and off-gas containing hydrogen and carbon dioxide. Finally, in the methanogenesis stage, these intermediate goods are metabolized into (mainly) methane and carbon dioxide (Cantrell et al., 2008).

3.6 Proposed WTE Plant in T&T

Studies have considered the implementation of waste-to-energy plants in T&T. A study by Singh et al. (2009) recommended that a waste-to-energy plant, rated at 450 t per day (tpd), should be established in T&T. The proposed location of the plant was the Beetham Landfill, Port of Spain, since the landfill receives the highest volume of municipal solid waste in the country. Although SWMCOL is legally responsible for the management of the Beetham Landfill, Singh et al. recommended that the proposed WTE plant operators should be responsible for managing the landfill. The WTE plant operators should store and sort the waste at the landfill, then transfer the waste to the gasification WTE plant.

Singh et al. estimated the capital costs for the plasma gasifier, incinerator, and conventional gasifier to energy plants at US$127.528 million, US$103.477 million, and US$120.493 million, respectively. The authors also assumed that the tippage cost would range between US$5 per ton to US$20 per ton. The tippage cost is the charge or fee applied by the WTE plant for the processing of waste. WTE plants produce electricity and charge this tippage cost/fee when they sell the electricity to the electricity distribution company that manages the electricity grid. In some countries, a feed-in-tariff is used in place of the tippage cost. Table 14.3 reveals the corresponding payback period.

Table 14.3 Payback period for waste-to-energy (WTE) plants

Plasma gasifier	$127,528,000				
Incinerator	$103,477,000				
Conventional gasifier	$120,493,000				
Tippage fee (1 t)	Tippage fee per day (450 t)	Tippage fee per year (164,250 t)	Plasma gasifier ($127,528,000) payback period (years)	Incinerator ($103,477,000) payback period (years)	Conventional gasifier ($120,493,000) payback period
$5	$2250	$821,250	155	126	147
$10	$4500	$1,642,500	78	63	73
$15	$6750	$2,463,750	52	42	49
$20	$9000	$3,285,000	39	31	37

Assuming a tippage cost of $20 per ton (t), a waste use of 450 t per day, a plant cost of US$127.528 million, and assuming no operational costs, the payback period would be 39 years. This is an unlikely scenario, but it is included for the analysis. If the plant's waste use is increased to 1000 tons per day (the Beetham Landfill daily waste collection rate), the payback period would be reduced to only 17 years. It is noteworthy that there is no data on the calorific value of solid waste in T&T throughout the year. The calorific value is an important factor as it determines the energy yield of a waste-to-energy plant.

A study by Marzolf et al. (2015) assumes that the calorific value of T&T waste may be similar to that of the municipal solid waste in Europe or the US, ranging between 8 and 11 mega-joules per kilogram (MJ/kg). Marzolf et al. recommended a waste-to-energy plant based on moving grate incineration technology. The capital cost of the plant was estimated to range between US$65 million and US$80 million. The operational cost was estimated to range from US$3 million to US$5 million. The tippage cost was estimated at US$15/ t, and the plant size was 500 t/d. Table 14.4 reveals the corresponding payback period.

Based on Marzolf et al.'s assumptions, if the moving grate incineration plant cost was US$80 million, the tippage cost was US$15 per ton, the plant waste usage was 500 t/d, and the operational cost was US$3 million per year, the waste-to-energy plant would operate at a loss. Even in a low-cost scenario, where the plant capital cost was US$65 million and the operational cost was US$3 million, the plant would still operate at a loss

Table 14.4 Payback period for moving grate incineration waste-to-energy (WTE) plant

Moving grate incineration capital costs	Tippage fee	Tippage fee/ day	Tippage fee/ year	Operational cost	Net revenue	Payback period
$65,000,000	$15	$7500	$2,737,500	0	$2,737,500	24
$65,000,000	$15	$7500	$2,737,500	$3,000,000	-$262,500	
$65,000,000	$15	$7500	$2,737,500	$5,000,000	-$2,262,500	
$80,000,000	$15	$7500	$2,737,500	0	$2,737,500	29
$80,000,000	$15	$7500	$2,737,500	$3,000,000	-$262,500	
$80,000,000	$15	$7500	$2,737,500	$5,000,000	-$2,262,500	

(of −$262,500 per year). In fact, the plant would only operate at a profit if no operational cost was assumed.

Additional factors such as plant efficiency, a low calorific value from moisture, lower productivity from occasional industrial action by disgruntled workers (strikes), and discounting the market interest rate to account for inflation can all reduce the real revenue that could be generated from the moving grate incineration waste-to-energy plant.

Although the above analysis considers possible revenue streams from the sale of electricity and does not consider possible revenue streams from the sale of feedstock and other recyclables, the analysis suggests that the volumes 450 t/d to 500 t/d are too low to make waste-to-energy economically viable. Waste volumes at 1000 t/d or greater are required to make waste-to-energy economically viable in T&T.

The GORTT has expressed interest in developing waste-to-energy in T&T. In fact, in 2019, the Ministry of Energy and Energy Industries (MEEI) allocated TT$9 million to develop renewable energy and energy efficiency capacity (PRTT, 2019b). Part of this initiative included the Public Sector Investment Program (PSIP)[5] for a waste-to-energy facility at the Beetham Landfill. Proposals were received from prospective developers to conduct a waste characterization study and to build, own, and operate a waste-to-energy facility (PRTT, 2019b). However, by the end of 2019, no project developer was selected to implement the project.

Although there are steep costs and long payback periods associated with waste-to-energy, there are nonetheless several opportunities from this venture. The next section presents the opportunities in the waste-to-energy value chain.

3.7 Opportunities and Risks in the Waste-to-Energy Value Chain

There is a multitude of opportunities in the waste-to-energy value chain. Table 14.5 provides a summary.

Stage 1: Collection of Municipal Solid Waste

[5] The PSIP is the annual project implementation program that is operated by the GORTT.

Table 14.5 Opportunities in the waste-to-energy (WTE) value chain

Activity in the value chain	Actors	Business opportunities
Stage 1: Collection of municipal solid waste	Private contracts	Contract revenue obtained from the municipal corporations to collect solid waste
Stage 2: Sorting of waste	Informal waste pickers	Revenue from sale of compost to organic fertilizer firms Revenue from sale on non-recyclables to a waste-to-energy plant
Stage 3: Recycling of wastes	Informal waste pickers	Revenue from sale of recyclables in the domestic market
Stage 4: Converting waste-to-energy	Waste-to-energy plant operator	Electricity generation Reduction of GHG emissions Conversion of processed wastes to industrial commodities

Per Table 14.5, the first stage is the collection of the municipal solid waste. This is already practiced in T&T. Private contractors are hired by municipal corporations to collect solid waste. The corporations can also use their own (daily-paid) staff to collect solid waste.

Stage 2: Sorting of Solid Waste

The next step within the value chain is the sorting of the solid waste. As identified by the latest (2010) waste characterization study, approximately 84% of the solid waste deposited in the landfills in Trinidad is recyclable, while approximately 27% of the solid waste is organic. While incineration can destroy any solid waste, the moisture in the solid waste reduces the calorific value. Therefore, the efficiency of waste-to-energy plants can be enhanced if the material is sorted, separated, and then dried. Moreover, since recyclable material may have a higher market value than if it was incinerated to generate heat, more value can be extracted from solid waste if recyclable materials are separated from the non-recyclable material.

Recyclable material should be separated from non-recyclable waste. If organics are excluded from the recyclables, then recyclable products would represent 56.58% of Trinidad's total solid waste. The recyclables could be allocated to recycling plants, while the organics can be allocated to a waste-to-energy plant to be decomposed through: (i) anaerobic digestion, (ii) gasification, (iii) mechanical biological treatment, or (iv) pyrolysis. From a value chain perspective, these waste-to-energy technologies are preferable for decomposing organic waste to incineration, as the former technologies can produce a variety of intermediate products, which could be sold, whereas the latter technology (incineration) produces only heat and electricity as its end product.

Presently, there is no official sorting of solid waste in T&T. Any sorting performed is done informally by waste pickers, which presents several health and safety concerns. First, waste pickers operate without the use of personal protective equipment (PPE). As such, waste pickers come into direct contact with waste that might threaten their health and safety (Seebaran, 2012). Landfills are also unsanitary; as a result, the extraction and consumption of organic waste (such as food) from such sites also poses risks to the waste pickers' health. Third, dead bodies are frequently found in the landfills in T&T (Williams, 2018). This sad reality poses a safety risk to scavengers, who run the risk of encountering criminals on-site (M. Solomon, personal communication, April 9, 2019). Fourth, violence occurs between scavengers, as they fight among themselves for the solid waste.

There is an opportunity for the GORTT to regularize waste picking through municipal solid waste public-private partnerships. The government could formerly organize waste pickers into small-scale enterprises that would be required to undergo safety training and immunization before being granted a license to sort the solid waste. The government can also provide the facilities at the landfill to help waste pickers sort the waste in a sanitary manner.

Stage 3: Recycling of Solid Waste

As previously mentioned, solid waste should be recycled to extract the most value from the solid waste value chain. Recyclable materials that could be targeted include plastics, paper, metals, and glass.

3.7.1 Plastics

An attempt has been made to recycle plastics in Trinidad. In fact, in 2010, Plastikeep was developed as a non-profit organization (NPO) to recycle plastic. Since inception, Plastikeep has successfully launched a system for the recycling of plastics in Trinidad (M. Solomon, personal communication, April 9, 2019). The organization educates the public about environmental degradation and the need to properly dispose of plastics. It encourages the public to dispose of their plastic waste in its branded bins, which are located in 67 collection centers predominately in north-western Trinidad (between Port of Spain to Chaguaramas). It then coordinates with a waste collection contractor (Waste Disposals) to collect the plastic from the bins, which is then transported to a facility to be sorted, weighed, chipped, baled, and exported to an extra-regional recycling facility.

After eight years in operation, Plastikeep was acquired by the GORTT under the Ministry of Planning's Community, Awareness, Recycle, Everyday (iCARE) program (GORTT MPD, 2018). During its first year of operation, Plastikeep recycled 28,764 kg of plastic. While there are no official statistics on the volume of plastics collected over the eight years, a simple arithmetic progression suggests that at least 230,112 kg of plastics were recycled in the period. Certainly, there is the scope to extend the plastic recycling services to all regions in T&T; more value can be captured domestically if a plastic recycling facility is developed locally.

3.7.2 Metals

Several waste pickers visit the landfills to salvage scrap metal; such materials are then sold to Premier Metals, a local company that is in the business of recycling non-ferrous metal. Upon collection, the metal is sorted into different grades, compressed, and then exported to foreign markets (China, Taiwan, Korea, and the Netherlands). It is noteworthy that the Old Metal and Marine Stores Act only allows for the recycling and exporting of scrap iron. However, non-ferrous materials such as copper, brass, and aluminum, which are widely available in the country, cannot be legally exported as scrap metal. Nevertheless, Premier Metals exports at least 8400 containers of scrap metal, containing 184,800 tons (167,647,740 kg) annually (M. Solomon, personal communication, April 9, 2019).

There is room to develop the actual recycling of metal in T&T, beyond the collection for export. Scrap metals that are allocated to metal recycling facilities can be recycled without any degradation of their properties. Motor vehicles, electrical appliances, industrial machinery, waste construction metals, and so on, can be recycled into useful materials such as aluminum, copper, lead, iron, steel, nickel, tin, zinc, and others. The commercial production of these materials can facilitate the development of heavy industry manufacturing value chains.

3.7.3 Paper

In Trinidad, paper recycling is performed by ACE Recycling Ltd. The business was established in 1996 by Aldwyn Clarke to help facilitate the sustainable management of solid waste in T&T (M. Solomon, personal communication, April 9, 2019). ACE Recycling Ltd has recycling bins placed in schools, communities, and shopping centers. The company collects wastepaper from the bins, which is then transported to a facility where the waste is sorted by grade and compressed into units called bales.

ACE Recycling Ltd collects approximately 13,500,000 pounds (6,123,497 kg) of wastepaper per year. While the paper is collected for free, approximately 20% of the paper is sold to the domestic mill, which is then recycled and sold to the domestic market. The remaining 80% of the bales is exported to foreign markets (in Korea, Taiwan, China, Italy, Indonesia, India, Mexico, the Dominican Republic, and Columbia).

There is the potential for ACE Recycling to play an expanded role if the solid waste at the landfills is sorted (by the waste pickers) and the paper is sold to the organization. The company could then process the paper and sell it to domestic or foreign markets. Alternatively, the GORTT could facilitate the development of waste pickers' capacity; they could be instructed on sorting and compressing the paper waste into bales, which could be sold to the local paper mill or foreign markets.

3.7.4 Glass

In Trinidad, Carib Glassworks Limited, a subsidiary of the beverage company Carib Brewery, encourages the recycling of its glass bottles. Carib Glassworks Ltd is the only producer of glass bottles in the English-speaking Caribbean, and it uses a deposit fee as an incentive to encourage the recycling of its bottles. In fact, it pays 30 cents per bottle to anyone returning bottles of its products to any of its bottle collection centers. Carib sterilizes and reuses the bottles that are in good condition and crushes those that are in bad condition, so that they may be used as raw material to produce new bottles.

The Carib Glasswork Ltd recycling initiative is completely voluntary. Since glass is 100% recyclable, the GORTT could help expand the glass recycling initiative in the country. This could be done by implementing glass bins to encourage the collection of glass, then arranging for the collection and sorting of the glass. Here the government has two options. The easiest option is to export the glass to foreign waste recycling facilities. The second option is to facilitate the development of a glass recycling facility perhaps through a public-private partnership. Indeed, while more difficult than the first option, the second option is attractive as it can create employment opportunities for several citizens of T&T interested in participating in the glass value chain.

Stage 4: Converting Waste-to-Energy

As previously mentioned, the GORTT has expressed interest in developing a waste-to-energy industry in T&T. By the end of 2019, the government did not confirm which developer or technology it preferred to use. Nevertheless, a multitude of products can be derived from the application of waste-to-energy technologies. Table 14.6 highlights the potential products.

The bio-oils, syngas, biogas, and fertilizers can all be exported to international markets. While generating electricity from waste is attractive from a waste management and a climate change mitigation perspective, from an economic perspective, it is not. The total installed electricity capacity in T&T was 2100 megawatts (MW); this is broken down (by plant) as follows:

Table 14.6 Products from waste-to-energy (WTE) technologies

WtE method	Product	Market
Pyrolysis	Bio-oil	Transport
Gasification	Syngas	Transport
Incineration	Electricity, heat	Electricity
Anaerobic digestion	Biogas, fertilizer	Transport, agriculture
MET	Biogas, fertilizer	Transport, agriculture

Source: Adapted from Yu et al. (2017)

- Point Lisas (single cycle)—844 MW
- Penal (combined cycle)—236 MW
- Cove Power Station (combined cycle)—64 MW[6]
- Scarborough Power Station—11 MW
- Trinity's Couva Power Station (single cycle)—225 MW
- TGU's Union Estate Power Station (combined cycle)—720 MW (RIC, 2017)

The actual supply of electricity produced could be slightly less than 2100 MW, due to transmission losses (which vary from 6% to 7%). The peak daily demand for electricity in T&T was 1339 MW in 2016 (RIC, 2017). If we assume a supply of 1941.77 MW,[7] then the country would have an excess supply of 602.77 MW. This excess supply is largely due to the cancellation of the smelter project upon the change in government in 2010 (L. Beckles, personal communication, May 23, 2018).[8]

Any attempt to produce commercial electricity from waste would increase this excess supply. Since the national electricity distribution company (the Trinidad and Tobago Electricity Commission [T&TEC][9]) has a take-or-pay power purchase agreement with the independent power

[6] The Cove Power Station is located in Tobago. It is currently the main power station on the island; the Scarborough Power Station is used as a back-up.

[7] This figure was derived as follows: (844 + 236 +64 + 225 + 720) × 0.93. This calculation assumes a 7% transmission loss.

[8] The TGU power plant was developed to supply energy for the smelter project.

[9] T&TEC purchases bulk power from all the IPPs and sells this electricity to customers through its transmission and distribution network (Charles, 2019).

producer (IPP), Trinidad Generation Unlimited (TGU), any increase in the excess supply would only worsen the losses of T&TEC.[10]

4 Recommendations and Conclusion

Waste-to-energy is an excellent initiative to address T&T's waste management problem. However, T&T's excess supply of electricity is a problem. Assuming an electricity supply of 1941.77 MW, then 10% would be 194.18 MW.[11] Given that T&TEC is already incurring a loss from paying for an excess supply of electricity that it does not need, any take-or-pay power purchase agreement with any potential waste-to-energy IPP would increase the excess supply of electricity and would worsen T&TEC's losses. An alternative option would be to integrate carbon credits into the waste-to-energy project.

The Clean Development Mechanism (CDM), defined in Article 12 of the Kyoto Protocol, encourages countries to implement GHG emission reduction projects. The CDM gave Annex I countries some flexibility in how they meet their GHG emission reduction commitments. In fact, CDM projects would earn a saleable Certified Emission Reduction (CER) credit for each ton of greenhouse gas they reduce or avoid. These credits could have been used by Annex I countries to meet a part of their emission reduction targets under the Kyoto Protocol. The present Paris Agreement replaces the Kyoto Protocol as the new climate change treaty. Furthermore, the COP is interested in creating a new sustainable development mechanism under Article 6 of the Paris Agreement.

This study recommends that the selected project developers for a waste-to-energy facility in T&T should consider integrating carbon credits as cash inflows to make the waste-to-energy facility economically

[10] As a result of this bad deal, T&TEC has been operating from a loss from since 2011. This loss stood at TT$612 million (approximately US$100 million) in 2015 (Trinidad and Tobago News, 2015).

[11] The GORTT expressed that it intends to facilitate the production of 130 MW of electricity from renewables. This 130 MW is defined as its 10% electricity supply. LightSource, a consortium of British Petroleum (BP), won a bid in February 2020 to supply renewable energy in T&T. The GORTT also indicated that it intends to facilitate the negotiation of a PPA with LightSource (Bridglal, 2020).

viable. This is possible only if the waste-to-energy facility can reduce GHG emissions by an amount in excess of the "business-as-usual" baseline. While the actual amount of waste that would be consumed by the potential waste-to-energy facility is unknown at this point, large amounts of solid waste may have to be consumed to generate the CERs. Once the CERs are earned, they can be sold to markets to fetch the best prices.[12]

The second recommendation of this study is the implementation of a municipal waste sorting system at the landfills in T&T. As previously established, municipal solid waste varies in its composition and moisture content. A large proportion of the waste is recyclable, and moisture in the waste could reduce its calorific value when decomposing in various waste-to-energy technologies. Therefore, it would be sensible for municipal solid waste to be sorted and separated to extract the recyclables from the organic and non-organic non-recyclable waste. The government could facilitate this sorting by providing the required sorting facilities.

Ideally, an integrated waste management system should be developed. The sorted and separated waste should be allocated to segments of the value chain where they can extract the most value. For example, plastic, glass, paper, and metals should be allocated to their respective recycling facilities, while organic waste can be allocated to the waste-to-energy facility for decomposition. Since there is an absence of plastic and metal recycling facilities in T&T, this study recommends that the government should consider the development of these facilities in T&T; this can be done through private-public partnerships.

Currently, waste pickers informally sort the solid waste at the landfills in T&T to extract useable materials. However, scavenging in these unhygienic landfills poses health and safety threats to these individuals. To address these health and safety concerns, this study recommends that the government introduce health and safety training as well as a licensing system for waste pickers. Waste pickers could be required to undergo training, perhaps in a workshop, on health, safety, and the use of personal

[12] The largest carbon market is the European Union Emission Trading Scheme (EU ETS). Its carbon credits are referred to as European Union Allowances (EUAs). Other notable markets are the Californian scheme which trades in California Carbon Allowances (CCA), the New Zealand Emissions Trading Scheme which trades in New Zealand Units (NZUs), and the Australian scheme which trades in Australian Units (AU) (Teeter & Sandberg, 2016).

protective equipment. Upon the completion of the program, waste pickers could be licensed to operate in the landfills.

As mentioned before, the GORTT has developed policies and legislation to regulate the solid waste management industry. This study supports the passing of the Beverage Container Bill to create a deposit incentive for bottles. This study also supports the enhancement of the scrap metal policy framework to facilitate the recycling of metals. Finally, this study highlights that there is the potential for more locally added value if a metal recycling facility is developed in the country.

The management of solid waste is troublesome in T&T. Increased economic activity and increased consumption are both contributing to the rise in the solid waste that is generated in the country. Furthermore, the present waste management system (which involves the municipal collection of solid waste and dumping it in landfills) seems to be unsustainable. Waste-to-energy presents an opportunity to address T&T's waste management problem; however, waste-to-energy must be implemented as a part of a holistic sustainable waste management system if it is to contribute to combating climate change in T&T.

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15

The Role of Businesses in Climate Change Adaptation in the Arctic

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1 Introduction

For several decades, the Arctic has been undergoing transformative change in climatic conditions (Intergovernmental Panel on Climate Change, 2014). The Arctic climate has changed at a faster rate than that of mid-latitudes (Overland et al., 2014), and the magnitude of Arctic-wide warming, documented over 30 years, shows a warming trend of 1.9 °C, a rate that is three times higher than the global average warming

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(Comiso & Hall, 2014). Environmental and ecological transformations happening in the Arctic are largely driven by economic activities in place outside the Arctic (Arctic Council, 2016). Transboundary pollution produced by natural resource exploitation and the effects of climate change has severe impacts on Arctic ecosystems and human communities, as Arctic ecosystems are intrinsically diverse, vulnerable, and dynamic. Most of these ecosystems are highly productive, providing essential ecological services for other interdependent ecosystems and human communities. A number of marine and terrestrial ecosystems are also interdependent and have been stressed by locally and globally produced pollution from different geographical and sectorial sources since the start of the industrial revolution (Arruda, 2019a).

The fast-changing climate scenarios have, among other causes, the rise of natural resources demand associated with the growth in world population and the world GDP per capita as an input variable. This growth justifies the necessity of expanded human activity with an increased need for minerals, food production, and energy resources. These in turn deplete soils and wastewater, exterminate pollinators and wildlife, as well as compromise genetic biodiversity, increase land-use, decrease biochemical (nitrogen and phosphorus) flows, and cause deforestation, savanization (Lovejoy & Nobre, 2018), and climate change. This increased demand for natural resources and the activities that attend to the real and artificial needs of a crescent human population has proved not to respect the global system boundaries or the basic principles of environmental resilience (Arruda, 2019b). The patterns of production and consumption need an urgent review in order to align, in a more coherent way, to the Earth's life-support capacity and the vital ecological processes that keep the planet fit for life (IUCN et al., 1991) recently presented in the Paris Agreement (United Nations Framework Convention on Climate Change, 2021) and the UN 2030 sustainability agenda and the Sustainable Development Goals (United Nations, n.d.). This should therefore be the focus of an economic approach of doing business in the Arctic.

The latest changes observed in the Arctic landscape reveal that ecosystems are undergoing irreversible regime shifts. The risk of losing biodiversity, marine and costal ecosystems, and ecosystem services represents a massive risk for coastal livelihoods and traditional economic activities (i.e. fishing communities, reindeer herding). This therefore entails a risk for the health and well-being of residents in the Arctic, as change in physical environment causes food insecurity and lack of safe and reliable drinking water, and may cause damage to infrastructure. Impacts on livelihoods of Indigenous Peoples are expected to go beyond the effects of economic and socio-political changes (Intergovernmental Panel on Climate Change, 2014). These changes call for both mitigation and adaptation policies and actions in order to ensure resilience of human and non-human Arctic systems (Arruda & Johannsdottir, 2021). Tall and Brandon (2019) have recognized tipping points related to global warming between 1.5 and 2 °C, with the Arctic being one of the warming hotspots. Reaching the tipping point would result in ~50% chance of ice-free Arctic in summer, a 35–47% reduction in permafrost, habitat loss for Arctic biodiversity, and collapse of the Greenland ice sheet.

The most important parameters for assessing climate change in the Arctic environment relate to sea ice, ice sheets, glaciers, and permafrost thaw behavior. In terms of sea-ice retreat, the understanding and analysis of the pan-Arctic sea-ice extent on a seasonal timescale, based on local and regional outlooks, provides stakeholders the necessary metrics and forecasts (e.g. ice-free dates, spatially explicit prediction maps) which, when combined to local sea-ice observations, can increase the level of information to residents of local Arctic communities, the maritime industry, and the broader public, encouraging engagement of the public through citizen-science activities and public surveys (Arruda et al., 2016). The interface between environmental sciences and social sciences has proved to be more important than ever due to the accelerated pace of Arctic landscape transformation.

The overall aim of this chapter is to analyze the role of business in the adaptation to Arctic climate change and to investigate how to assess risks in the field in order to create adequate adaptation mechanisms and enhance adaptation methods and capabilities. An additional question is to know, in practical terms, the role of businesses in the adaptation process and the effective contributions from businesses to design an adaptation framework in the Arctic. This chapter starts by discussing the economic structure in the Arctic (subsistence, mixed, market), the business environment (e.g. small communities, infrastructure), how they influence business adaptation in the Arctic, and how businesses can contribute to adaptation in the Arctic. Seeking answers to the above questions forms a viable base for a more structured framework of how business and entrepreneurship can promote adaptation and sustainable development for the Arctic region.

2 Economic Aspect of Doing Business in the Arctic and Business Adaptation

Business opportunities have emerged from climate change (Emmerson & Lahn, 2012). Previously inaccessible mineral resources have become accessible and been developed through mining and oil and gas projects. The sea-ice retreat brings about shorter shipping routes, which are of interest for transportation of global goods as well as in cases of large-scale projects carried out within the Arctic region vis-à-vis the opening of the Northeast Passage, which tends to increase current and future Arctic marine activity. The transport of natural resources like oil, gas, and hard minerals such as zinc and nickel is the primary driver of ship traffic in the Arctic. The global tourism industry has also come to the Arctic via summer cruise ship voyages (Johannsdottir et al., 2021) resulting in increasing shipping and logistics within and through Arctic waters. In this sense, a new corridor of trade and tourism moved up the North putting enormous pressure on the Arctic that needs to be monitored carefully because it implies enhancing Arctic marine safety, protecting Arctic people and the environment, and the need to build Arctic marine infrastructure. In order to capitalize these business opportunities, businesses involved need to manage unique and significant Arctic risks (Emmerson & Lahn, 2012) and take into account and maneuver different scales of risks (Johannsdottir & Cook, 2019). This level of implementation will require coordination of Arctic states, industry, and public-private partnerships.

Doing business in the Arctic will entail a more rigorous understanding of the many challenges facing trans-Arctic shipping, requiring more rigorous economic analyses of potential routes that would be ice free for short periods in summer as well as an understanding of how to protect the Arctic marine environment from accidental release or illegal discharge of oil into Arctic waters (Ellis & Bringham, 2009). It will also involve more uniformity of Arctic Shipping Governance, the mandatory application of the Guidelines for Ships Operating in Arctic Ice-Covered Waters (Arctic Guidelines), the identification of areas of heightened ecological and cultural significance, and the designation of "Special Areas" or Particularly Sensitive Sea Areas (PSSA) in face of changing climate conditions and increasing multiple marine use. Arctic states should encourage the implementation of measures to protect these areas from the impacts of marine shipping and promote the engagement of Arctic coastal communities with the shipping industry. Other priority measures are associated with assessing and preventing the risk of introducing invasive species through ballast water, cooperation in the field of oil spill prevention, information systems, and circumpolar environmental response capacity (Ellis & Bringham, 2009).

The following sections will focus on the economic structure in the Arctic, the business environment in the Arctic, business adaptation in the Arctic, and business contribution to climate adaptation in the region.

3 Economic Structure in the Arctic

The increased industrialization of the Arctic has gradually resulted in a change from nomadic living to sedentary communities, which leads to changing lifestyles, priorities, and values. Climate change and modernization have thus become two intrinsically linked forces that severely alter the context in which the local populations of the Arctic sustain a livelihood (van Voorst, 2009; Arruda & Krutkowski, 2017). Because of government policies, Inuit communities of the Arctic Circle today have become reliant on waged employment in the oil and gas sector, which has given rise to income disparity and social inequality within settlements, where some inhabitants earn wages and others do not take part in the market, also called the wage economy (see Fig. 15.1; Angell & Parkins, 2011). Many residents of remote coastal communities now look for

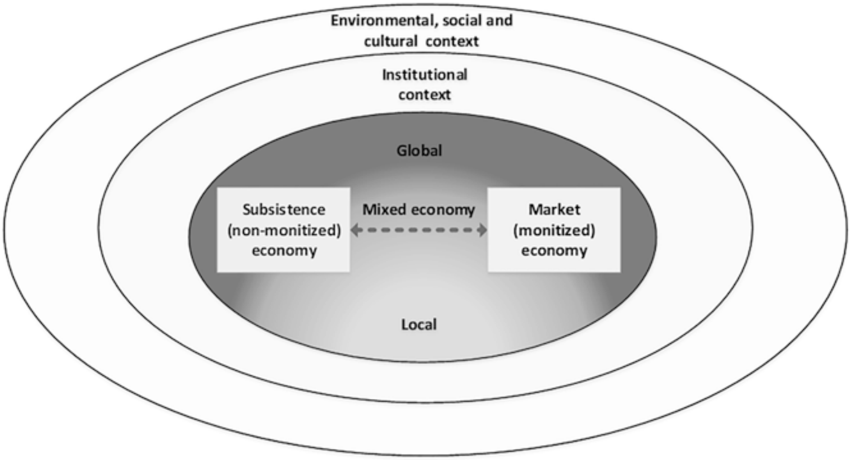

Fig. 15.1 A conceptual framework of Arctic economies and how they are embedded within the institutional, environmental, social, and cultural context. (Source: Vammen Larsen et al., 2019, p. 688)

seasonal work outside of the community as hunting guides, mine workers, and oil rig employees, as well as on fishing fleets and send remittances back to their families, consequently influencing traditional way of gathering food and thus food security (Cunsolo Willox et al., 2013). In the past, the seasonal migration of the Inuit was "geared to the state of the sea ice and movements of game animals" (Ellen, 2002, p. 202), but currently, the Inuit struggle to adapt to the alterations caused by the mixed economy. Furthermore, climate change has also been seen to have direct and indirect negative impacts on well-being and mental health in an Inuit context, where "land-based activities and a loss of place-based solace and cultural identity" (Ellen, 2002, p. 202) are causing family stress, increasing alcohol and drug usage, and amplifying mental health stress factors and previous traumas thus increasing indention for potential suicides.

The interplay between market, mixed, and subsistence economies, as well as different scales of actions, ranging from local to global, can be seen in a conceptual framework developed by a group of Fulbright Arctic Initiative (FAI) scholars. The framework also recognizes the institutional context, as well as the interplay between the environmental, social, and cultural aspect of doing business in the Arctic (Vammen Larsen et al., 2019). Climate change impacts in the Arctic must be viewed from a systemic and existential point of view, not just from the natural environment and the economic standpoint, as the Arctic is a place of "meanings, culture, and socio-historical context" for Indigenous population in the region (Durkalec et al., 2015).

The vast wilderness of the Arctic and the importance of the ocean and what it provides in the form of living and minerals resources (Mäenpää et al., 2017) are fundamental characteristics that help define the Arctic economic structure based on small economies, limited diversification of economic activities, and reliance on raw material exports (Glomsrød et al., 2017). The industries are heterogeneous showing specific clusters including the petroleum and mineral mining in Arctic Russia, Alaska, and Northern Canada, natural resource extraction in Greenland, Iceland, and the Faroe Islands, and secondary industries in Arctic Finland and Sweden (Glomsrød et al., 2017). Traditional subsistence activities, including hunting and fishing, are also of great importance for livelihoods and lifestyles, in areas such as Greenland and Northern Canada, and reindeer herding in Arctic Norway, Russia, and Scandinavia (GRID-Arendal, 2005).

The eight Arctic nations present specific economic structures based on a diverse range of economic activities and socio-environmental policies:

- In the Canadian Arctic, the government defines the economic activities by sector. The main activities relate to clean Arctic technologies and services, cold climate manufacturing, northern infrastructure, engineering and design, transportation and logistics services, mining equipment and services, Arctic maritime, harsh environment oil and gas equipment and services, information communications technology and Arctic earth observation, aerospace and defense, northern cultural, creative, and specialty food industries, and Arctic research and education (Government of Canada, 2016). Indigenous traditional livelihoods, namely hunting, fishing, and arts and crafts, are identified as the long-lasting lifeline and mainstay of the local economy (Arruda & Johannsdottir, 2021).
- In Alaska the main industries, in terms of value added, are mining and quarrying (i.e. oil and gas extraction, and other mining and quarrying

activities), meaning that petroleum is the backbone of the economy. Other important economic activities are public administration and defense, transportation by pipeline and storage, and unspecified service activities. The seafood and tourism industries are also worth mentioning (Glomsrød et al., 2017).

- In the Arctic Russia, petroleum and other mining industries are of critical importance, with a high dependency on primary production, predominantly of oil, gas, and other minerals. The highest value added by industry in Arctic Russia is by far from petroleum and other mining activities, followed by construction, transportation and storage, wholesale and retail trade, and real estate activities (Glomsrød et al., 2017).
- The Greenlandic economy is based on four main pillars: "fisheries, raw materials, tourism and other land-based business" (Organisation for Economic Co-operation and Development, 2005, p. 1), followed by service activities, wholesale, retail trade, construction, public administration, defense, transportation, and storage (Glomsrød et al., 2017).
- The Icelandic economy is fundamentally based on tourism, energy, and fisheries. Extensive use of renewable energy is one of the characteristics of the Icelandic economy, with important sources of renewable energy, mainly hydro and geothermal, to meet the high level of energy consumption mainly from the energy-intensive industries, such as aluminum smelting (Arruda & Johannsdottir, 2021) and data centers.
- In Finland, the main industries are forestry, natural resources extraction, mining and metal industries, tourism, bio, renewable energy and offshore industries, shipping, construction, environmental and maritime technology, Arctic infrastructure development, navigation and transportation in icy waters, and research and education (Arctic Council, n.d.-a).
- The cornerstones of the Northern Norwegian economy are fishery, marine resources, and livestock husbandry, with fisheries and aquaculture being the most critical sectors with regard to exports. Tourism, sustainable energy (hydro and wind power), power from liquefied gas, minerals, and transit are also becoming important (Arctic Council, n.d.-b).
- In Arctic Sweden, there is a strong emphasis on the manufacturing industry, more specifically basic metals, wood, and paper. Mining is of

great importance, as well as utilities (i.e. electricity production, gas, and water supply), tourism, and other private services.

4 Business Environment in the Arctic

The Arctic region presents a unique set of characteristics that influence the business environment and entrepreneurship. Despite its sparsely populated communities and vast land area, challenging climatic and geographical conditions, and its wealth in natural resources, the region presents a range of business opportunities and additional challenges associated with climate change adaptation not seen elsewhere in the world. The local condition "extreme climate, unique natural phenomena, snow, ice, permafrost, culture, distances between people, poor transportation system and constraints to on starting, operating—and maintaining a business" (Middleton et al., 2020, p. 4) are said to "foster a unique interplay between people, technology, nature, market, and ways of doing business" (Middleton et al., 2020, p. 4). However, as of late, Arctic businesses are defined as "a modern phenomenon with specific features in four perspectives: motivation, competitive advantage, branding, and clustering" (Middleton et al., 2020, p. 4).

The Arctic business environment is therefore dynamic and influential beyond the boundaries of the region with annual growth in commercial activities (Arruda & Johannsdottir, 2021; British Antarctic Survey, n.d.). The Arctic business environment has developed at a fast pace taking the lead in several industries, ranging from more traditional roots like oil and gas, mining, metallurgy, fisheries, and shipping (Nordic Council of Ministers, 2018), to forestry and bioeconomy in areas of the European Arctic like North Finland, North Sweden, and North Norway (Arruda & Johannsdottir, 2021), and tourism (British Antarctic Survey, n.d.).

The Arctic is also a region of innovation, entrepreneurship, and indigenous cultural businesses, as new business approaches have emerged to deal with the pressing challenges related to climatic and socio-environmental impacts and to address specific needs and opportunities of the region (Nordic Council of Ministers, 2018). These approaches have emerged based on collaborative synergies of pioneering technologies and new economic models like Smart specialization and circular economy—approaches aiming to prioritize public research and innovation investments in priority domains that will lead to economic transformation of regions based on the strengths of specific economic contexts (Foray, 2018). The practical application of technological opportunities oriented to provide solutions to socio-environmental problems could unveil the role of businesses and knowledge-intensive entrepreneurs in a changing Arctic (Malerba & McKelvey, 2020). Technological innovation associated with smart specialization and knowledge-intensive entrepreneurship (Arruda & Johannsdottir, 2021) can create new modes of business operation based on collaboration for local and regional resilience based on systematic alignment to the Sustainable Development Goals (SDGs) and practical application toward sustainability.

It is emphasized that business development must be rooted in the Arctic people(s), innovation, and sustainable development as this approach enables human capital and unique resources of the region to become globally competitive. Urbanization is taking place as younger generations expect "services, opportunities, and education offered in greater metropolitan areas"; therefore, economic hubs and business models must be established to fulfill those needs through innovation, "new technologies in transport, communication, raw material processing, etc.", revising the remote concept (Nordic Council of Ministers, 2018, p. 7).

The Arctic Economic Council (AEC), established by the Arctic Council, is an independent organization facilitating Arctic business-to-business activities and responsible economic development. It emphasizes sustainable business development in the Arctic. Five working groups highlight the main AECs themes which are marine time transportation, investment and infrastructure, responsible resource development, connectivity, and blue economy. The focus areas, also evident in AECs publications, conferences, meetings, practices, and protocols, are aimed at benefitting both local communities and businesses (Arctic Economic Council, n.d.).

It should be noted that the wealth in natural resources in the region presents a range of trade-offs between industries such as fisheries, reindeer herding, and oil and gas. Investment decisions therefore must rely on political and regulatory conditions at different levels, namely at local, national, and global levels, but these conditions are subject to change. In case of megaprojects, such as energy projects, businesses are also exposed to risk factors of other types, including geological, environmental, and operational risks (Emmerson & Lahn, 2012).

In the region manmade infrastructure is also at risk due to the thawing of permafrost. This calls for investments to relocate communities and tangible structures (Anisimov et al., 2007), including buildings, bridges, roads, and pipelines, consequently requiring new types of design and adaptation methods (Emmerson & Lahn, 2012). Already, anecdotal evidence suggests disappearing of Indigenous People's livelihoods and uninhabitable local villages (Arctic Council, 2016). Additionally, there are infrastructure gaps in the region such as in the case of transportation infrastructure, pipelines, surveillance and search and rescue capability, and communication technology (Emmerson & Lahn, 2012).

In regions where small communities are dealing with multinational corporations there is a risk of human rights abuses and environmental issues caused by the corporation's activities. It can, however, be challenging for stakeholder to voice their concerns over the actions of large corporations. Corporations may respond in an exaggerated and disproportionate manner to those voicing corporate accountability, the latter even facing lawsuits, threats, harassment, and even death. This raises the "barriers for victims to obtain justice" (Dowd & Aba, 2017).

5 Business Adaptation in the Arctic

The enduring question is how to balance development with traditional life ways. Development projects essentially affect every aspect of how indigenous people live in the North—their nutrition, modes of transport, type of work performed, and dwelling characteristics. It is time to recognize that any economic opportunities that industrial and resource exploration activities can bring should be carefully planned and harnessed so as to help indigenous communities meet their adaptation goals. At the same time, the state should strengthen the native economy with its associated values and preferences so that its very foundations are not undermined (Berger, 1986).

To deal with climate change challenges in the Arctic, actors on different levels both within and outside the region need to be part of a collective debate and decision-making process as well as share responsibility as the region is home to many inhabitants and rich in resources. The issue is that different actors may view their interests differently with different material outcomes, and some interests may be conflicting, such as in case of oil and gas extraction, commercial fisheries, infrastructure projects, and subsistence way of living (Arctic Council, 2016; Johannsdottir & Cook, 2019; Vammen Larsen et al., 2019).

Business adaptation in the Arctic will, for the time being, need to deal with the Arctic paradox of Arctic communities living side by side with fossil fuel developments as they depend on fossil fuel production and consumption, while Arctic renewable energy resource solutions, that is, solar, wind, geothermal, hydro, tidal, and biomass, are being developed and scaled up (Arruda, 2019b). At the same time, risks of climate change are materializing in the region as transformative change in climatic conditions is happening in the Arctic (Intergovernmental Panel on Climate Change, 2014). The adaptation process will therefore need to address different groups' interests, and distinct opinions about the paths of development for the region based on different perspectives and mindsets. Decisions will need to be made in terms of energy systems, food security, and principles and criteria for a green transition with effects locally and globally. Crucial debates about phasing out fossil fuels and other meaningful conversations about climate change mitigation and adaptation will need to take place in collaborative coordination among the Arctic nations to create transparent structures and frameworks to protect communities and the environment. It is undeniable that businesses have the important role of supporting the correction of inequalities of climate change in the Arctic, but for this businesses will need to show the highest level of adherence to the Sustainable Development Goals ever (Arruda, 2019c; Arruda & Johannsdottir, 2021).

The business case for climate change adaptation is based on two main aspects, namely expected return and benefits, and expected costs and risks (Johannsdottir & Cook, 2015). Among the business opportunities identified are industrial development and small and large infrastructure investments in mining and energy projects, social services, telecommunication, shipping and logistics, fisheries, and tourism (Emmerson & Lahn, 2012; Arctic Economic Council, n.d.; Ministry of Foreign Affairs of Denmark, 2020). However, this development is not without risks, businesses operating and/or investing in the Arctic expose themselves to various types of risk factors. These include risks of climate hazards and extreme weather, and consequent physical risk to assets, price risk and investment risk, regulatory risk, risk of pollution, social and political conflicts, including opposition from NGOs and activists, litigation risk, and reputational risk (Acclimatise, 2009; United Nations Framework Convention on Climate Change, n.d.). All of these risk factors need to be assessed and managed for responsible business conduct in the region, otherwise businesses risk losing their social license to operate—an intangible license to operate evident in the acceptance of stakeholders that are influenced by or can influence the operation of businesses (Heikkinen et al., 2016). Areas of priority for enhancing Arctic sustainable business practices consist in addressing risks and opportunities in Arctic value chains as well as applying risk management tools to identify risky supply chain segments. In northern countries, the due diligence system applied to supply chains has the role of identifying and assessing risk in specific strategic supply chains or segments of supply chains in order to establish robust corporate management systems, provide adequate response to risks, as well as provide adequate auditing and reporting. There are several benefits of implementing risk-based due diligence associated to efficiency gains, licensing granting (social and environmental), diversification, reputation management, and access to markets (Arruda & Johannsdottir, 2021).

6 Business Contribution to Climate Adaptation in the Arctic

The importance of stakeholder engagement for Arctic business operation cannot be overstated. To guide this dialogue a stakeholder management model can be employed. It includes six steps, which are (1) identification of stakeholders, (2) assessments of who stakeholders are, (3) dialogue to identify their claims and interests, (4) integration of interests and claims into strategy and operation, (5) measurement of performance, and (6) communicate results to the stakeholders. This is then of course a cycle of continuous improvements (Fifka & Loza Aduai, 2015). But who are the stakeholders? Often, they are categorized as economic stakeholders, such as customers, suppliers, shareholders, competitors, creditors, and unions; organizational stakeholders, namely, employees, directors, and executives; or societal stakeholders, including communities, NGOs, governments, regulators, media, opinion formers, or special interest groups, just to name some (Bhattacharya et al., 2011; Freeman et al., 2017; Hopkins, 2016). However, this categorization is not considered to be sufficient in the Arctic context, where the natural environment and non-human species, as well as human stakeholders, that is infants, elders, youth, and future generations, must be included as well (Arruda & Johannsdottir, 2021) given the interconnectedness between environmental, social, and cultural context, and the different types of economies coexisting (Vammen Larsen et al., 2019).

Various conventions, principles, guidelines, tools, and standards are recognized as being fundamental for business operations in the Arctic context. These include the UN Global Compact, the Organisation for Economic Co-operation (OECD) Guidelines for Multinational Enterprises (Organisation for Economic Co-operation and Development, 2011), the Global Reporting Initiative, Social Accountability 8000, Nasdaq ESG Reporting Guide, the International Labour Organization (ILO) conventions, the UN Declaration on the Rights of Indigenous Peoples, the UN Principles on Businesses and Human Rights, the International Organization for Standardization (ISO) Standards, the Carbon Disclosure Project, UN Principles for Responsible Investment (PRI, n.d.), the Arctic Investment Protocol, and more (Arruda & Johannsdottir, 2021). These support business and technical skills but, more importantly, emphasize the social and societal skills needed for enhancing the respect for human rights, local communities, and the natural environment.

The Arctic Investment Protocol, previously developed by the World Economic Forum, is one of the tools that aims to balance the aspirations of the four million Arctic residents and the emerging investment opportunities in the region. The economic growth should rest on sustainability, inclusion, equality, fairness, resilience, and well-being of communities. Six principles are emphasized (Arctic Economic Council, 2020):

- Build resilient societies through economic development.
- Respect and include local communities and indigenous peoples.
- Pursue measures to protect the environment of the Arctic.
- Practice responsible and transparent business methods.
- Consult and integrate science and traditional ecological knowledge.
- Strengthen pan-Arctic collaboration and sharing of best practices.

The Arctic business environment must adapt to the vast change in climate taking place in the region. Under such conditions risk assessment and management are fundamental to ensure businesses can work sustainably, successfully, and safely in the Arctic (Emmerson & Lahn, 2012), in harmony with the inhabitants, non-human species, and the natural environment (Arruda & Johannsdottir, 2021). This also means to adopt and employ best practices, such as for risk management processes and frameworks, to have crisis response plans in place, to carry out exercises and learn from worst case scenarios (Emmerson & Lahn, 2012), and be transparent about the operations (Heikkinen et al., 2016). Supporting resiliency of Arctic communities, and ensuring that their inhabitants will thrive, also means the success of responsible businesses operating in the Arctic.

7 Discussion

Businesses have the important role of supporting the correction of inequalities and risks of climate change in the Arctic. A mixed strategy of adaptation and mitigation could be the beginning of an operative strategy for the Arctic with the multicultural understanding of each stakeholder's role in the development project, by making them active parties and beneficiaries of development and prosperity, being crucial to this process. Indigenous communities must be an integral part of development projects based on shared values and traditional knowledge (Arruda, 2019b).

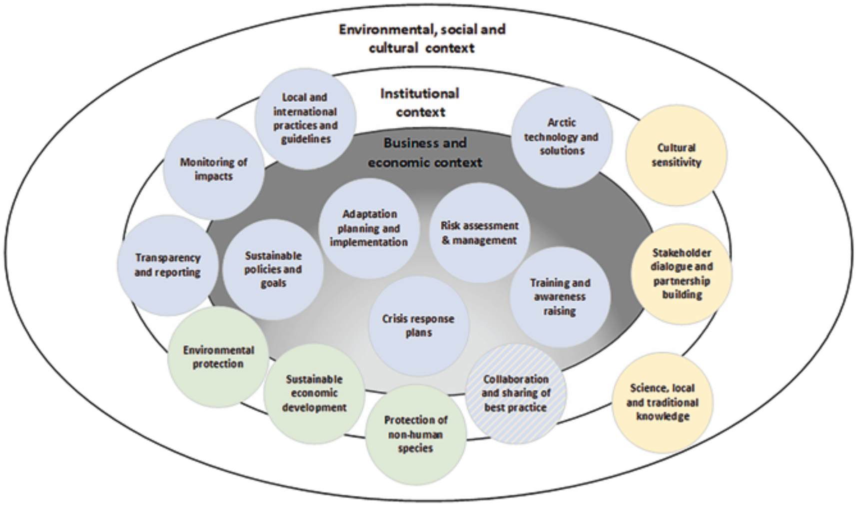

Fig. 15.2 A conceptual framework of Arctic economies embedded within the institutional, environmental, social, and cultural context, including essential elements of business adaptive capacity

Figure 15.2, developed by the authors, starting from the conceptual framework in Fig. 15.1, (Vammen Larsen et al., 2019) and integrating the results of the analysis presented in the preceding sections, presents a diagram integrating the main elements of adaptive capacity and adaptation, thus demonstrating through which means businesses can contribute to climate adaptation in the Arctic while running sustainable, successful, and safe businesses in harmony with the inhabitants and the non-human environment, and while protecting the natural environment. The green color represents the sustainability aspect, non-humans, and the natural environment. The yellow color represents the social and societal capacity building and cultural sensitivity, based on stakeholder dialogue, partnership building, science, and local and traditional knowledge. The blue color highlights the prerequisites for sustainable and responsible business practices and the circle with stripes (blue/yellow) presents the social-business aspect evident in collaboration and sharing of best practices.

The circles are placed in the diagram based on the extent to which they are business/stakeholder related. The ones in the business/economic sphere are business related, but the others are based on the interplay between all three spheres of the conceptual framework. In many cases the circles overlap and connect all three spheres, such as transparency and reporting. Although this is the role and responsibility of the business, they should be based on international best practices and standards and shared with external stakeholders both in the institutional sphere and in the social sphere. The same applies to the monitoring of impacts. This should be carried out by the business, or institutional actors, such as environmental agencies, but the monitoring might be based on natural science methods or carried out through surveying stakeholders in the institutional sphere and/or the social sphere. Although few elements of the diagram are placed in one or two spheres, they may also interconnect with other spheres, such as science, and local and traditional knowledge. In this case, the circle connects the two outer spheres, but the outcome may have implication for the business/economic sphere as well. This diagram highlights that businesses do not operate in isolation and that they need to understand and take responsibility for the implications of their operations for the outer spheres of the diagram. This is extremely important in the Arctic context in the case of their adaptive capacity and adaptation in the region.

8 Conclusion

The Arctic has seen transformative change for several decades with climate change being one of, but not the only element. Climate change in the Arctic is faster and stronger than in most other parts of the world, which means that adaptation is, and needs to be, further reaching and more fundamental, and it needs to happen at a faster pace. From a business perspective, climate change has led to new business opportunities, but also to new risks and costs. The discussion in this chapter, and the conceptual framework shown in Fig. 15.2, highlights the importance of economic development that is sustainable. The chapter has shown that climate change adaptation in the Arctic is a highly complex endeavor. It requires considering the environmental, social and cultural context, the institutional context, and the business and economic context. These spheres are inherently interconnected. The role of businesses in climate change adaptation and mitigation in the Arctic therefore needs to be understood in a context that is broader than the immediate business and/or economic one. Businesses must approach their role and responsibilities with "a genuine concern for not generating negative impacts (externalities) for people, society, the environment, and the economy" (Arruda & Johannsdottir, 2021, p. 171).

Adaptation requires social and societal capacity building and cultural sensitivity, based on stakeholder dialogue and partnership building as well as science, and local and traditional knowledge. Building on this fundament, technologies and further solutions that consider the specific Arctic situation and development can and need to be developed. Businesses need to establish sustainable policies and goals, and actively engage in adaptation planning and implementation. Corresponding risk assessment and management goes hand in hand with training and awareness raising and establishing crisis response plans.

Local and international practices and guidelines can inform decision makers and serve as a benchmark or best practices, but at the same time, these practices and guidelines need continuous revision and updating in order to keep up with ongoing climate change and unfolding impacts. Such updates and revisions require continuous monitoring of impacts and corresponding reporting to achieve best possible transparency—which closes the circle to stakeholder dialogue.

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16

Climate Risk on the Rise: Canada's Approach to Limiting Future Climate Impacts

Daniel Filippi and Kathryn Bakos

1 Introduction

The United Nations Intergovernmental Panel on Climate Change (IPCC) projects that global warming is effectively irreversible and extreme weather events such as floods and fires will continue to increase in frequency, intensity, and duration throughout the twenty-first century (IPCC, 2019). Due in part to these extreme weather events—combined with aging infrastructure, increased urbanization, loss of natural infrastructure, and lack of protection measures at the household level—there has been a total loss of $2.98 trillion USD globally (2010–2019) in direct economic damages and insured losses, which is $1.1 trillion USD higher than in the previous decade (Aon, 2019). Specifically, in regard to Canada, Property and Casualty (P&C) insurance claims have doubled every five years since the 1980s (Fig. 16.1; Kirchmeier-Young & Zhang,

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https://doi.org/10.1007/978-3-030-86803-1_16

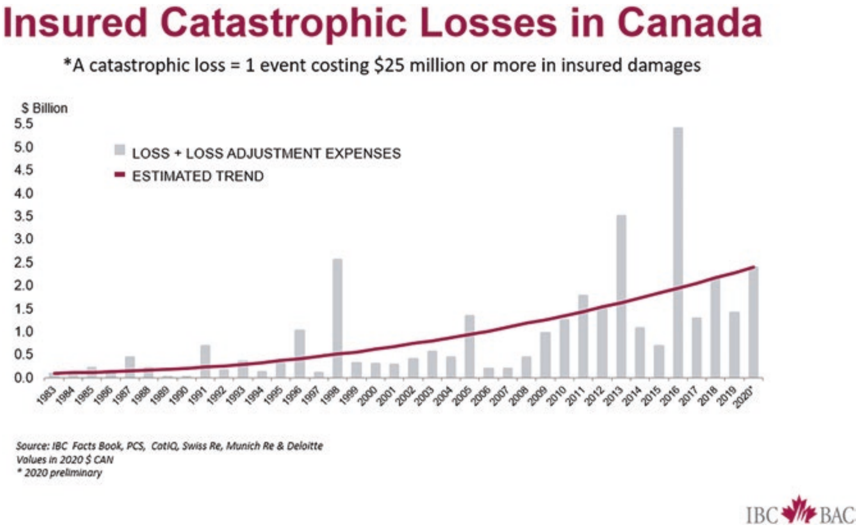

Fig. 16.1 Costs of extreme weather: Catastrophic insurable losses ($CAD). (Note: Graph of catastrophic insurable losses in Canada from 1983 to 2020. Total losses normalized for inflation, per-capita wealth accumulation, and set in 2020 CAN dollars (as of November 2020). This is a comparison of "apples to apples") (IBC, 2020a)

2020; Insurance Institute of Canada, 2020). These catastrophic losses ("cat loss") refer to any extreme weather event that results in $25 million CAD or greater insurable loss (IBC, 2020a). Figure 16.1 shows a discernable upward trend in losses averaging more than $1.2 billion CAD annually since 2009 (Feltmate et al., 2020).

Compounding this issue, the Canadian government's Disaster Financial Assistance Arrangements (DFAA) payments, which refer to funds transferred to provincial/territorial governments to provide financial relief for costs associated with natural disasters, have increased nearly tenfold between 2004 and 2014 (GOC, 2020). In the coming years, DFAA will increase its current trajectory and average over $900 million CAD per annum with $673 million CAD (~75%) going toward flood-related relief (Fig. 16.2; PBOC, 2016). These amounts exceed resources as the program budget has only averaged $100 million CAD per year since its inception in 1975 (PBOC, 2016).

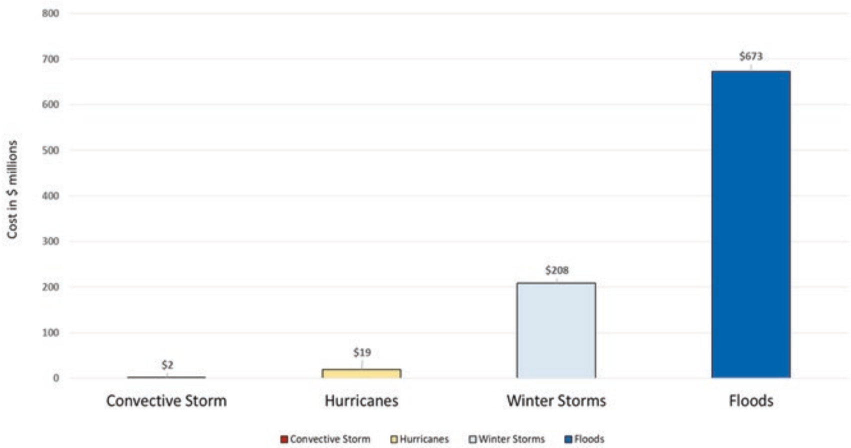

Fig. 16.2 Estimated Disaster Financial Assistance Arrangements (DFAA) annual weather costs. (Note: Estimated DFAA annual weather-associated costs in government funds (millions), with figures provided by the Office of the Parliamentary Budget Officer (PBO) [Story, 2016])

Canadian homeowners, municipalities, businesses, and all levels of government must begin adapting to severe weather events by incorporating measures to mitigate risks around households, corporate structures, and natural habitats. If changes are not made within Canada the economy will continue to suffer extreme losses, which will have direct and indirect implications throughout economic systems. IBC states that due to under-insurance, 60–80% of economic losses resulting from extreme weather events are borne by taxpayers (IBC, 2014). It is the Canadian economy, specifically the Canadian taxpayer, who experiences the physical, financial, and psychosocial implications of extreme weather events. A joint report completed by the Federation of Canadian Municipalities (FCM) and the Insurance Bureau of Canada (IBC) estimates that an investment from all three levels of government of $5.3 billion CAD a year will be required to fund the municipal infrastructure and local adaptation measures necessary to reduce the impacts of climate change in Canada (IBC, 2020b). This type of funding will help lower economic costs and, in turn, the stresses associated with extreme weather events.

To begin addressing community-level impacts, devising initiatives that homeowners can take must be an initial step. Approximately 10% (or 800,000 households) of Canada's population is located in areas deemed "high-risk" flood zones (Moudrak & Feltmate, 2017). A study conducted by the University of Waterloo found that of 2300 Canadian participants living in areas deemed at high risk under Canada's Flood Damage Reduction Program (FDRP), 94% were unaware their homes were at risk of flooding (Thistlethwaite et al., 2017). Furthermore, fewer than 28,000 km of river systems in Canada have been mapped for flood risk; and of these, approximately 50% were mapped before 1996 under the FDRP, meaning maps are 25 years out of date (Nadarajah, 2016). Canada's FDRP began producing necessary flood risk maps for urban areas across Canada in 1975 (except Prince Edward Island and the Yukon Territory, as both were viewed as "low risk"), with over 1000 communities and associated floodplains mapped (Sandink et al., 2010). The program was successful in helping Canada to redirect investment and key infrastructure developments (residential, municipal, and commercial) away from flood-prone areas. Canada was a global leader in flood preparedness and mapping during this time, as countries within Europe and the Caribbean requested assistance and direction on how to develop similar programs (McClearn, 2019; Henstra et al., 2019). In 1996, the FDRP ended due to federal government budget cuts, and floodplain mapping became the primary responsibility of individual provinces. Wealthier provinces, such as Ontario, continued mapping flood zones with support from conservation authorities, while cash-strapped provinces, like those in the Maritimes, experienced a reduction in flood-mapping activities overall (McClearn, 2019; Conservation Ontario, 2019). As a result, access to accurate and up-to-date flood maps varies across the country, province-to-province.

Canada is no longer the leader it once was due to inaccurate flood mapping, alongside exceedingly large payouts being issued due to rising extreme weather events. The less prepared the country continues to be for climate change-related extreme weather events, the more residents, companies, and municipalities will be the hardest hit by extreme weather events. For example, in 2019, Quebec's premier, François Legault, offered homeowners located within the province's floodplains a maximum of

$250,000 to purchase homes and/or properties, so residents could relocate elsewhere; this is the highest expropriation offer in Canada to date (Perreaux, 2019; Flavelle, 2019). The average home price in Quebec is $340,000 (as of 2020), while the average for the rest of Canada's housing stock is $531,000 (Statista, 2020a, 2020b). Residents who accepted this offer from Quebec's government were potentially "on the hook" for a minimum of $90,000 to pay off mortgages, if they had not already done so. In addition, a flooded basement (a main reason for increasing "cat losses") in Canada costs on average $43,000 to repair, which tends to not be fully covered by a homeowner's insurance. Assuming no insurance coverage or a low cap rate, restoring a basement may prove cost-prohibitive for owners, specifically for the 48% of Canadians who reported a monthly surplus of less than $200 in 2019 (Simpson & Chhim, 2019). As a result, homeowners are generally uninformed and lack the necessary resources to protect themselves against ever-increasing flood risks (Carrick, 2019); without proper planning and foresight, mortgage defaults could increase.

2 Canada's Efforts in Climate Adaptation

2.1 Standards & Guidelines

With support from organizations such as the Standards Council of Canada, National Research Council, and Canadian Standards Association, practical and cost-effective guidelines and standards have been developed to mitigate many forms of extreme weather risk across Canada.

Below are examples of standards which highlight ways Canada can prepare for flood events at the household and community level.

1. *CSA Z800*: This guideline outlines the top 80 visual inspections homeowners can conduct around a home to limit the likelihood of flooding. This guideline was the basis of the Home Flood Risk Assessment Training (HFRAT) course developed by Intact Centre on Climate Adaptation (ICCA) and offered to professional home inspectors, engineers, technicians, and developers (CSA Group, n.d.).

2. *CSA W204*: This standard was developed to be used by municipalities in implementing requirements and recommendations for the design of flood-adaptive greenfield development, along with the adoption/implementation of natural infrastructure and built/gray infrastructure. It includes general principles of community-level design, new planning recommendations, and policies to better protect new communities (SCC, 2019).
3. *CSA W210*: This standard includes new recommendations and an applicable framework for screening both flood hazards and vulnerabilities within current residential communities. The standard highlights how to identify and prioritize various flood risk preparedness actions for large and small municipalities with varying levels of capacity (Filippi, 2020).

2.2 Site-Specific Guidance

Site-specific guidance is necessary in helping Canadians achieve practical and cost-effective means to reduce household flood risk through programs similar to the Home Flood Protection Program (HFPP). The Intact Centre on Climate Adaptation (ICCA, University of Waterloo) developed the HFPP, which includes three key elements:

1. *Free online resources/education materials*: electronic and paper factsheets, how-to videos, information on participating communities, and local flood protection subsidies available within municipality (Evans & Feltmate, 2019).
2. *Home flood protection assessment*: Similar to a home inspection, 90-minute onsite flood risk assessment services are made available to homeowners including an easy-to-read summary report (Evans & Feltmate, 2019).
3. *Customized outreach strategy*: Program planning and promotions developed in collaboration with local municipalities, emergency services, conservation authorities, community groups, media outlets, and insurance providers to complement and enhance ongoing flood risk reduction efforts (Evans & Feltmate, 2019).

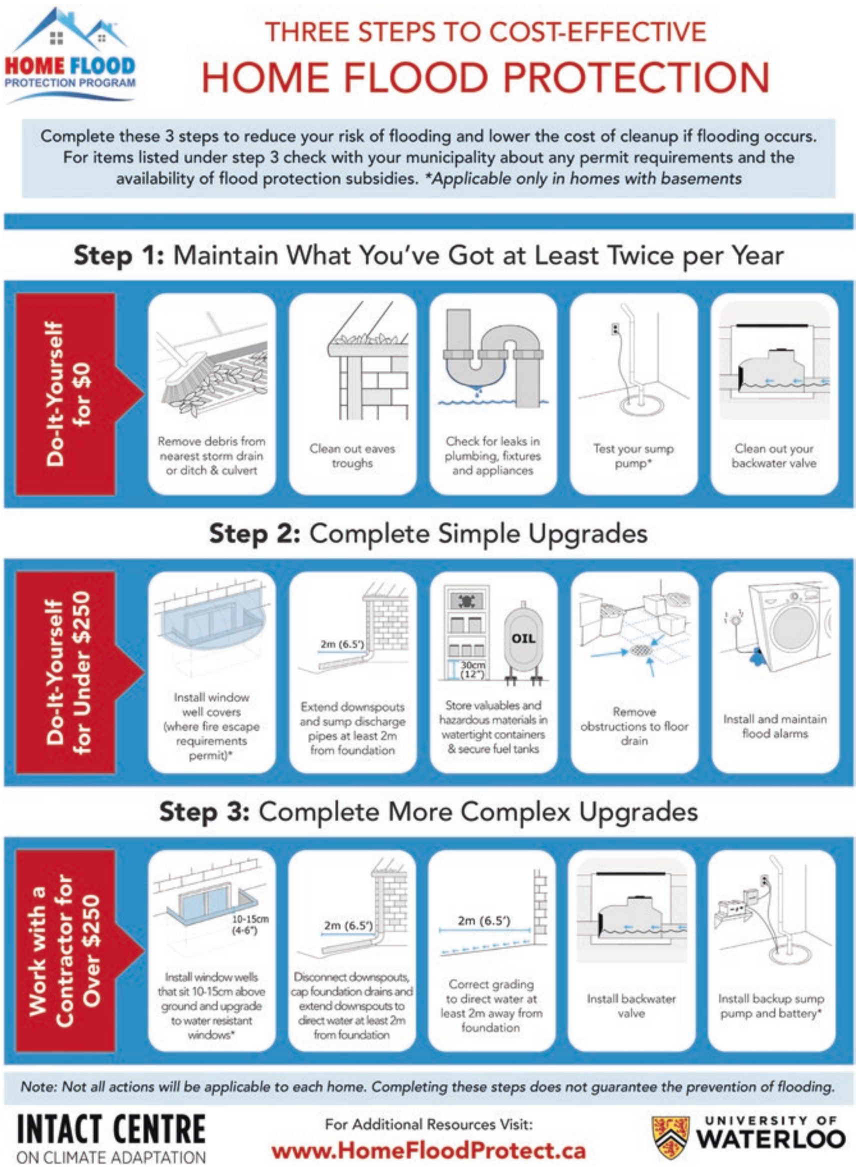

Fig. 16.3 Three-step document to home flood protection. (Note: Three-step document created by ICCA highlighting simple and cost-effective adaptation actions to limit the risk of flooding in and around the home [Moudrak & Feltmate, 2020])

Figure 16.3 summarizes the top 15 actions that homeowners can take to reduce flood risk. The program's results indicate that direct conversations between homeowners and trained flood risk mitigation professionals are effective in motivating residents to take action to reduce flood risk at the household level. These results led the ICCA to develop multiple training programs for home inspectors, real estate agents, mortgage professionals, insurance brokers, and municipal employees (ICCA, n.d.). This training allows homeowners to acquire information confidentially from trusted professionals on how to best protect their homes.

2.3 Financial Standards and Disclosure Guidelines

In addition to standards and guidelines that prepare Canadian households and communities for flood events, Canada has passed official regulation that requires publicly traded companies to disclose material climate risks through the Canadian Securities Administrators (CSA)—Staff Notice CSA-51-358. For approximately ten years, the CSA have required publicly traded companies disclose material climate risks. Fiduciary duty requires the disclosure of this information, as it could affect the decision of an investor to buy, hold, or sell stock in a given company (OSC, 2020; BOC, 2019). These implications could directly affect the Canadian economic system, influencing the livelihoods of citizens and the distribution of community resources. The problem, however, is that securities commissions simply do not know which climate risks are material; as a result, they cannot enforce their own mandate. To correct this oversight, securities commissions should prioritize establishing a core group of climate risks, specific to each industry sector, which issuers should be required to report.

Relative to climate change, the outstanding challenges for investors are to identify which extreme weather events have the highest probability of affecting individual industry sectors/sub-sectors and assess whether potential investee companies have implemented appropriate actions to mitigate extreme weather risks specific to sectors/sub-sectors (Feltmate et al., 2020). In this regard, the ICCA has developed a practical means to factor climate change and extreme weather risk into portfolio management, consistent with the direction proposed by the Task Force on Climate-Related Financial Disclosures (TCFD) (Feltmate et al., 2020).

The Climate risk matrices (CRMs) prioritize the top one or two means by which each category of extreme weather (e.g., flood, fire, wind) may negatively impact industry sectors, while simultaneously identifying actions companies should take to mitigate prioritized risks (including probable and tail risks), per Fig. 16.4 (Feltmate et al., 2020). This directive allows climate risk information to be understood and interpreted by investors, enabling them to price risk and ensure the efficient allocation of investment capital (BOC, 2019). Although CRMs address the needs of investors, value is also available to securities commissions (to guide

	Flood	Fire	Wind Storm	Ice and Snow Loading	Thawing Permafrost
Key Climate Risk Impacts	Flood-induced high water levels result in inadequate electrical clearances below lines that are hazardous to the public	Fire along transmission corridors can cause outages if corridors are not adequately clear of brush Vegetation/tree contacts with transmission lines can cause arcing, fires and outages	Vegetation/tree branches can fall onto T&D lines causing outages T&D lines can be brought down by wind forces	T&D lines and structures can collapse under heavy ice loading	Thawing/ discontinuous permafrost can displace transmission tower foundations, causing structural collapses and outages
Mitigation Measures	Ensure structures are tall enough for safe clearance under foreseeable flood levels, or lines are installed underground	Conduct patrols (visual inspection of utility equipment and structures) in fire prone areas Clear vegetation along transmission corridors	Clear vegetation along transmission corridors Install anti-galloping devices on conductors and ensure structures are designed to withstand winds	Install visual monitors to detect ice loading. Before ice loads build, boost current to melt ice (i.e., short the line)	Modify structure/ designs to readily permit adjustment of towers when line patrols identify permafrost thaw displacement
Key Questions to Determine Readiness to Mitigate Climate Risk	What percentage of T&D lines in flood-prone areas have sufficient clearance to safely accommodate a 1:200 year flood without de-energizing the line?	What percentage of total length of overhead transmission lines in wildfire-possible areas are closer than 10 metres horizontally to tree branches?	What percentage of total length overhead Transmission lines in treed areas are closer than 10 metres horizontally to tree branches that are higher than the conductors?	Are overhead lines that are susceptible to icing monitored by cameras that observe icing on the conductors?	Are your transmission structures, in discontinuous permafrost areas, of a design where the structured footings can be adjusted without de-energizing the line?
Excellent Answer	> 75%	None	< 5%	Yes	Yes
Good Answer	50% or higher	< 10%	< 25%		Yes, the most recent ones

Fig. 16.4 Climate risk matrix for electricity transmission and distribution industry sector. (Note: Climate risk matrix—electricity transmission and distribution (material highlighted in red reflects prioritized areas of focus applied to portfolio management) [Feltmate et al., 2020])

expectations on climate risk relative to disclosure), credit rating agencies (to identify borrowers' key climate risk liabilities), and boards of directors (to set a framework in which board members can ask appropriate climate risk-related questions of management) (Feltmate et al., 2020).

3 Case Study of Global Climate Adaptation Efforts

Although climate adaptation practices, policies, guidelines, and tangible actions have been developed, Canada must begin to take note of counterpart program innovations at both the government and private industry level, given the relative success seen in these countries.

3.1 The Netherlands: A Three-Tiered Approach

Canada and the Netherlands are very similar when it comes to their overall "vulnerability" rating, as reported by the United Nations University's Institute for Environment and Human Security (UNU-EHS). In 2020, the Netherlands received a vulnerability score of 24.87%, while Canada received a score of 26.89%. A lower vulnerability score indicates that a country is less likely to be environmentally, socially, and economically devastated by extraordinary circumstances, while also indicating the ability to recover quickly if a major event does occur. With this in mind, the Netherlands is less vulnerable than Canada, even though it possesses an "exposure" score three times higher than Canada's (31.72% compared to 10.36%). Exposure scores are calculated by the likelihood of a natural hazard (sea-level rise, earthquakes, etc.) occurring in a given country. These two indices, "vulnerability" and "exposure", are calculated together to assign a country's "WorldRiskIndex" score, per Fig. 16.5. As a result, the Netherlands ranks 65th out of 181 countries in terms of its WorldRiskIndex score of 7.89% (which is considered high risk), while Canada ranks 156th with a WorldRiskIndex score of 2.79% (which is considered very low risk) (Bündnis Entwicklung Hilft, 2020).

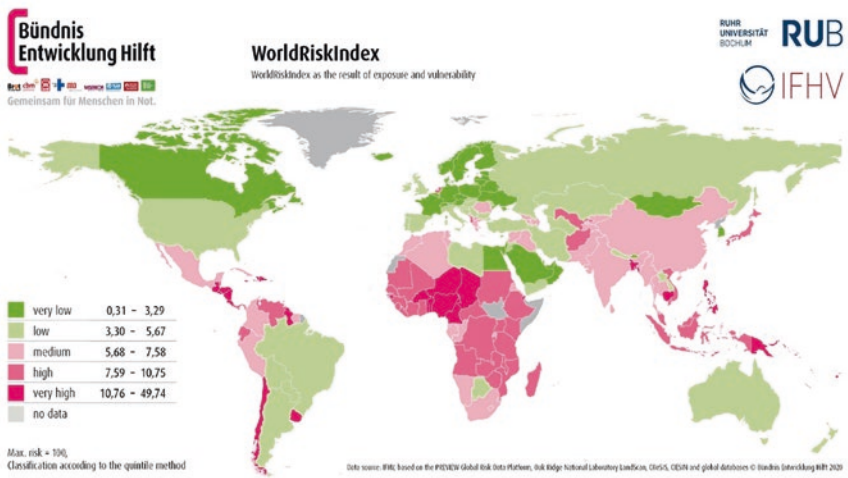

Fig. 16.5 "WorldRiskIndex" map. (Note: A Country's "WorldRiskIndex" is created by combining a country's "vulnerability" and "exposure" scores. Although Canada's WorldRiskIndex score is much lower than the Netherlands, Canada's higher vulnerability score means the Netherlands would rebound from major disasters faster [Bündnis Entwicklung Hilft, 2020])

Even though the Netherlands possesses a much higher exposure and overall risk score, the country is more likely to recover from an event compared to Canada due to its innovative approaches to limiting major disasters, due in part to lessons learned from the North Sea Flood of 1953 (which killed more than 1800 people and evacuated another 100,000) (Hall, 2013). Innovations after the North Sea Flood resulted in major improvements to the country's coastal defenses, flood management practices, policy reform, and early-warning systems. The Dutch have begun working with blue-green infrastructure, allowing rivers more space to meander and flo out into natural floodplains, which assists in reducing floods' impact on residential areas. Additionally, common urban infrastructures such as garages, parks, levees, and public squares now act as emergency catch basins and reservoirs during major flood events (Esteban et al., 2020; Morrison, 2019; Kimmelman, 2017).

Finally, all three levels of government are responsible for how the Netherlands handles flood risk management, ensuring quick recovery from extreme weather events, unlike in Canada, where the responsibility lies with varying government bodies depending upon the province.

The three levels of government involvement in the Netherlands are as follows:

1. **The Municipality**

    - Municipalities are able to access data, maps, and so on from the Rijkswaterstaat (Ministry of Infrastructure and Water Management) and forecast incoming rainfall events to determine whether warnings or evacuations are necessary (Esteban et al., 2020). Municipalities in the Netherlands have adopted a three-step approach (Capture, Store, and Drain) to handling excess water, which has led to various multi-faceted public spaces assisting in flood management, in addition to being gathering places for communities (Dai et al., 2017).

2. **Water Boards** (*Waterschappen or Hoogheemraadschap*)

    - Regional government bodies are responsible for water management (water quality, flood adaptation, etc.). There are currently 21 water boards that represent the 12 provinces of the Netherlands. These boards hold elections every four years and function independently from the country's other government bodies (Sten, 2019; Toonen et al., 2006; Kiesraad, n.d.).

3. **Rijkswaterstaat**

    - Over time, the Rijkswaterstaat (Ministry of Infrastructure and Water Management) has developed and made available pertinent information for flood adaptation planning, which includes up-to-date flood maps and simulations. Municipalities across the Netherlands can access this information to better prepare for future flood events and better design adaptive community strategies (Esteban et al., 2020; Government of the Netherlands, n.d.).

Canada must institute more sound, uniform, and collaborative approaches at all three levels of government to ensure property and peoples' livelihoods are less affected by the devastating impacts of natural disasters.

3.2 FEMA in the United States

The United States handles flood insurance and risk much differently from Canada. Although standard homeowners' insurance does not cover flood damage (similar to Canada), the federal government works with insurers to alleviate the impacts of flooding (i.e., hurricanes, heavy rains, etc.). In 1968, the National Flood Insurance Program (NFIP) was created and offered to eligible renters, homeowners, and businesses (FEMA, n.d). The NFIP is administered and run by the Federal Emergency Management Agency (FEMA), under the US Department of Homeland Security (DHS) (FEMA, n.d). The program has become the country's main flood insurer, backing over five million homes and businesses and providing 96% of all flood coverage in the United States (Zou, 2020). The second major function of the NFIP is to develop and modernize flood mapping. By continually mapping flood hazard areas/zones, associated regulations and flood insurance requirements can evolve. This program is duly named "Risk Mapping, Assessment, and Planning" (Risk MAP). The Risk MAP program sets annual coverage premiums, while determining which properties are eligible for subsidies (Zou, 2020). In this way, flood insurance premiums are set based on risk, but homeowners who have prebuilt structures located in the floodplain, prior to the Risk MAP program being initiated, are exempt from higher premium rates and still receive coverage (Zou, 2020). Finally, the NFIP works in collaboration with approximately 90 different private insurance companies to offer flood insurance to property owners and renters. Unlike Canada, it is the US federal government, and not individual insurance companies, setting rates (FEMA, n.d.).

Problems do arise, however; as the NFIP and FEMA are subject to approval by Congress and are impacted by the federal government's changing mandates and election cycles. Furthermore, any new home or business located in a FEMA- and NFIP-deemed "high-risk" flood zone that possesses a mortgage from a listed government-backed lender is required by law to have flood insurance (FEMA, 2020). This stipulation makes sense to protect the mortgage originator's investment, but makes things quite difficult for owners. Some owners are unable to afford the legally mandated high rates, leading to buyers being priced out of the market (FEMA, 2020). The requirement for business/home owners to have flood insurance is not instituted in Canada, regardless of the location or the perceived risk of flooding (McLachlan, 2021).

Ultimately, the program's core requirements are sound, allowing for fair and equitable insurance coverage to be accessed by owners living in high-risk zones and encouraging flood protection measures to be implemented to ensure insurance subsidies and/or reductions.

Canada should look to institute an updated and more equitable program that ensures affordable flood coverage for all. With this, Canadians would understand the significance of flood insurance, and benefit from a fulsome coverage policy, while reducing the likelihood of mortgage defaults. The Canadian federal government could look to implement these types of programs through Public Safety Canada.

3.3 Flood Re

In the United Kingdom (UK), a relatively novel approach attempts to ensure residents are protected from flooding. This example offers an interesting look into how reinsurance firms could operate in the near future.

Flood Re is a reinsurance pool, specifically for flood insurance, that offers coverage to both residential and smaller commercial properties deemed by the UK's mapping program to be "high risk" (IBC, 2019). Flood Re utilizes a pool of money to pay out individual insurance firms for claims paid to customers. Created in 2013, this pool of funds was established to allow individuals to pay for subsidized flood insurance. If claims following a flood event surpass the pool of money within Flood Re's reserves, then a specific levy can be imposed by the program, which calls on insurance companies associated with the program to provide further funding (IBC, 2019). The full amount of risk-based coverage costs will increase incrementally until 2039 (IBC, 2019), and within this timeframe, it is expected that the UK government will contribute to de-risking the country's most vulnerable properties to the point where traditional insurance purchasing and operations will be reinstated (IBC, 2019).

The reinsurance pool started as a result of increased flooding events due to climate change, urban development, and densification, which caused many insurance providers to become wary of offering flood insurance or simply couldn't afford to as a growing number of people were located in floodplains or other high-risk areas. Meanwhile, other insurers offered coverage, but costs were too high for average homeowners to afford; as a result, it was thought that this could lead to a number of homeowners opting to not pay for flood insurance to protect their homes. As a result, the federal government intervened and collaborated with private insurers, leading to the development Flood Re, a non-profit to ensure high-risk areas were offered affordable insurance (King, 2020).

Flood Re is the first of its kind to receive a sign-off from private insurers and backing by government legislation to offer available and affordable insurance coverage to those at the greatest risk in the country—the program directly affects approximately 350,000 homes (IBC, 2019). Even with many positive features, the program has faced scrutiny, including claims of its inability to offer enough risk reduction incentives to invest in flood-adaptive actions. This could potentially lead to more inequality between subsidized premiums and technical risk prices, as Flood Re had not considered the potential of increased frequency in flood events due to continued climate change impacts.

Although the Flood Re program possesses shortcomings, it deserves considerable recognition as an example of how governments and private industry can collaborate and limit the impacts of climate change. Since Canada was the last G8 country to offer overland flood insurance, an example of how Canada is lacking leadership in regard to flood insurance offerings (Gollom, 2017), implementing a program like Flood Re, could be a monumental step forward. If established, this could create a meaningful reinsurance-style partnership with insurance providers, while offering "build back better" subsidy requirements and stipulations to ensure more robust and accountable offerings to Canadians coast-to-coast.

3.4 Global Adaptation Measures: Disclosure of Risk

The European Environmental Agency (EEA) released a report in 2018 assessing the risk climate change poses to various member countries and determined how this information could assist in developing adaptation policies (EEA, 2018). The EEA report highlighted that adaptation would ensure that the EU is better prepared to handle the impacts of heat waves, floods, droughts, and so on (EEA, 2018). The report's aim was to promote a better understanding among experts and policymakers involved in adaptation planning, contributing to more informed decision-making in key vulnerable sectors across Europe (agriculture, fisheries, infrastructure development, etc.) (EEA, 2018).

In concert with this report, the TCFD, an international framework, considers physical, liability, and transition risks, while identifying what constitutes effective financial disclosures across industry sectors (TCFD, 2020). Global governments and companies now have recommendations to measure and respond to climate change risks better, while encouraging alignment with disclosure needs (TCFD, 2020). This type of framework allows climate risk information to become more widespread and useful within investment decision-making (TCFD, 2020). By utilizing this information, investors can understand the financial implications associated with climate change, emphasizing the importance of transparency in pricing risk and opportunities (TCFD, 2020). Ultimately, this will lead to allocating capital to companies that have identified climate risk and implemented adaptation measures to protect against these impacts (TCFD, 2020).

Society's failure to integrate the impacts of climate change into economic decision-making puts investors, financial institutions, credit rating agencies, capital markets, and so on at unnecessary risk (Moudrak & Feltmate, 2020). A recent example of taking a step in the right direction, the Government of New Zealand passed legislation requiring the disclosure of climate-related risks to comply with the TCFD (Reuters, 2021).

As more frameworks (Sustainability Accounting Standards Board (SASB), CDP, GRI, etc.) evolve though, disclosure recommendations vary and lack consistency. The market is calling for more practical disclosure information and comparability that would come with standardization (SEC, 2021). Currently, not all companies do or will disclose without a mandatory framework resulting in the misallocation of capital, so a standard comprehensive framework is required to produce consistent, comparable, and reliable data that investors need (SEC, 2021).

4 How Can Canada Better Adapt to Climate Change?

Canada needs to determine how extreme weather impacts communities, as a whole. By utilizing standards and guidelines already developed by organizations such as the Standards Council of Canada, National Research Council, and the Canadian Standards Associations, the country can assess and operationalize risk mitigation measures at the community level. Canada is moderately prepared when it comes to adaptation planning, municipal resilience projects, and instituting available federal and provincial funding for climate change implementation; however, more needs to be done. Canada must learn from the likes of the United States' NFIP program, the UK's Flood Re reinsurance program, and the countrywide watershed management of the Netherlands' three-tiered approach. Learning from the Netherlands, adaptation is simply a function of how a country anticipates the impacts of climate change and incorporates this into the function of daily life. Canada could use this as a blueprint for steps that can be taken now and forecast significant measures in the coming years to prevent risks associated with climate change in the near future.

As previously stated, Canada was once revered for its flood management, but today a lack of preparedness now defines the country's climate change response. Canada must look to alternative options, with governments working with private industry and implementing specific bodies/committees of government to focus solely on watershed management in all provinces. New regulations, codes, and guidelines must be developed to take into account new climate modeling data to help build "future-proof" climate-resilient cities across the country. Additionally, the federal government, through the Ministry of Natural Resources (NRCan) and Public Safety & Emergency Preparedness Canada, must work with the country's Indigenous governments, provinces, and territories to effectively develop and provide all Canadians with access to accurate and updated flood mapping. A nearly comprehensive inventory is tentatively set to be completed by the end of 2022; if completed, this effort will be a step in the right direction (Meyer, 2020; Trudeau, 2019). Finally, according to the Insurance Bureau of Canada, there should be an option for Canada to create a "high-risk flood pool of properties that would not otherwise be offered affordable insurance (or any flood insurance)" (IBC, 2019, p. 11). Homeowners would still need to pay premiums that reflect individual risk levels, but coverage under this option should be affordable, capped, and/or subsidized (IBC, 2019, p. 11). Responsibility is in the hands of government investment and taxpayers, which will be essential in "lowering the public safety and personal financial risk of those Canadians living in high-risk areas" (IBC, 2019, p. 13).

Furthering steps taken by the Canadian Securities Administrators and New Zealand's Federal Government, Canada, and countries around the world, should implement federal legislation requiring the disclosure of climate-related risks that comply with one globally recognized framework, while establishing a core group of climate risks, specific to each industry sector, which issuers would report to ensure securities commissions (and other agencies) know which climate risks are material.

This is key to developing guidance that contributes to improving the resiliency of communities, and business that operate within those communities, particularly in regard to climate adaptive infrastructure and determining where the allocation of funds can lead directly to preventing loss. Additionally, homeowners, municipalities, and/or businesses that disclose and adapt against risks should receive discounts on insurance premiums, mortgage interest rates, and gain access to interest-free loans. With more widespread and financially accessible adaptation actions, Canadians can have a positive impact at the individual level while also contributing to reducing growing levels of insurable and uninsurable losses, and DFAA payments.

Finally, throughout this chapter, flooding has been shown to be a high cost and key concern for Canadians. On a global scale, coastal flooding alone could amount to $14.2 trillion worth of losses by 2100, representing 20% of global Gross Domestic Product (GDP) (Kirezci et al., 2020). GDP tends to fall short of incorporating environmental factors into its valuation, so a standardized risk-based assessment including impacts from severe weather events and externalities must be incorporated into GDP calculations allowing for a more realistic representation of economic performance (iPolitics, 2020). As an example, under current GDP calculations, rebuilding following storm damage (damage that could have been averted had adaptation occurred) has a positive influence on GDP. This is a "false economy" measure, meaning this was money that suffered an opportunity cost, as it is now unavailable for building necessary community assets such as roads, schools, and medical and community centers (iPolitics, 2020). Armed with this understanding, Canada should move away from "false economy" measures and toward incorporating negative externalities into decision-making (iPolitics, 2020).

5 Conclusion

As the IPCC admonishes, global warming is effectively irreversible, and extreme weather events will continue to increase in frequency, intensity, and duration. The growing magnitude of extreme weather events will continue to challenge citizens, communities, governments, businesses, economies, and so on globally. As these impacts unrelentingly unfold, Canada must allocate resources to assist homeowners, communities, and businesses in adapting against climate change.

Utilizing standards, codes, and guidelines already developed, Canada can assess and operationalize risk mitigation measures at community levels and institute collaborative approaches throughout all three levels of government, such as the Netherlands' three-tiered approach, to minimize the devastating impacts of climate change. Canada can ensure affordable flood coverage by looking to the United States' FEMA model, while programs like Flood Re in the United Kingdom could help guide the creation of meaningful partnerships with private insurance providers and offer "build back better" subsidies to ensure more robust and accountable offerings are provided to Canadian homeowners.

Canada must continue to expand efforts to distribute free online resources/education materials, incorporate flood protection assessments into property inspections, and customize outreach strategies that complement and enhance ongoing flood risk reduction efforts. Opportunities and investments must be available for governments to work collaboratively with private industry to institute specific bodies/committees that focus solely on watershed management in all provinces. New climate modeling data should be used to develop future regulations, codes, and guidelines that will help build climate-resilient cities, while effectively developing and providing access to up-to-date, publicly available, flood maps to all Canadians.

Canada should follow through with federal legislation requiring crown corporations and private sector businesses to disclose climate-related risks and opportunities in compliance with global financial frameworks, contributing to the resiliency of business operations throughout the country. Finally, Canada must ensure that GDP calculations incorporate negative externalities into decision-making, moving away from "false economy" measures, so capital can be redirected to resilient infrastructure development.

Armed with insights from these global examples, Canada has the potential to become a strategic leader in the global fight against climate change; all we need to do is take the first step.

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17

Unlocking Climate Finance to Compensate Caribbean Small-Island Developing States for Damages and Losses from Climate Change

Don Charles

On September 2, 2019, Hurricane Dorian hit the Bahamas (NWS, 2019). As the hurricane reached the Grand Bahama Island and the Great Abaco Island, it flattened entire communities, demolished homes, and washed out roads, all while destroying infrastructure such as the airport and a hospital. The official death toll rose to 43 by September 7 (Silva & Imam, 2019), and by September 12, 2500 people were declared missing (Dedaj, 2019).

Hurricane Dorian was the first Category 5 hurricane on record to make landfall on the Grand Bahama Island. With wind speeds of 185 mph, it was also the strongest hurricane on record to hit the Great Abaco Island. Even more unusual was its slow path across the Bahamas. In fact, the hurricane moved approximately 25 miles in 24 hours, which is the shortest distance tracked by a major Atlantic hurricane in a 24-hour period since Hurricane Betsy in 1965 (Masters, 2019). The hurricane

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remained over the Bahamas for 40 hours before it moved north on Tuesday, September 3, as a Category 2 hurricane (Kaplan, 2019).

The occurrence of Hurricane Dorian in 2019 marks the fourth straight year in which at least one Category 5 hurricane formed in the Atlantic, which represents the longest such streak on record (Kaplan, 2019). The storm's rapid intensification over the weekend of August 31 to September 1 was unprecedented for a hurricane that was already so strong (Kaplan, 2019). In 2017, the Atlantic hurricane season was hyperactive. It featured seventeen named storms, ten hurricanes, six major hurricanes, and an Accumulated Cyclone Energy (ACE) of 226 units (Charles, 2019b; Crow, 2017). In contrast, 2018 recorded fifteen named storms, eight hurricanes, and two major hurricanes, whereas 2019 counted eighteen named storms, six hurricanes, and three major hurricanes in the Atlantic (NOAA, 2021). In the Atlantic, an average hurricane season accumulates approximately 100 Accumulated Cyclone Energy (ACE) units per season. A season is considered above-average when the ACE exceeds 120 units, and a season is considered "hyperactive" when the ACE exceeds 150 units (Charles, 2019b).

The rapid intensification of hurricanes, the stationarity of hurricanes over land, and the increase in the frequency of hurricanes and other storms are all features of climate change.

Hurricane Irma caused US$187 million in damage to Anguilla (Bello, 2018), US$32.3 million in damage to the Bahamas (Ibarra-Bravo, 2018), US$1649.7 million in damage to the British Virgin Islands (BVI), US$1.04 billion in damage to Sint Maarten (Williams, 2018), and US$289.6 million in damage to the Turks and Caicos Islands (Peralta, 2018). Karen Clark and Company (KCC) estimates that Hurricane Dorian caused US$7 billion worth of damage to the Bahamas (Barbados Today, 2019; McKenzie, 2019).[1]

Notably, the international disaster database (EM-DAT) recorded damages for 148 hurricanes in the Caribbean between 1950 and 2014. The hurricanes caused roughly US$52 billion in damage (in 2010 constant

[1] The estimated insured and uninsured losses on Abaco was US$4 billion, the losses on Grand Bahama was US$2 billion, and the loss on New Providence was US$1 billion (Barbados Today, 2019; McKenzie, 2019).

prices). Therefore, more damage is being recorded from hurricanes in the Caribbean as climate change occurs (Acevedo, 2017; EM-DAT, 2020).

While the Bahamas' catastrophic risk insurance payout of US$13 million with the Inter-American Development Bank (IDB) was triggered, this insurance claim figure was significantly less than the cost of restoration. In the wake of Hurricane Dorian, Deputy Prime Minister and Minister of Finance Peter Turnquest announced that the Government of the Bahamas was considering taking 10% from each ministry's budget to channel funds to help finance the country's restoration effort (ZIZ News, 2019).

Such financial arrangements lead to the question of who should be financially responsible for the damage and loss caused by Hurricane Dorian and other future hurricanes that climate change either triggers or worsens. The governments of small-island developing states (SIDS) in the Caribbean do not have the financial resources to self-fund the restoration of their countries after a hurricane. Therefore, they may consider loan financing, which in turn increases their debt. Potentially liable industrialized countries may rely upon the argument that the geography science cannot directly link their anthropogenic carbon emissions to any specific hurricane, and thus they cannot be mandated to pay. If this argument continues to be perceived as valid, high-emitting countries will evade accountability for their anthropogenic greenhouse gas (GHG) emissions.

There is a need for high-emitting countries to be forced to internalize the negative externality of their anthropogenic GHG emissions. Moreover, there is a need to mobilize damage and loss climate finance for SIDS apart from standard adaptation and mitigation finance. These issues are at the heart of the debate as to how climate finance should compensate for loss and damage in SIDS.

This chapter's objective is to explore how to mobilize financial resources to compensate Caribbean SIDS for loss and damage that are the result of climate change and extreme weather events, and is structured as follows. The second section reviews the status of the issue of loss and damage in international climate change negotiations. The third section explores the concept of insurance, since it is proposed as the mechanism to address loss and damage. The fourth section provides a discussion of a proposed mechanism, namely voluntary insurance. The fifth section highlights additional financial mechanisms that can be used to compensate SIDS for loss and damage. The sixth section concludes.

1 Loss and Damage in Climate Change Negotiations

Understanding loss and damage from climate change hinges on the notion that there are some impacts of climate change that extend beyond adaptation and mitigation action. In other words, loss and damage refer to climate change impacts that exceed the adaptive capacity of countries, communities, and ecosystems. These impacts include the effects of extreme weather events such as hurricanes, irregular storms, unexpected flooding, erratic droughts, as well as slow-onset events such as sea-level rise, desertification, and the melting of glaciers (Kreienkamp & Vanhala, 2017).

Low-income countries (LICs) raised the issue of loss and damage as early as 1991, when the Alliance of Small Island States (AOSIS) called for a mechanism through which to compensate vulnerable SIDS for the adverse effects of sea-level rise (UNFCCC, 2012). The AOSIS also proposed an international insurance program funded by high-GHG-emitting industrialized countries as the compensation mechanism. While this notion of compensation for loss and damage was rejected by the high-income countries (HICs) in the early 1990s (Warner & Zakieldeen, 2012), the idea influenced Article 4.8 of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) treaty:

> In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change. (UN, 1992, p. 14)

The issue of loss and damage from climate change was again raised in 2001 at the seventh Conference of the Parties (COP 7); there was however no follow-up action on the subject (UNFCCC, 2012). At the thirteenth Conference of the Parties (COP 13) in 2007, the subject was raised again; this time, the term "loss and damage" officially appeared in a UNFCCC report, the Bali Action Plan (UNFCCC, 2018). The report calls for enhanced action on adaptation, stating that "disaster reduction strategies and means to address loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change" (UNFCCC, 2008, p. 4). The report also nods toward insurance as a compensation mechanism, as it states that enhanced action would include "risk management and risk reduction strategies, including risk sharing and transfer mechanisms such as insurance" (UNFCCC, 2008, p. 4).

At the sixteenth Conference of the Parties (COP 16) held in Cancún, Mexico, in 2010, parties agreed to review the issue of loss and damage for two years under the Cancún Adaptation Framework (Kreienkamp & Vanhala, 2017). Following this review parties agreed to establish institutional arrangements such as an international mechanism on loss and damage at the next Conference of the Parties (COP) in Doha, Qatar. Subsequently, at the nineteenth COP in Warsaw, Poland, the parties agreed to the Warsaw International Mechanism on Loss and Damage (WIM) (Kreienkamp & Vanhala, 2017). The WIM formally recognizes the need to address the loss and damage associated with the impacts of climate change, including extreme weather events and slow-onset events, in LICs that are vulnerable to the negative effects of climate change. In summary, the WIM acknowledges the need for climate action that goes beyond adaptation and mitigation action. Pursuant to Decision 3/CP.18, the WIM attempts to perform the following functions:

1. Enhance the knowledge and understanding of comprehensive risk management approaches to address loss and damage associated with the adverse effects of climate change. This includes data collection, information sharing, assessing gaps, and the sharing of lessons learned from best practices.
2. Strengthen the dialogue and coordination among relevant stakeholders.
3. Enhance action and support, including finance, technology, and capacity-building. This includes technical support from the UNFCCC

and its subsidiary organizations to governments of LICs (UNFCCC, 2021).

Two years later, at the twenty-first COP in Paris, France, parties agreed to a new international climate change treaty: the Paris Agreement. The Paris Climate Agreement aspires to be an improvement on the previous international climate change treaty, the Kyoto Protocol, as it encourages emissions reduction action by all parties, rather than imposing emissions reduction requirements only upon the HICs.[2] Indeed, the voluntary emission reduction action ushered in through the National Determined Contributions (NDC)[3] framework addresses the deadlock created by the Annex I classification problem (Rietig, 2019).

Article 8 of the Paris Climate Agreement reaffirms the WIM as the main vehicle through which the UNFCCC may address loss and damage associated with climate change impacts. The Article reiterates the already-established functions of the WIM with no new provisions. Nevertheless, a breakthrough was made as Article 8 of the Paris Agreement finally acknowledges loss and damage as an issue separate from adaptation. Therefore, the adoption of the WIM confirmed that there are now essentially three action areas in the climate negotiations: mitigation, adaptation, and loss and damage associated with climate change (Mace & Verheyen, 2016).

[2] Under the Kyoto Protocol, Parties were classified as Annex I countries, and non-Annex I countries. Initially, thirty-eight countries were classified as Annex I countries, and they were assigned Quantifiable Emissions Limitations and Reduction Obligations (QELROs). However, non-Annex I countries had no legal requirement to reduce their GHG emissions (Charles, 2016). This eventually created a problem; as time progressed, some non-Annex I countries such as China and India eventually became high emitters of GHG, but had no legal requirements to take GHG emission reduction action. Industrialized countries, especially the United States (US), and countries in Europe resented this and viewed the Annex classification as a free pass for China and India to free ride and not pursue any GHG emission reduction action. Moreover, the Annex classification was seen a tool given to China and India to give them a cost advantage in international trade, since they did not have to implement the high cost measures which would reduce their GHG emissions in electricity production and industrial production.

[3] Prior to COP 21, countries were encouraged to submit their Intended Nationally Determined Contributions (INDCs) to the UNFCCC. These INDCs were voluntary plans which highlighted sectors in which the country may take GHG emission reduction action. When the Paris Agreement entered into effect in 2016, countries' INDCs automatically became their NDCs (Charles, 2019a).

Decision 1/CP.21, Paragraph 52 of the Paris Decision, text explicitly states that “Article 8 of the Agreement does not involve or provide a basis for any liability and compensation” (UNFCCC, 2015, 8). This clause, which removes liability and compensation from the WIM, was deliberately included to prevent any HIC from being held liable for the impacts of climate change on other countries (Calliari et al., 2020).

Although anthropogenic GHG emissions are responsible for the worsening of the greenhouse effect, which in turn causes an increase in world temperatures and the corresponding climate change, climate sciences (geography and climatology) cannot specifically link any one country to climate change (Lees, 2016; Linnerooth-Bayer et al., 2019). This is due to GHG emissions increasing the global concentration of GHGs. Collectively, GHGs act as a blanket to trap outgoing thermal radiation and reflect it upon the Earth.[4] Therefore, the combined effect of all countries' GHG emissions is responsible for climate change.

A second issue that suppressed the discussion of loss and damage was the climate sciences' inability to accurately account for what portion of the loss and damage was naturally occurring and how much was due to anthropogenic causes. Climate change results in the increased frequency and intensity of extreme weather events; however, climate change does not cause every tropical storm.

While climate science cannot determine the effect of each country's respective GHG emissions on climate change, SIDS continue to be impacted by extreme weather events and threatened by slow-onset events. Recognizing this problem, the parties at COP 21 agreed to Decision 1/CP.21, which

> requests the Executive Committee of the Warsaw International Mechanism to establish a clearinghouse for risk transfer that serves as a repository for information on insurance and risk transfer, in order to facilitate the efforts of Parties to develop and implement comprehensive risk management strategies. (UNFCCC, 2015, p. 8)

[4] For further details on the relationship between GHGs and the trapping of thermal energy, see Held and Soden (2000).

From 2016 to 2019, or the Paris Climate Agreement "era," the WIM Executive Committee looked to insurance as the mechanism for addressing loss and damage (Calliari et al., 2020; Linnerooth-Bayer et al., 2019). The following section explores the prospects of an insurance mechanism for loss and damage from climate change.

2 Insurance to Cover Loss and Damage

Insurance is a tool that is used to reduce the financial risk associated with a loss; disaster insurance is based on the same principle. It can trigger a payout by the insurer when a natural disaster occurs, for example, when a hurricane hits a country, or when unexpected higher-than-normal rainfall causes massive flooding. At its most basic level, insurance commits an economic agent to pay a fixed amount at regular intervals (a premium) into a common fund, from which money is retrieved (a payout) to compensate for losses arising from a predefined event (coverage). The payout helps to alleviate the financial impact of external shocks so that the livelihood of the people and the businesses of the insured country are not jeopardized by the occurrence of an extreme natural event.

2.1 Voluntary Insurance for Loss and Damage

Given that commitments under the Paris Climate Agreement are based on voluntary action, an appropriate way to address the loss and damage problem is the introduction of a voluntary disaster insurance within the COP framework. Voluntary insurance is attractive as it allows for the pooling of climate finance to address loss and damage in excess adaptation and mitigation needs without attributing liability, or responsibility of climate change impacts, to any specific country.

One of the main reasons why as many as 195 UNFCCC country parties agreed to the Paris Climate Agreement was due to the voluntary nature of commitments. The United States, in particular, wanted an agreement with no legal repercussions. Moreover, due to the difficulty involved in gaining congressional approval, the US desired an agreement which it could ratify by executive approval (Mace & Verheyen, 2016).

The voluntary nature of the Intended Nationally Determined Contributions (INDCs) was used to persuade non-Annex I countries, which had no emission reduction commitments under the former Kyoto Protocol, to agree to pursue GHG emission reduction action. This was a contentious issue for several HICs; they grew reluctant to remain in legally binding climate change treaties, while other high-emitting countries that are competitive in international trade had no emission reduction commitments as they were classified as non-Annex I countries.[5]

Since voluntary commitments were effective in convincing both Annex I and non-Annex I countries to agree to take GHG emission reduction action, the voluntary principle may be useful in influencing all parties to agree to a voluntary insurance mechanism for loss and damage. The insurance mechanism should be offered to all parties, as there is a need to provide cross-subsidization for high-risk and vulnerable countries to be covered adequately by the damage insurance mechanism.

Voluntary insurance for loss and damage requires risk sharing, risk transfer, and risk pooling.

1. Risk sharing refers to the need to share the risk between high-emitting countries and highly vulnerable countries. The mutuality principle of insurance causes the countries (policyholders) in the insurance to pay premiums in line with their risk. However, this principle limits the potential of voluntary insurance as high-risk countries are also predominantly LICs. These LICs cannot afford to pay high premiums. Therefore, the solidarity principle is needed. It is noteworthy that low-risk/low-emitting countries may be hesitant to join the damage insurance. Their low risk will likely lead to a low need for insurance payouts. Therefore, they may perceive the purchasing of insurance and paying

[5] Initially, the Kyoto Protocol had thirty-eight countries with Quantified Emission Limitation and Reduction Objectives (QELROs). However, Canada withdrew from the Kyoto Protocol from December 2012. Canada, a HIC, became reluctant to stay in an international treaty to take climate action, while high-emitting non-Annex I countries that are competitive in international trade has no such QELROs.

of premiums as unnecessary. As a result, moral suasion may be needed to help build consensus and stimulate collective action.

2. Risk shifting refers to the need to shift the risks of highly vulnerable countries to high-emitting countries. In other words, it is the need to shift the financial burden of the impacts of the highly vulnerable countries to high-emitting countries. This relies on the accountability principle in insurance, which links economic agents' actions with outcomes.
3. Risk pooling refers to allowing both high- and low-risk countries to pay contributions to a fund, which in turn could be disbursed to parties in need. This relies on the principle of solidarity in insurance, as the premium paid by the participants of the insurance (policyholders) will not be in full accordance with their risk. This is necessary to facilitate cross-subsidization.

It is notable that at its inception, an international voluntary insurance for loss and damage from climate change program may be insufficient to adequately compensate affected countries. This may be due to insufficient finances in the fund at its start.[6] Some time may be needed to help accumulate sufficient finances to compensate affected countries.

The insufficient finances may be addressed in two ways. First, if a fund finances the insurance, then once a proportion rather than all of the funds earned every year is disbursed, the fund can grow over time. The second avenue for addressing fund size is by mirroring the strategy of the Global Stocktake.

As an outcome of COP 21, parties agreed to develop NDCs and to review their progress in achieving their targets in the NDCs under the Global Stocktake. The transparency under this system is designed to encourage countries to do more to take climate action when they are lagging behind. This sample principle can also be applied to the potential voluntary insurance for loss and damage, as it may include donor

[6] In order to determine how much finance is required for loss and damage, the climate change–related damage can be estimated. Acevedo (2017) estimates that damages in percent of GDP increase by about 3% with every 1% increase in wind speed. Therefore, forecast for wind speed can be used to estimate the potential loss and damage, which in turn can highlight the amount of finance which may be required.

countries paying their contributions to the insurance fund. Moreover, if during the review of the Global Stocktake the insurance mechanism is still found to be inadequate, there should be future negotiations at the COP to increase the premiums for the insurance.

It is worth noting that disaster insurance already exists in the Caribbean region as the Caribbean Catastrophe Risk Insurance Facility (CCRIF). The regional disaster insurance fund paid out a total of US$61.5 million to Caribbean nations for recovery from Hurricanes Irma and Maria in 2017 (Artemis, 2017). However, as these hurricanes caused damage in excess of 100% of the GDP for some of the affected countries, the regional disaster insurance payout was insufficient to finance the total cost of recovery.

3 Discussion of Proposed Mechanisms

The notion that voluntary insurance should cover the loss and damage that climate change causes is not farfetched. In fact, disaster insurance has been used by countries and regions before. For example, the Caribbean region has the CCRIF, a parametric insurance which insures sixteen countries against earthquakes, hurricanes, and excess rainfall. This insurance is a macro-insurance as it mobilizes finances for the government of the affected country. Moreover, in 2018, Chile, Colombia, Mexico, and Peru united in the Pacific Alliance and through the intermediation of the World Bank were able to obtain parametric macro-insurance to cover against earthquakes (World Bank, 2018c). The total coverage was estimated at US$1.36 billion (World Bank, 2018c).

The African Union has the African Risk Capacity (ARC), which was launched in 2012 to provide coverage against droughts, tropical cyclones, and floods (ARC, 2020). There remains room for improving the ARC as it is secured on a largely ad hoc basis after the occurrence of natural disasters. This can result in delayed payments to the governments of affected countries (ARC, 2020).

The Pacific region implemented the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) in 2007 to provide coverage against several named perils such as earthquakes, tropical cyclones, and extreme rainfall (World Bank, 2017). The fund also provides disaster risk assessment tools to its members to help them model, assess, and mitigate their exposure to natural disasters (World Bank, 2017).

In the aforementioned examples, macro-disaster insurance provides several benefits:

1. It creates a framework to mitigate the economic impact of losses when disasters strike, as a payout may be triggered.
2. It poses very little moral hazard since the payout is based on the occurrence of an event rather than an actual loss.
3. It mobilizes finances for relief and recovery efforts, which eventually trickle down to the most vulnerable populations in a time of need.

Notably, the above-mentioned disaster insurance frameworks do not provide sufficient financing to cover the total cost of the damage and loss from climate change. Additionally, they do not distribute the risk among high-GHG-emitting countries. Nevertheless, this chapter argues for the introduction of a voluntary insurance framework introduced at the UNFCCC level to address damage and loss from climate change. Premiums can be paid by all countries regardless of their risk. This can create a sufficiently large pool to diversify the risk among participating countries, which in turn would be less costly to reinsure. Moreover, this voluntary framework can help high-GHG-emitting countries internalize the negative externality of their emissions.

Notably, the proposed voluntary insurance mechanism refers to an additional financing framework. It should not reduce any of the climate finance that is already allocated toward climate change adaptation and mitigation. Otherwise, the insurance might be used as an "alibi" to reduce adaptation and mitigation efforts.

4 Other Financing Mechanisms

Apart from voluntary insurance, there are multiple tools that can be used to raise funds to finance damage and loss from climate change.

One instrument that can finance for loss and damage in Caribbean SIDS is grants from donor agencies and countries. In fact, after extreme weather events, several countries and donor agencies do allocate grants to affected countries. Following Hurricane Ivan in 2004, for example, the IDB distributed a grant of US$200,000 to Grenada for construction material and medical supplies. In addition, a grant of US$100,000 was approved for St. Vincent and the Grenadines and St. Lucia for the same purpose, and a grant of US$200,000 was issued to Jamaica to help rehabilitate housing (IDB, 2004). In 2018, the World Bank allocated US$50 million in grant financing to Dominica to help restore agricultural livelihoods, strengthen resilience, and rebuild houses destroyed by Hurricane Maria (World Bank, 2018a). In 2019, the United States Agency for International Development (USAID) channeled US$7.5 million in humanitarian assistance to the Bahamas to aid restoration efforts in the aftermath of Hurricane Dorian (Charles & Wilner, 2019).

While it is commendable that the international community mobilizes aid and grant financing for countries affected by extreme weather events, these grants alone are insufficient to cover the total cost of restoration. Disaster trust funds can also be used to pool finance for relief and recovery efforts for countries that experience an extreme severe weather event. These trust funds may be capitalized by allocations from multiple donor agencies.

Several regions have used disaster trust funds to help build their resilience to natural disasters. For instance, in 2005, the Economic and Social Commission for Asia and the Pacific (ESCAP) established the Multi-Donor Trust Fund for Tsunami, Disaster and Climate Preparedness in the Indian Ocean and South East Asian Countries (ESCAP, 2017). The fund was used to contribute to the development of an integrated regional early warning system (EWS) comprising a network of collaborative centers connected to sub-regional and regional platforms. In 2011, the mandate of the fund was expanded to include climate and disaster preparedness (ESCAP, 2017). This resulted in the implementation of projects to build countries' responsiveness both to sudden natural disasters and to slow-onset disasters. In 2015, the fund's scope extended to include the SIDS of the Southwestern Pacific (ESCAP, 2017). Over the 2005–2017 period, the fund managed to pool US$15.5 million to finance twenty-six projects in nineteen countries (ESCAP, 2017). A notable achievement was the operationalization of the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) and the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) (ESCAP, 2017).

A disaster trust fund was also implemented in the Caribbean region. In fact, over the 2013–2016 period, the Caribbean Development Bank (CDB) operated the Community Disaster Risk Reduction Trust Fund (CDRRTF) to finance community-based disaster risk reduction (DRR) and climate change adaptation (CCA) in its borrowing member countries (CDB, 2016).[7] This was also a multi-donor fund as it was capitalized by grants from the Department of Foreign Affairs, Trade and Development, Canada; the Department for International Development, United Kingdom; and the CDB.

Although the main pillars of disaster risk management are risk identification, risk reduction, preparedness, financial protection, and resilient recovery (Weeks & Bello, 2018), the CDRRTF was not focused on building these capacities at a countrywide level. Instead, the fund was used to finance small-scale community projects which would be implemented by community groups.

The proposed insurance would be different from a disaster trust fund as the insurance would be parametric based and used to generate payouts to governments when extreme weather events occur. The objective of the payout is to cover the cost of the loss and damage from the extreme weather event. In contrast, a disaster trust fund can be used to finance climate adaptation and mitigation projects even when an extreme event does not occur.

Another option for financing recovery from extreme weather events and slow-onset disasters is the use of remittances. Remittances, which are largely personal transactions from migrants to their friends and families, are often used to help the recovery of affected families. This type of funding does not benefit everyone in an affected community equally, since not

[7] The borrowing member countries of the CDB are Anguilla, Antigua and Barbuda, the Bahamas, Barbados, Belize, the British Virgin Islands, the Cayman Islands, Dominica, Grenada, Guyana, Jamaica, Montserrat, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Trinidad and Tobago, and Turks and Caicos Islands.

everyone has a family member living in another country that is in an economic position to provide them with financial support.

Alternatively, financing can also be mobilized through a debt-for-climate swap—a transaction in which a proportion of a country's debt is written off in exchange for a commitment by the debtor to use its previous debt service payments to fund climate action. In fact, the Economic Commission for Latin America and the Caribbean (ECLAC) is lobbying for debt-for-climate swap for the Caribbean as a mechanism to tackle the twin challenges of high debt and vulnerability to climate change (ECLAC, 2018). While the debt-for-climate swap intends to target adaptation and mitigation action, there is a view to extend the initiative to address damage and loss from climate change. A debt-for-climate swap would be different from the proposed insurance as it would finance various climate action projects, whereas the proposed insurance seeks to generate funds to cover the cost of the loss and damage from the extreme weather event.

Credit instruments such as bonds and loans can also be used to help fund countries' resilience to and recovery from extreme severe weather events. A traditional bond is a fixed income security issued by the government, or a government agency, and is used to finance public expenditure. A catastrophe bond is a bond that is used to finance relief and recovery efforts after a natural disaster. These, like other bonds, have two components: a par value and a coupon. The par value, or the principal, is used for the rebuilding effort and is scheduled to be repaid by the bond's maturity. The coupon, which is the interest on the catastrophe bonds, tends to be high since natural disasters often affect a wide range of economic agents when they occur.

Several countries have experimented with catastrophe bonds. In 2018, for example, the World Bank issued catastrophe bonds that provided Chile, Colombia, Mexico, and Peru with a total of US$1.36 billion (World Bank, 2018b). Table 17.1 provides a summary of the transaction details.

In 2014, the Caribbean region issued its first catastrophe bond to help support the Caribbean Catastrophe Risk Insurance Facility (Artemis, 2017). While the governments of disaster-stricken countries may be open to multiple avenues of financing, Caribbean governments should be cautious when it comes to bonds since they are loans and the region already

Table 17.1 Catastrophe bonds in Latin America

Classes	Chile—US$500 million Colombia—US$400 million Mexico (a)—US$160 million Mexico (b)—US$100 million Peru—US$200 million
Tenure	Mexico—Two years Chile, Colombia, and Peru—Three years
Risk premium	Chile—2.50% Colombia—3% Mexico (a)—2.50% Mexico (b)—8.25% Peru—6%

Source: World Bank (2018b)

has a high debt burden. Any additional debt would increase the country's indebtedness and its likelihood of facing debt overhang.

Governments may also borrow directly from multinational development institutions such as the European Investment Bank (EIB), the Inter-American Development Bank, and the World Bank, as well as regional institutions such as the Corporacion Andina de Fomento—Development Bank of Latin America (CAF), the Caribbean Development Bank, and the Central American Bank for Economic Integration (CABEI).

5 Conclusion

High-GHG-emitting countries are eager to deny scientific links between their emissions and specific extreme weather events. While the international community continues to debate climate change, Caribbean countries, as well as other LICs, are battered by extreme weather events. Even more worrisome is that SIDS often lack the financial capacity to cover the loss and damage from these events.

Presently, the Caribbean region receives grants, aid, remittances, and other financial inflows. While these financial flows are welcome by countries in need, as they are vital in helping finance the cost of relief effort immediately after extreme weather events, they are not sufficient to cover the total cost of recovery. Furthermore, Caribbean countries are often tempted by debt financing options to help cover recovery costs. This chapter argues that the governments of the Caribbean region should not have to use debt instruments since they are not the primary aggravators of the climate problem. Instead, they should be compensated by high-GHG-emitting countries.

There is a need for high-emitting countries to internalize the negative externality of their anthropogenic GHG emissions, but no country wants to be held accountable for the loss and damage that the SIDS face from them. A similar deadlock occurred during Kyoto Protocol negotiations, and countries were able to overcome this by moving toward voluntary GHG mitigation action. Perhaps the solution to the loss and damage compensation problem is for countries to move toward voluntary compensation mechanisms.

Insurance is presently proposed as a mechanism to address loss and damage finance; there has however been little action to bring this to fruition. Voluntary insurance may be the key to stimulate movement between the different categories of countries. If there is participation by both types, then the insurance provider could pool sufficient funds and transfer risk from high-climate-risk countries to the low-climate-risk countries.

The proposed voluntary insurance can be implemented through several steps. First, the Caribbean SIDS should meet and agree to collectively lobby for the insurance. Second, as this insurance would require collective action, it should be raised at the COP level. Third, a committee should be established to annually forecast the potential loss and damage that the Caribbean SIDS may incur due to climate change. This can indicate how much finance is needed to cover the cost of the loss and damage. Fourth, as the Caribbean SIDS build consensus, eventually a decision can be made at the COP level to mobilize finance to address loss and damage from climate change through the proposed voluntary insurance mechanism. If countries agree to this proposed voluntary insurance, all countries can pay premiums regardless of their risk, and payouts can be made to SIDS after experiencing named perils (hurricanes and other extreme weather events). This framework would effectively cause the high-GHG-emitting countries to internalize their negative externalities without facing any legal liability. Moreover, it would be a milestone achievement in mobilizing climate finance for the most vulnerable countries.

Notably, other SIDS are also facing climate change impacts. While these impacts may not necessarily be hurricanes, they cause SIDS to incur additional public costs. Therefore, the principle of voluntary insurance can be extended to other SIDS grappling with climate change impacts.

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18

Integrating Local and Indigenous Knowledge for Climate Change Adaptation in Africa

Madhuri Pratap

1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Clean Development Mechanism (CDM), and the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) mainly focus on increasing the adaptive capacity of developing countries by providing them financial support and technology transfer (Macchi et al., 2008). Mitigation and adaptation are considered the primary mechanisms to combat climate change. However, how Indigenous knowledge emerged as a central component in adaptation discourse is not often studied. The first mention of Indigenous knowledge by the IPCC was seen in its fifth assessment report, but with little consideration of Indigenous knowledge systems as well as the historical and contextual complexity of Indigenous experiences (Ford et al.,

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2016). On the other hand, Cancun Agreement (CP16) held in Cancun in 2010, after which adaptation gets an essential place in climate policies, focuses on the synergy between scientific knowledge and local or Indigenous knowledge (Ford et al., 2016). Furthermore, the US Third National Climate Assessment focused on Indigenous peoples and their engagement in climate adaptation (UNFCCC, 2014).

Despite reinforcing climate adaptation and addressing vulnerability in an underdeveloped area, the Kyoto agreement and the Intergovernmental Panel on Climate Change (IPCC) primarily focus on reducing carbon emissions. According to Centre for International Governance Innovation (CIGI) Special Report, the involvement of Africa in the Clean Development Mechanism (CDM) and carbon trading arrangements under the Kyoto Protocol has been minimal (Lisk, 2009). Furthermore, acknowledging the local communities coping strategies and adapting capacity in Africa get very little attention (Ford et al., 2016).

Africa is one of the most sensitive continents to climate change and variability (IPCC, 2014). In Africa, the Indigenous knowledge system helps inhabitants sustain and cope with the dire consequences of climate extremes as well as adapt to changing climatic conditions. The UN General Assembly on the adoption of the UN Declaration on the Rights of Indigenous People in 2007[1] stated that the vast majority of the people of Africa are Indigenous but do not create new or specific rights for Indigenous peoples. However, according to *CEESP News (by Kanyinke Sena, co-chair of Specialist Group on Indigenous Peoples, Customary and Environmental Law, and Human Rights)*, Indigenous knowledge is not recognized by African governments in their Nationally Determined Contributions (NDCs) and at the local communities and Indigenous people platform (LCIPP). At the LCIPP negotiations at COP 24, there is minimal participation from African countries. It is also confirmed that in their adaptation communications to the UNFCCC, out of the 44 NDCs submitted by the African States, only 9 countries (South Africa, Gambia, Ghana, Somalia, Namibia, South Sudan, Tanzania, Zimbabwe, and the Central African Republic) mention

[1] On January 30, 2007, the African Union Assembly adopted a Decision on the United Declaration on the Rights of Indigenous Peoples, affirming the will "to maintain a united position in the negotiations amending the Declaration and constructively work alongside the other Member States of the United Nations in finding solutions to the concerns of African States." See Doc. Assembly/AU/Dec. 141 (VIII), 30 January 2007.

traditional or Indigenous knowledge. At the regional level, there is not much effort by government agencies (e.g., the European Union (EU)) and Southern African Development Community (SADC) in helping the Indigenous people in climate adaptation (Andonova et al., 2009). Although most African states accepted the importance of Indigenous knowledge, there is no specific legislation on Indigenous people. In 2013, the African Development Bank (AfDB) Group approved the Integrated Safeguards System (ISS) for environmental and social sustainability. However, there are no legal obligations and commitments (African Development Bank Group, 2013). The UN Declaration on the Rights of Indigenous Peoples (UNDRIP) and the African Charter on Human and Peoples' Rights (ACHPR) have no direct provision for Indigenous people in their declaration, and it is without any legal binding. The provisions for integration of indigenous peoples into their safeguard system in Africa has been led by a range of international organizations such as The African Development Bank (AfDB), The United Nations Development Programs (UNDP), The European Investment Bank (EIB), and European Bank for Reconstruction and Development (EBRD), but standalone safeguard policies are ineffective (African Development Bank Group, 2016).

The livelihood practices of Indigenous people of Africa help their communities to adapt to the uncertainty of climate change. However, Indigenous knowledge uptake in African nations' adaptation policy is lopsided and considered "unscientific" (Brugnach et al., 2017). Although Indigenous knowledge emerged as a central component in climate adaptation, it is still not embodied in climate adaptation policies. The increasing threat of climate change is reducing the community's well-being, and the adaptation strategies embedded in Indigenous knowledge can provide a solution in relevance to the local context. However, there is an underrepresentation of Indigenous knowledge within the national policy mechanism. It may be due to the uncodified and oral character of Indigenous knowledge. The review provides insight into local knowledge's sustainability by building synergies between support provided by the government agencies and local knowledge in decision making. In this chapter, the review throws light on the role and perspectives of local and Indigenous knowledge (LIK) in climate change adaptation in Africa. It also provides insight into the adjustment of local people in the changing climate scenario with government support. Based on the review, some recommendations are also proposed to bridge the gap between local and Indigenous households and government support in climate change adaptation.

2 Methods

To assess local or Indigenous knowledge and its interface with government support for climate change adaptation in Africa, we conducted a thorough literature review. First, published peer-reviewed journal articles from January 2010 to July 2019 were searched. The search engines used were Google Scholar data, Web of Science, ScienceDirect. The keywords used are “climate change adaptation and Africa,” “Indigenous knowledge or local knowledge or traditional knowledge or local ecological knowledge and climate change adaptation or climate variability or global warming,” “local knowledge or Indigenous knowledge, climate change, and Africa,” and “climate change adaptation and government policies in Africa.” In each search, the first 80–110 papers were scanned, after which there is repetition of papers or irrelevant articles. We scanned 380 abstracts and selected 120 papers for in-depth analysis. In 120 papers, 88 papers fit the objectives of the chapter. Papers focusing on local knowledge and government support for adaptation practices in Africa were selected for this purpose. The publications from governments, development agencies, and NGOs were also searched and analyzed. The following questions guide the literature review: are the local households in Africa still dependent on local and Indigenous knowledge? How relevant is local and Indigenous knowledge in the changing climate scenario in Africa? What is the missing link between local and Indigenous knowledge and government adaptation measures? How government policy is linked with LIK?

2.1 Analytical Approach

To draw extensively from literature, we divide it into three distinct domains: (1) local and Indigenous knowledge (LIK)-based approach: the papers that considered government support (GS) as one factor while

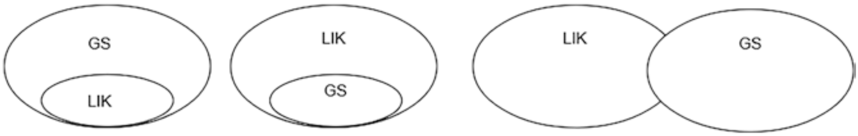

Fig. 18.1 Different approaches between local and Indigenous knowledge (LIK) and government support (GS)

seeing LIK as the primary approach was classified as LIK-based approach. (2) Government support-based approach: literature considered LIK as one among other factors, but GS as a principal approach was classified as GS focused. (3) Linkage between LIK- and GS-based approach: papers that did not fit in either category focused primarily on institutional development, where both LIK and GS were classified in the integration approach.

Three possible conceptualizations of the connection between LIK and GS are shown in Fig. 18.1: (1) LIK-based approach, (2) GS-based approach, and (3) linkage between LIK- and GS-based approach.

3 Analysis and Findings

Based on the literature, a framework is developed to evaluate the local and Indigenous knowledge evolving structure. This framework, presented in Table 18.1, lays out recommendations on how local and Indigenous knowledge is significant in climate adaptation and helps mitigate local household marginalization. The analytical framework is designed around three themes and their respective sub-themes.

Are the local households in Africa still dependent on local and Indigenous knowledge? How relevant is the local and Indigenous knowledge toward changing the climate scenario in Africa?

3.1 LIK-Based Approach

The review provides insight regarding the trust that local households have in LIK and traditional practices and skills with the following points.

Table 18.1 Analytical framework

Theme	Sub-theme	Criteria
LIK-based approach	Potential and value of LIK for local household	• Believe in Indigenous knowledge and observation • Importance of traditional practices and skills • Local households' efforts to preserve their local ecosystem
	Readapting the identified skills and solutions	• Acquisition of new knowledge • Local communities share innovative ideas with other communities • Expansion of social networks and access to external support
	Relevance of LIK in changing climate scenario	• Decline of diversified agriculture and traditional activity • Decrease in the ability to predict the timing and productivity of resources • Limitations of local households in adaptation to climate change • Unable to change practices • Doubt on the accuracy of LIK in seasonal weather prediction
GS-based approach	Local household perspective of government support	• Lack of participation and integration of Indigenous knowledge in risk reduction activities • Lack of coordination between local households and local authority • Government fails to recognize the legitimacy of local population land and territorial rights.
	Government perspective	• Government adaptation practices are not acceptable to local households • Local households evaluate external adaptation strategies in light of their knowledge • Lack of belief and trust in local households' government efficiency

(*continued*)

Table 18.1 (continued)

Theme	Sub-theme	Criteria
Linkage between LIK and GS	Linking LIK and GS	• Co-ordination between government and local households • Localization of outside knowledge • Blend of knowledge in adaptation practices
	Integration of Indigenous knowledge in government policies and measures	• Integrating Indigenous knowledge in government policies and measures

3.1.1 Potential and Value of LIK

- *Believe in Indigenous knowledge and observation*—Despite awareness of the uncertainty of climate change, the local households still believe in the observations, past experiences, unrecorded tales and rumors. Fabiyi and Oloukoi (2013 in Nigeria) confirm that LIK is pertinent to local households. The case study of Ubisi et al. (2019) in Nkomazi Local Municipality, Mpumalanga, South Africa, holds the same notion that Indigenous knowledge is essential in the adaptation to climate change and variability. The argument is also supported by Taremwa et al. (2016) in Rwanda, which shows Indigenous practices is effective in climate change resilience. The studies in Malawi, Botswana, and Uganda also highlight that the Indigenous knowledge and personal experience are considered precious in the community (Briggs & Moyo, 2012; Kolawole et al., 2014).

- *Importance of traditional practices and skills*—Mohamed-Katerere's (2002) research in Zimbabwe concludes that local traditional leaders focus on intertwining land use practices and cultural beliefs. This philosophy is called "environment-spiritual connection." It emerged from the assessment of literature that the local households considered LIK as efficient and effective in dealing with the uncertain changes in climate and focuses on preserving the local ecosystem. In addition, local households rely on Indigenous knowledge and consider it more accurate because of their experience and observation.

- *Local households' efforts to preserve their local ecosystem*—Fritz-Vietta et al. (2017) in southwest Madagascar and Leonard et al. (2013) in Tropical Africa argue that local households effectively manage land and natural resources. Local households view local indicators as better indicators of weather forecasts (Elia et al., 2014) and traditional knowledge as an essential resource to enhance adaptive capacity (Granderson, 2017). Kpadonou et al. (2019) delved deep and provided evidence that LIK improves food security, reduces pressure on natural resources, and provides skill as well as insight for cost-effective land use activity. However, the Indigenous knowledge is not static, and it keeps on changing by adding new knowledge. It is analyzed in the next section.

3.1.2 Readapting the Identified Skills and Solutions

It is also confirmed by the review of studies that local households revised their skills and solutions to adapt to any change in the climate.

- *Acquisition of new knowledge*—Local households focus on acquiring new knowledge and modifying LIK in climate uncertainty. Local households revised their skills and activities to adapt to any change in the climate. Codjoe et al. (2014) in Sub-Saharan Africa elicited that LIK has practical application. It can be exemplified in Chikwawa District in southern Malawi, which shows a change in local households' adaptation strategies, including changes in cropping patterns and intensification of livestock production (Nkomwa et al., 2014). Similarly, in West African Sahel, Kpadonou et al. (2012) point out that local households developed new skills in response to climate vulnerability and effort to acquire new knowledge to deal with the vagaries of climate change.

- *Local communities share innovative ideas with other communities*—Reed et al. (2007) demonstrated in Kalahari Botswana that rotational grazing system (a system where a large pasture is divided into smaller paddocks allowing livestock to be moved from one paddock to the other easily) is shared with other communities to reduce land degradation.

- *Expansion of social network and access to external support*—There is an emphasis in the study on expanding social networks and on access to external support by local households for non-traditional adaptations. Boillat and Berkes' (2013) findings confirm the progression of irrigation systems using modern technology by combining different types of knowledge in Bolivia. It is pertinent from the review that LIK is still beneficial for the local household by devising new coping and adaptation strategies. The community acknowledges the volatility of climatic change and makes the necessary changes in its strategies accordingly.

3.1.3 Relevance of LIK Within the Changing Climate Scenario

It can be elucidated from the review that the vision of the local household lacks the potential to deal efficiently with the current climate scenario.

- *Decline of diversified agriculture and traditional activity*—The dependability of local households on local knowledge is examined in different studies, which recognizes LIK as less reliable Kpadonou et al. (2012) point out that local households cannot meet the climate threats with the traditional practice. Similarly, Kalanda-Joshua et al. (2011), study in Nessa, Mulanje, Malawi region, criticize the accuracy of LIK and elicit that the community has less confidence and dependency on it. The study also claimed that local indicators used for climate forecasts are no longer relevant. Elia et al. (2014) in the semi-arid central Tanzania villages of Maluga and Chibelela confirmed uncertainty about seasonal weather forecasts. The study articulates that the local household indicators for weather prediction are plant phenology, birds, amphibians, mammals, insects, wind direction, and the solar system. However, these indicators are becoming unreliable due to climate change and vulnerability. The above argument is further validated in the study of Basdew et al. (2017) in Southern Africa. The researcher illustrates that despite many local households possessing Indigenous knowledge on climate prediction, the local households cannot accurately forecast the climate's vagaries.

- *Decrease in the ability to predict the timing and productivity of resources*—Despite the confidence in LIK indicators, households do not or cannot change their practices in response to drought (Ifejika Speranza et al., 2010). Due to a lack of data points, there is a decline and downscaling of forecasts based on LIK indicators (Valdivia et al., 2010). Despite many local indicators used for local climate forecasts, there are limited climate adaptation strategies in various sectors (Kangalawe et al., 2011).
- *Limitations of local households in adaptation to climate change*—The local and Indigenous households in Africa with low adaptive capacity are unable to keep pace with the changing climate scenario. Reed et al. (2007) provide evidence that adaptations based on LIK cannot keep pace with rapid rates of environmental change. Although LIK is dynamic, the pace of change is not equal in all the systems regarding capacity and learning. Some systems are more inclusive of drawing information and learning whereas others are conservative and tightly institutionalized. The study of Ajani (2013) in Sub-Saharan Africa and Amare (2018) in West-central Ethiopia supported the above argument. It claimed that not all Indigenous knowledge is appropriate and provides the right solution to the given problem.
- *Unable to change practices*—Kangalawe et al. (2011 study in semi-arid Tanzania) articulate that the local household and their knowledge are not self-sufficient but have many constraints like limited infrastructure and knowledge. Besides, there are several obstructions in local adaptation, including poverty and institutional aspects, and low integration of climate adaptation strategies in various sectors. Ifejika Speranza et al. study (2010) on semi-arid areas of the former Makueni District, Kenya, has finely interwoven the complexity of the local household to change their practices. Inadequate and inappropriate resources restrict the local household despite rich Indigenous knowledge.

- *Doubt on the accuracy of LIK in seasonal weather prediction*—Jiri et al. (2015) in Zimbabwe opine that not everyone in the community is aware of the Indigenous knowledge. Whereas Kalanda-Joshua et al. (2012), in the District of Manical and Zimbabwe, believe that the elder mainly owns the knowledge, making it less reliable. Egeru (2012), in Teso, Uganda, also carries the same kind of notion. According to the researcher, the younger community member has less Indigenous knowledge of weather forecasting. Therefore, it makes traditional weather forecasts less reliable.

What is the missing link between local and Indigenous knowledge and government adaptation measures?

From the above section, it is clear that there is a decrease in the reliability of local households in dealing with changing climatic conditions. However, the question arises: how the Indigenous knowledge persists in the face-off with the governmental support for climate change adaptation to local households? It is crucial to understand the government issues inherent in LIK integration. This section deals with the *missing* link between local and Indigenous knowledge and government adaptation measures with two angles (1) local household perspective of government support and (2) the government agencies' perspective.

3.2 GS-Based Approach

3.2.1 Local Household Perspective of Government Support

The review also covered the perspective of local households regarding government support based on the different sub-themes:

- *Lack of participation and integration of Indigenous knowledge in risk reduction activities*—The local authority manages the conservation and the risk reduction activities, but the ignorance and lack of communication between local authorities and households prevent cooperation. For example, the information about an impending disaster is communicated by the authority. However, the local community has to accept and integrate it with their traditional knowledge, which is impossible due to a lack of coordination. It is further highlighted in the review.

- *Lack of coordination between local households and local authority*—Naess (2013) considers a tussle between the government and local households in semi-arid Tanzania because the government bans the use of a forest reserve. The officials reserve accessibility is only to groups with resources and skills; otherwise, the local households has to pay the government to use the resources. Elia et al. (2014) approach is different because it is emphasized that due to a lack of accessibility of information, the local households are still dependent on the local indicators such as the stars, wind, color of the sky, cloud, and cloud cover. Likewise, Fitchett and Ebhuoma's (2017) study in the Delta State of Nigeria shows that due to the inaccessibility of scientific information, the community majorly relies on Indigenous knowledge for their information on climate variability and longer-term climate change. Second, even if the information was available, local households considered it unnatural, or the technical terms were not easily understood (Basdew et al., 2017).
- G*overnment fails to recognize the legitimacy of local population land and territorial rights*—Ajani (2013) in Sub-Saharan Africa claims that the vulnerability of the local Indigenous knowledge is quadrupled not only due to the adversity of climate change but also due to the discrimination as well as exclusion from climate adaptation strategies as well as the failure of the government to recognize the right of Indigenous people.

3.2.2 Government Perspective

The review shows that poor communication and engagement, and top-down institutional processes mitigate the Indigenous household's voice and provide a lack of recognition of Indigenous culture and practices.

- *Government adaptation practices are not acceptable to local households*—Kalanda-Joshua et al. (2011) in Malawi, elucidated that people did not give much importance to scientific weather and climate prediction due to lack of incorporation of Indigenous knowledge. The other constraint in the integration of GS is the imposing behavior of the official. The government officer commands and imposes the different practices on the local households without their active participation. Theodory (2016), in the Ngono River Basin, Tanzania, highlights that the practices of the government are not accepted or recognized by local households. The research focused on the imbalance of power between extension staff and other members of the community. The community member did not accept the scientific knowledge recommended by the extension staff because it does not fit the particular socio-cultural context. Similarly, in the Bamenda Highlands of Cameroon, a study conducted by Tume et al. (2019) showed that Indigenous knowledge is slowly lapsing as the government does not promote it.
- *Local households evaluate external adaptation strategies in light of their knowledge*—In the above section, it is clear that local households consider LIK as a vital factor for adaptation. However, they are willing to accept the additional knowledge and information from external agencies as per their suitability and need for adaptation. Naess (2013) study verified that the Tanzania government banned the local varieties and encouraged drought-tolerant varieties. However, the local households were willing to change their local variety because they realized a decline in rainfall, and local varieties are no longer feasible.
- *Lack of belief and trust in local households' government efficiency*—Leonard et al. (2013) view that the government cannot establish its trust in the local household due to its authoritarian approach. The community has less faith in the conventional information as they considered it unreliable and untimely, as exemplified in the study of Elia et al. (2014) in semi-arid central Tanzania. The promotion of Western knowledge by the government without integrating Indigenous knowledge reduces the confidence of community members (Iloka, 2016).

3.3 Linkage Between LIK and GS

The association between LIK and GS is divided into two sections. In the first section, we analyze the interplay between LIK and GS based on the studies. Then, we examine how the policies and programs integrate the LIK in government interventions. Despite the contradiction between local knowledge and government support, a different perspective and a set of studies agree that there can be an association between LIK and GS.

3.3.1 Linking LIK and GS

In the review, the collaboration between local households and government agencies is highlighted.

- *Coordination between government and local households*—In Africa, local households in the Nganyi communities of western Kenya (Ogallo, 2010) and the Messa village of southern Malawi (Kalanda-Joshua et al., 2011) cooperate with the government agencies to produce an accurate forecast and enhance community resilience. The local households are not well equipped and independent to face the vagaries of climate change alone. They depend on government support to make their living. Due to vegetation loss, increased temperature, and ineffectiveness of traditional practices in Africa's Kalahari Desert, the local households live around government-drilled bores for water (UN, Department of Economic and Social Affairs Indigenous Peoples). The local households apply both Indigenous and modern technology and practices to cope with the consequences of climate change on food security.

- *Localization of outside knowledge*—In the *Atankwidi* basin, north-eastern Ghana, Derbile (2010) confirms that the local households localized the knowledge gained from external agencies. In combating disasters like floods and drought, the local households integrate the knowledge for adaptation in agriculture. Mugambiwa and Makhubele (2021) propagate that the integration of local-level strategies is of paramount importance for climate governance in water and land resource management.

- *Blend of knowledge in adaptation practices*—Local households are prepared to blend the Indigenous knowledge and information from external agencies. For example, although the agro-pastoralists use Indigenous knowledge-based forecasts, they also rely on external sources of information from the Kenya Meteorological Department, which broadcast seasonal information and short-term daily weather in newspapers, radio, and television (Ifejika Speranza et al., 2010). Hence, studies illustrate the integration of LIK and acceptance of GS by the local households.

3.3.2 Integration of Local and Indigenous Knowledge in Government Policies and Measures

There is broad agreement in the literature that local climate change adaptation can be improved by integrating Indigenous knowledge in government policy support. Consequently, there is an effort by the government to promote and protect local and Indigenous knowledge while mitigating the climate change impacts by their incorporation in government policies. It is reflected in Table 18.2.

4 Discussion and Conclusions

The primary purpose of this study is to review the perspective of LIK of local households in coping with climate change in Africa. The review concluded that Africa is constantly adjusting to survive in the fluctuating climate scenario. Furthermore, the outcomes of this review suggest that, in Africa, local households have strong trust in the efficiency and effectiveness of their local knowledge.

Table 18.2 Integrating indigenous knowledge in government policies and measures

Policies and programs for Indigenous people in Africa	Objectives and features
1. The Protection of Indigenous Knowledge through the Intellectual Property System: A Policy Framework (2009), South Africa. Department of Trade and Industry	The South African Department of Trade and Industry (Dti) creates a legal framework that protects and promotes traditional knowledge using existing intellectual property law mechanisms. The bill helps to protect South Africa in seeking traditional knowledge beyond the area of patents.
2. Africa's Development (NEPAD) Agency (2001)	The New Partnership for Africa's Development (NEPAD), an African Union strategic framework for pan-African socio-economic development, addresses critical challenges facing the continent—poverty, development, and Africa's marginalization internationally—and provides unique opportunities for African countries to take complete control of their development agenda.
3. Convention on Biological Diversity (CBD) and Nagoya Protocol	South Africa's legal approaches and policy approaches to Indigenous knowledge and Indigenous biological as well as genetic resource protection primarily derive from the CBD and its Nagoya Protocol framework.
4. The National Environmental Management: Biodiversity Act, 2004 (NEMBA)	The National Environmental Management: Biodiversity Act, 2004 (NEMBA), and the Bioprospecting, Access, and Benefit-Sharing Regulations, 2015, were promulgated by the South African government to implement the CBD (DEA, 2015). It promotes the sustainable use of Indigenous biological resources and the fair and equitable sharing of benefits from bioprospecting involving Indigenous biological resources.
5. Indigenous Knowledge Systems (IKS) Policy, adopted in November 2004	The Indigenous Knowledge Systems (IKS) Policy, adopted in November 2004, resulted from an interdepartmental effort to create a guide for recognizing, understanding, integrating, and promoting South Africa's wealth of Indigenous knowledge resources (Department of Science and Technology, 2004).

(*continued*)

Table 18.2 (continued)

Policies and programs for Indigenous people in Africa	Objectives and features
6. National Indigenous Knowledge Systems Office (NIKSO)	The DST established the National Indigenous Knowledge Systems Office (NIKSO) to nurture national IKS priorities through proactive engagement in science and technology, open up academic opportunities, and promote and protect intellectual property rights (IPR) of communities and ensure equitable sharing of resources.
7. African Indigenous Knowledge System (AIKS)	The AIKS helps in the integration of Indigenous knowledge in formal education by the contextualization of the school curriculum. The role of Indigenous knowledge in sustainable development at the micro-level and poverty alleviation is mainly focused.
8. Centre for Scientific Research, Indigenous Knowledge and Innovation (CesrIKi)	The University of Botswana formed a Centre for Scientific Research, Indigenous Knowledge, and Innovation (CesrIKi). It recognizes the IKS and links scientific research with IKS. For documenting IKS in the country and promoting IKS among communities, it has undertaken several surveys.
9. REDD+ projects	The REDD+ projects in Kenya and Tanzania are attributed to participatory planning involving local citizens whose knowledge is crucial in the technical analysis to address the drivers of deforestation and forest degradation as well as barriers to sustainable management.
10. UNISDR's Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR, 2015)	It addresses the issues related to Africa's disaster risks, scientific, technical, and academic communities at all scales (in keeping with UNISDR's Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030) examined the need for and importance of Indigenous communities.

(*continued*)

Table 18.2 (continued)

Policies and programs for Indigenous people in Africa	Objectives and features
11. AfDB	The African Development Bank mainly assesses the issue of Indigenous Peoples in Africa and recognizes the existence of Indigenous Peoples' unique circumstances.
12. Integrated Safeguards System (ISS)	The ISS includes the Policy Statement (PS), a declaration of the Bank's commitment to environmental and social sustainability (AfDB, 2012).
13. African Commission on Human and Peoples' Rights	In Africa, the African Commission on Human and Peoples' Rights Working Group has elucidated the concept of Indigenous peoples in the African context by considering nomadic and pastoral communities.

Although the external agencies support adjustment, local households still have more faith in local indicators and depend on their local forecast. The local households rely on local knowledge when dealing with climate change impacts. However, it is also recognized that LIK of households is not sufficient in facing the ongoing changes in the climate. Local households learned to revise and readjust their skills and techniques to survive in these changing climate adversities. Nevertheless, they have not entirely given up their local and Indigenous knowledge as they rearrange their adaptation strategies. However, local households cannot self-sustain the adversities of climate change. Their dependence on government support and technology is increasing to reduce these risks. Without adequately addressing the gap between the institutional barrier of the government policy framework and local knowledge, it is unlikely that the local household can be empowered through knowledge recognition and integration. Furthermore, the government does acknowledge that local and Indigenous knowledge requires attention when it comes to knowledge integration. However, no formal mechanism exists yet to ensure that this knowledge is preserved.

From the review, it can be said that in Africa, local households and governments have a different outlook to see and identify the cause of the problems. It is challenging for two different visions to take on a similar path to a solution. The local household is considerably more embedded into their culture that they lack the belief and trust in their government. The African government official also has infrequent communication with local households and does not promote local households' engagement in the government's initiatives.

Both the top-down and bottom-up approaches are not feasible in climate change adaptation in Africa. The changing climatic condition hits Africa the hardest, but local and Indigenous households revised skills can cope with these changes. However, literature illustrates a few examples of climate adaptation that depend solely on local and Indigenous knowledge or government support. The adaptation to climate change cannot be based on fixed knowledge. However, it is evolving and revitalizing itself in combination with external knowledge and support. Therefore, to reduce the risk and enhance the adaptive capacity, involvement and recognition of local and Indigenous knowledge are imperative. The interface between the Indigenous knowledge and government plan for climate adaptation is possible by preserving this knowledge and mainstreaming the local household's in climate adaptation and development.

5 Recommendations for the Integration of LIK and GS

The LIK-based framework lays out criteria that the government policies should fulfill to represent local knowledge adequately. Our analysis suggests three main recommendations to ensure that the local knowledge is represented in the government programs. First, there is a need to reframe the government policy and practices so that, within the integration perspective, stakeholders with different outlooks and solutions work together with a common consensus as well as trust to cope with the adversities of climate change. Second, to integrate the LIK and GS, it is essential to focus on the middle-up approach instead of concentrating on a top-down

(GS) and bottom-up approach (LIK). Since the primary purpose of LIK is to fix problems within the present structure of the climate uncertainty so that the system will function better, it does not attempt to alter the structure of the system. At the same time, GS focuses on the capacity-building effort with targeted actions that entail institution-building and a technological approach to developing the community to deal with climate vagaries in advance. Lastly, a mechanism that ensures that final decision-making power for policy affecting local knowledge and practices still lies with local households rather than solely the government. Furthermore, guaranteeing that local knowledge is promoted and its integrity is not compromised, the efforts to entwine the LIK and GS can be practical.

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