Implications of the UN Sustainable Development Goals for the world's forests.

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Declaration of Authorship

The candidate confirms that the work submitted in this thesis is his own, except where work formed as part of co-authored publications has been included. The contribution of the candidate and of other co-authors is detailed below. The candidate confirms that appropriate credit has been given where reference has been made to the work of others.

This thesis is submitted in a University of Leeds alternative thesis-by-publication format. Chapter 2 of this thesis has been peer reviewed and published in the journal Forest Policy and Economics. Chapter 3 is prepared for submission to a suitable journal. Chapter 4 has been invited for resubmission to the journal PLOS Sustainability and Transformation, and amendments suggested by two anonymous reviewers have been made to the manuscript presented herein.

This thesis is comprised of an introductory chapter, three manuscripts, a concluding chapter and appendices (as a separate file).

Chapter 2 is the following publication:

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The work was conceived and written by JAC, with advice from all co-authors. Data collection was done by JC with assistance from NT and JW-H. All other aspects were done by JAC.

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The work was conceived and written by JAC, with advice from all co-authors. Literature reviews were conducted by JAC, with assistance from IVC, LF and TM to review non-English documents. DB assisted with preparation of Figure 4.4. All other aspects were done by JAC.

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Abstract

The advent of the United Nations Sustainable Development Goals (SDGs) provided a framework that explicitly embedded the conservation of natural ecosystems among other development objectives. Fundamental to the SDGs is the notion that interactions can occur between their constituent goals and targets in the form of synergies and trade-offs, and that, wherever possible, the former should be promoted and the latter mitigated. Using the conservation of forests (relevant to several SDG targets) as a case study, this thesis seeks to better understand how progress in non-environmental aspects of the development agenda could facilitate or hinder this cause. Through a systematic review, I identify 63 SDG targets associated with potentially beneficial, damaging or mixed impacts on forests, and highlight how potentially damaging targets are often better researched and understood. Using open access data for 122 countries, I explore the empirical relationships between achievement of the SDGs and changes in net forest cover between 2017 and 2020. These analyses suggest that higher achievements in goals on health, education, energy, economy and industry are associated with lower net forest loss, while the processes of improving in goals on economy and climate change mitigation are associated with higher net forest loss. I present a novel framework that combines document analysis and indicator data for 24 SDG targets, to assess the possible implications of a country's anticipated development trajectory for forests. Applying this to framework to 48 tropical countries, I highlight key areas of each country's national development agenda that should be monitored or prioritised in order to avoid risks, seize opportunities, and provide enabling conditions for effective forest conservation. The thesis concludes with a summary of the major findings, a discussion the novel contributions and limitations of the work, and suggestions for further work that could help progress the topic further.

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DA	Dominance analysis
DHS	Demographic and Health Surveys
FAO	Food and Agriculture Organization of the United Nations
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GFRA	Global Forest Resources Assessment
GFW	Global Forest Watch
HDI	Human Development Index
IFs	International Futures integrated modelling tool
LAC	Latin America and the Caribbean
MDGs	Millennium Development Goals
NGO	Non-Governmental Organisation
NTFP	Non-timber forest product(s)
NWFP	Non-wood forest product(s)
ODA	Official Development Assistance
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
PLSR	Partial Least Squares Regression
REDD+	Reducing emissions from deforestation and forest degradation
RMESP	Root mean squared error of the prediction
SDG	Sustainable Development Goal
SDGI	Sustainable Development Goal Index
UN	United Nations
VIP	Variable importance in the projection
VNR	Voluntary National Review

Chapter 1 Introduction

"*What we are doing to the forests of the world is but a mirror reflection of what we are doing to ourselves and to one another*"

- Mohandas Karamchand Gandhi

Which aspects of human progress can be most damaging to the natural environment, and which can facilitate its conservation and overall betterment? What level of progress can we expect to see in these areas over the coming years? Answering these questions will enable governments and development agencies to address the world's societal needs without jeopardizing natural ecosystems and the essential services that they provide, and to achieve both environmental and non-environmental development objectives harmoniously. However, despite a growing recognition in recent decades that matters of human progress and well-being are linked with matters of the environment in myriad ways, understanding of these relationships is often lacking. Motivated by this, this thesis seeks to contribute to the growing efforts fill this knowledge-gap by exploring past and possible future relationships between the modern sustainable development agenda and one specific (yet critically important) type of ecosystem – forests.

Despite being essential for the survival and well-being of human societies, forest ecosystems face numerous threats. Between 2010 and 2020 the global forest area declined by an estimated 1.2% (UN DESA and UNFF Secretariat, 2021). While undoubtedly cause for alarm, this figure disguises the fact that some countries and regions have experienced forest gains, while in others the overall rate of decline has been gradually slowing. Concerted research efforts have made great progress in understanding the processes that drive losses and gains of forests around the world, and increasingly acknowledge that many of these are intrinsically linked with matters of human development. Also in recent decades, the global community has made efforts to standardise the ways in which sustainable development is targeted and monitored, most recently through the development of the United Nations (UN) Sustainable Development Goals (SDGs[1]). These two aspects combined provide an opportunity through which to assess, monitor, and ultimately influence the ways that sustainable development affects forests. This thesis examines how achievement of the modern sustainable development agenda can, and potentially could, interact with forest conservation around the world.

In this introductory chapter, I first provide background information on forests, including their importance to humans, their global conservation status, and the major factors that are affecting their integrity (section 1.1). In section 1.2, I provide a brief timeline of key milestones in the evolution of sustainable development from the perspective of the UN, culminating in the adoption of the 17 SDGs by all member states. Section 1.3 describes how interactions between SDGs can shape development outcomes in both desirable and undesirable ways, and provides a summary of the most common ways in which this is studied. Section 1.4 moves beyond the topic of mapping interactions among the SDGs, and describes work that has attempted to forecast the ways that interactions may manifest in the future. In section 1.5, I consolidate the topics of the previous four sections by providing a summary of the past work on SDG-forest interactions, including the research gaps that this thesis hopes to fill. The chapter concludes with a summary (section 1.6), followed by a breakdown of the major aims and objectives of this thesis (section 1.7).

1.1. Forests: their conservation and importance for human well-being

This thesis is about the conservation, sustainable management, and overall betterment of natural forest ecosystems. The definitions of 'forest' used in this thesis are explained in each chapter, as per the nature of the research and data presented. Ultimately, this work concerns itself with natural forests only, and follows the definition used by the UN Food and Agriculture Organisation (FAO) and the UN Forum on Forests (UNFF): "Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include

[1] The SDGs are collectively known by several names, including the 2030 Agenda, the Global Goals, and the Sustainable Development Agenda, and these are used interchangeably throughout this thesis. Similarly, when referring to specific goals, the terms goal(s) and SDG(s) are used interchangeably. For example, the terms 'goal 1' and 'SDG 1' refer to the same thing.

land that is predominantly under agricultural or urban land use" (FAO, 2022; UN DESA and UNFF Secretariat, 2021). Importantly, this definition excludes tree stands in agricultural production systems, including timber and oil palm plantations, orchards and agroforestry systems. While I recognise that such habitats can provide benefits relative to other human-made systems (Paquette and Messier, 2010), this thesis is, in large part, motivated by the conservation of biodiversity, which these systems typically lack, at least relative to their natural counterparts (Barlow et al., 2007; Hua et al., 2022; Onyekwelu and Olabiwonnu, 2016).

Studies examining the ways that humans and forests interact can be broadly classified into one of two types; those considering the roles that forests play in supporting humans and their needs, and those considering how the actions of humans affect forests. Though this thesis is chiefly concerned with the second of these two topics, in the following section I introduce the former in order to contextualise the importance of the latter.

1.1.1. Ecosystem services derived from forests

Although a reliable estimate of the exact number of people considered 'dependent' on forests and forest products does not exist, it is estimated to include around one third of the human population (FAO and UNEP, 2020). To describe the numerous ways in which people use and/or depend on forests, it is helpful to think in terms of ecosystem services – benefits obtained by people from ecosystems. The Millennium Ecosystem Assessment (2005) identified four main types of ecosystems services: supporting services (processes that underpin the production of all other ecosystem services)[2]; regulating services (beneficial moderation of natural phenomena); provisioning services (benefits based on resources extracted from nature); and cultural services (non-material benefits provided to people by nature).

Among the most widely discussed services provided by forests is their role in climate regulation. Forest biomass and soils store around 45% of terrestrial organic carbon (Waring et al., 2020), thereby playing a key role in influencing the global climate

[2] Supporting ecosystem services provide benefits to humans indirectly through the provision of other ecosystem service types, and so are not discussed further here.

system. Forests also regulate climates at a local level, for example through the provision of shade and the distribution of atmospheric water (Ellison et al., 2017). Other important regulating services provided by forests include water and pollution regulation, and the moderation of potential shocks and disasters from floods, erosion, and pests and diseases, among others (Brockerhoff et al., 2017).

Provisioning services provided by forests include food (for both humans and livestock), water (both for drinking and irrigation), fibre, medicines, and a variety of wood products, ranging from timber to fuel (Brockerhoff et al., 2017; FAO and UNEP, 2020; UN DESA and UNFF Secretariat, 2021). These products may be used directly for subsistence purposes, or sold locally or further afield, thereby generating income and supporting livelihoods and economies (FAO and UNEP, 2020; Rasmussen et al., 2017; Shackleton et al., 2011). The formal production of wood and non-wood forest products (NWFPs) is estimated to provide around 45 million jobs globally and to generate a labour income of more than US$ 580 billion per year (FAO and UNEP, 2020). Commercial charcoal and wood fuel production alone provides employment for more than 40 million people, and generated an estimated revenue of around US$ 33 billion in 2011 (FAO and UNEP, 2020). These estimates are, however, highly uncertain, and also do not take into account the informal sectors, which estimates suggest provided 41 million jobs and generated a revenue of US$ 124 billion in 2011 (FAO and UNEP, 2020). Importantly, these estimates do not reflect the multitude of benefits derived from forest products at a subsistence level. By definition, benefits of this kind do not necessarily have employment or monetary values, or at least do not enter the system of national accounts, making it challenging to summarise their importance. Nevertheless, a number of investigations, typically at (sub-)national levels, have highlighted the huge importance of subsistence-level use of forest products (typically non-timber forest products, or NTFPs), which include fuelwood, edible/medicinal plants, game, honey, resins, essential oils and fibres, among others (Shackleton et al., 2011; Timko et al., 2010). The utility of forest products destined for subsistence use is often thought to exceed the cash income that residents derive from the commercial sale of NTFPs (Lacuna-Richman, 2002). Moreover, these products can play important roles in poverty mitigation and avoidance, and can act as ‘safety-nets’ or ‘gap-fillers’ to help overcome times of emergency and seasons with lower agricultural productivity, respectively (Ofoegbu et al., 2017; Shackleton et al., 2011; Timko et al., 2010). Crucially, subsistence use of forest products is often disproportionately more common among people or households with a lower socio-economic standing, including the landless poor, the unemployed, women, and indigenous groups (Ajaz-Ul-Islam et al., 2013; Lacuna-Richman, 2002; Mallik, 2000; Timko et al., 2010; Wickramasinghe et al., 1996).

Examination of historical art, folklore and religions from around the world shows that cultural values associated with forests have often featured prominently (Boada et al., 2018; Crews, 2003). Despite significant changes in the human cultural landscape, this persists today, including in many works of contemporary art (Piñón, 2017; Scott, 2011) and several religions (for example, 'sacred' forests can still be found in many countries of the world (Govigli, 2020)). The basis for this likely lies, at least in part, in the unique aesthetic and other sensory experiences that can be gained from being inside forests, and which have likely inspired people in a range of ways, perhaps by invoking a sense of calm or 'connectedness', or by providing a source of spiritual enlightenment. Similarly, forests can be used for a range of recreation activities, including walking, cycling, camping and birdwatching, among various others (Bell et al., 2009; Douglass, 2016; Peyron et al., 2002). Work has shown that many people will preferentially choose areas with trees for their recreation needs (Peyron et al., 2002), and are even willing to pay a premium for the experience (Dwyer et al., 1989). Use and enjoyment of forests in the ways described above has been shown to significantly improve both physical and mental health (Iwata et al., 2016; Karjalainen et al., 2009). Cultural ecosystem services, including those provided by forests, have often been considered 'intangible' compared with other service types (Atkinson and O'Brien, 2019) and are consequently relatively less well defined and quantified (Daniel et al., 2012). Nevertheless, acknowledgement of their importance is steadily becoming more widespread, and indicators are being developed so that cultural services can be more readily quantified along with other ecosystem service types (Atkinson and O'Brien, 2019).

1.1.2. Deforestation and forest degradation

Despite such exceptional importance, the total area of forest across the world is thought to have shrunk by around half during the last three centuries (Laurance, 2014), although declines began long before this (Bhagwat, 2014). Historic rates of decline have been uneven across time and space; broadly speaking, prior to the 1950s, most significant deforestation occurred in the temperate regions of the world, largely as a result of expanding agriculture, after which forest loss began to slow in these areas, only to increase in the world's tropical regions (Houghton, 2015). Table 1.1 shows that between 2010 and 2020, the global forest area shrunk by an estimated 4.74 million hectares (or an average of 0.12%) per year, but that the overall rate of decline in global forest area has slowed over recent decades. A closer look at these values (Figure 1.1) uncovers stark differences in the changes in net forest area between regions of the world; while Asia, Oceania and Europe have all shown net increases in forest cover in the last decade, North and Central America, South America and Africa have all shown net losses. In South America, the rate of forest loss has slowed between the periods 2000-2010 and 2010-2020, whereas in Africa the rate has increased over the same timeframe.

Table 1.1. Annual rates of global forest area change. Source: FAO and UNEP (2020), licensed under CC BY-SA 3.0 (https://creativecommons.org/licenses/by-nc-sa/3.0/).

Period	Mean annual net change (million ha/year)	Mean annual net change (%/year)
1990–2000	–7.84	–0.19
2000–2010	–5.17	–0.13
2010–2020	–4.74	–0.12

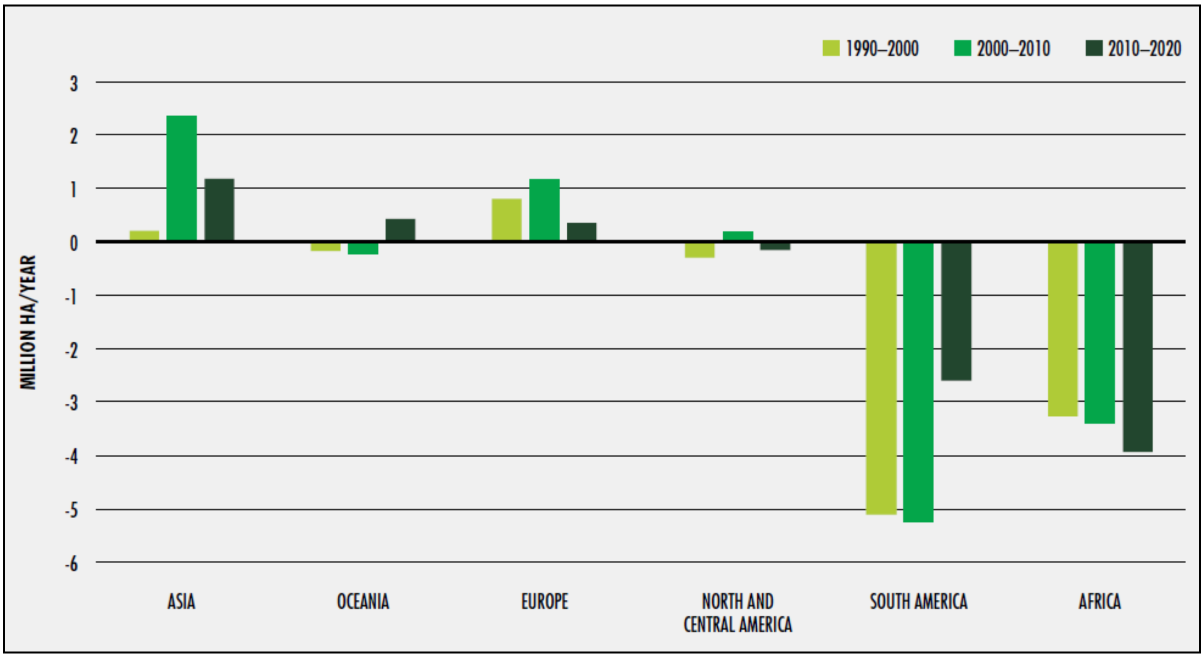

Figure 1.1. Net forest area change (million hectares per year) by region and decade Source: FAO and UNEP (2020), licensed under CC BY-SA 3.0 (https://creativecommons.org/licenses/by-nc-sa/3.0/).

The 2020 Global Forest Resources Assessment (FAO and UNEP, 2020) broadly defines forest degradation as "a reduction or loss of the biological or economic productivity and complexity of forest ecosystems resulting in the long-term reduction of the overall supply of benefits from forest, which includes wood, biodiversity and other products or services". However, this same report (as well as others, e.g. Ghazoul et al., 2015; Vásquez-Grandón et al., 2018) notes that this definition is not broadly agreed upon, and a review by Simula (2009) identified more than 50 different definitions used in the literature. Among the main challenges of defining forest degradation is the fact that it can take many forms, including various changes in structure, composition and/or ability to regenerate (Dupuis et al., 2020), and so combining these into a single definition is not straightforward. Moreover, given that forests are naturally dynamic, identification of a reference state from which compare and determine degradation is also challenging, and even if some reference state can be defined, then determining how far from this a forest should be to qualify as degraded is not clear (Vásquez-Grandón et al., 2018). In many instances, scholars attempting to apply working definitions of forest degradation have used predefined timeframes during which a forest may (or may not) return to some reference state in order to indicate degradation. However, the timeframes used in such works can vary widely, and may range from a few years (e.g. Vancutsem et al., 2021) to multiple decades (e.g. Dantas de Paula et al., 2015), again highlighting a general lack of consistency around the topic.

In a comprehensive review of this topic, Ghazoul et al. (2015) proposed a definition that focuses more on a forest's ability to return to a state that is structurally and functionally comparable to surrouding undisturbed areas without human intervention, irrespective of time. Where intervention of any kind is required then the authors suggest that a forest should be considered degraded. A more recent review of the same topic by Vásquez-Grandón et al. (2018) suggested that it may in fact be preferable to use locally-derived definitions of degradation, which can be tailored to specific management objectives and/or key attributes or ecosystem services of interest. Despite extensive discussion on the topic, at the time of writing there remains no widely accepted defintion of forest degradation.

As well as being difficult to define, forest degradation can also be challenging to measure. In contrast to deforestation, which can be readily quantified over wide areas through use of satellite imagery, measuring forest degradation can require on-the-ground surveys to detect more subtle disturbances (Murdiyarso et al., 2008). Metrics used to assess forest degradation using on-the-ground surveys have included species richness (Devi and Behera, 2003), aboveground biomass (Eckert et al., 2011), levels of human disturbance (Ahrends et al., 2021), and edaphic factors such as soil water content (Reddy et al., 2021), among various others. In recent times, however, there has been some progress in quantifying and monitoring forest degradation using remote sensing technologies, including satellites, LiDAR and unmanned aerial vehicles. Work utilising such technologies to assess forest degradation has typically done so through quantification of forest characteristics such as canopy cover, forest density, forest connectivity and aboveground biomass, among others (Dupuis et al., 2020; Gao et al., 2020; Mitchell et al., 2017), often also including a measure of regeneration times following an observed change (e.g. Rappaport et al., 2018; Vancutsem et al., 2021; Yesuf et al., 2019). Nevertheless, despite the valuable insights that remote sensing technologies can provide into certain aspects of forest degradation, these are generally still limited to macro-scale metrics such as those listed above, while their application to more subtle types of degradation (e.g. changes in species composition) remains challenging, meaning that such studies are relatively few (Dupuis et al., 2020).

Notwithstanding the challenges surrounding its definition and measurement, forest degradation is now widely acknowledged as a critical global issue. Forest degradation can produce significant carbon emissions (Asner et al., 2005; Pandey et al., 2020; Pearson et al., 2017), and compromise a forest's capacity to provide reliable provisioning and regulating services (Banerjee and Madhurima, 2013; Foley et al., 2014; Kyaw et al., 2020; Shanley and Luz, 2003), among other issues. Recent work in the Brazilian Amazon has shown that forest degradation is now a greater source of forest disturbance and greater contributor to the loss of aboveground biomass than deforestation (Matricardi et al., 2020; Qin et al., 2021). In Africa's Congo Basin, approximately 70% of the remaining forest is thought to be affected by forest degradation (Shapiro et al., 2021). Other studies report similarly concerning findings for other parts of the world, especially in the tropics, and recent work by Vancutsem et al. (2021) concluded that forest degradation was responsible for around one third of all changes in tropical moist forest cover during the period of 1990 to 2019, and also highlighted the importance of forest degradation as precursor to deforestation.

1.1.3. Understanding the drivers of forest change

To try to address the loss and degradation of forests in many parts of the world, the scientific community has made great efforts to understand the drivers (i.e. the causal or contributing factors) of these changes. Geist and Lambin (2001) classified drivers of deforestation as either 'direct' (or 'proximate'), meaning those that directly result in change (e.g. agriculture, fuelwood extraction etc.), or 'indirect' (or 'underlying'), meaning the social, political and demographic factors (e.g. corruption, insecure land tenure etc.) that underpin the direct drivers. Based on this, the authors identified 42 direct drivers (grouped broadly into three categories: agricultural expansion, wood extraction, and infrastructure extension) and 57 indirect drivers (grouped broadly into five categories: economic factors, policy/institutional factors, technological factors, cultural (or socio-political) factors and demographic factors). Based on 152 case studies of tropical deforestation, they note that no single direct or indirect drivers dominated the findings, but rather that combinations of causative factors were more common. These included combinations of agriculture, wood extraction and road development (mainly driven by economic, policy, institutional and cultural factors), agriculture and wood extraction (mainly driven by technological factors), and population-driven agricultural expansion (Geist and Lambin, 2001).

More recent assessments of drivers of forest change at an international level include the work of Hosonuma et al. (2012), who used a literature review to assess direct drivers of deforestation and forest degradation in 46 countries. Although this work did not include an assessment of indirect drivers, the authors' inclusion of drivers of forest degradation in their work marks an important improvement on the Geist and Lambin report cited above. This work showed that agriculture (including commercial, local and subsistence) was the dominant driver of deforestation, while timber extraction, logging, fuelwood collection and charcoal production were the dominant drivers of forest degradation, but that the relative importance of these factors varied regionally (Figure 1.2) (Hosonuma et al., 2012). A still more recent effort to quantify the drivers of global forest loss (but again, not including forest degradation, nor indirect drivers) is the work of Curtis et al. (2018), who, based on examination of satellite imagery, concluded that the most important drivers between 2001 and 2015 were, in descending order, commodity-driven agriculture, forestry, shifting agriculture and wildfires.

Evident from a brief review of work aiming to assess drivers of deforestation and forest degradation at a global (or at least multi-continental) scale, is that (a) forest degradation receives notably less attention than deforestation, and (b) indirect drivers receive less attention than direct ones. As was noted earlier, the techniques and metrics required to identify deforestation are much more well established than those for forest degradation (Murdiyarso et al., 2008), which explains in large part the first of these two shortcomings. In a similar way, the identification of direct drivers is more straightforward than indirect ones, owing to the typically more conspicuous nature of the former, and the often complex mechanisms through which the latter operate (Hosonuma et al., 2012; Indarto and Mutaqin, 2016; Kissinger et al., 2012). Nevertheless, a great deal of information on each of these topics is available from literature examining drivers at (sub-)national scales, and in Chapter 4 of this thesis, as part of a wider assessment (described later), I review and synthesise this information for 48 tropical countries.

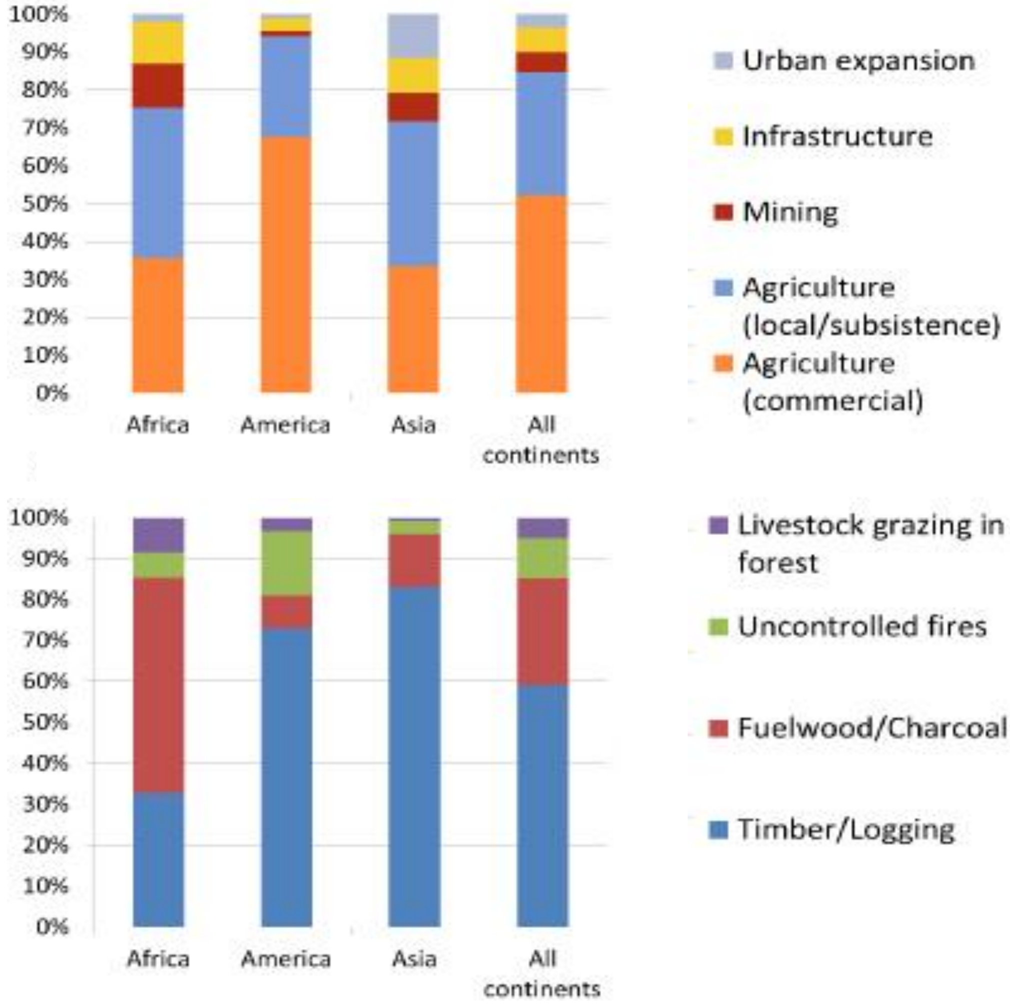

Figure 1.2. Relative contributions of direct drivers of deforestation (above) and forest degradation (below) based on an assessment of 46 countries. Source: Hosonuma et al. (2012), licensed under CC BY-SA 3.0 (https:// creativecommons.org /licenses/by-nc-sa/3.0/).

Also apparent from the literature on drivers of deforestation and forest degradation is that many (but not all[3]) of the commonly recorded direct and indirect drivers can be explicitly linked to one or more topics or themes that commonly feature in the literature

[3] For example, fire (both natural and human-caused) is a commonly cited driver of forest change (Curtis et al., 2018; Geist and Lambin, 2001; Ghazoul et al., 2015; Hosonuma et al., 2012; Zhao et al., 2021), but is not a topic typically covered in the sustainable development literature.

on sustainable development. Such linkages can be broadly thought of as cases where some form of societal or economic progress results in a driver being either (a) created or worsened, or (b) mitigated. Examples of the former can occur alongside the development of infrastructure, a key feature of modern sustainable development agenda (Inter-Agency and Expert Group in Sustainable Development Goal Indicators, 2016), but also a commonly cited driver of forest loss (Laurance et al., 2015; Seiler, 2003; Sloan et al., 2018). An example of the latter is the reduction of corruption, another feature of the sustainable development agenda (Inter-Agency and Expert Group in Sustainable Development Goal Indicators, 2016), but in this case one whose achievement can be expected to have positive implications for forests (Koyuncu and Yilmaz, 2009; Laurance, 2004; Sommer, 2017).

The idea that human progress in matters not typically associated with the natural environment can influence drivers of forest change forms part of the overarching basis for this entire thesis, and will be duly explored in more detail in upcoming sections and chapters. Before doing so, however, it is important to provide some background on the sustainable development movement, including how it integrates environmental and non-environmental issues, as well as on current thinking around how different aspects of sustainable development can interact. These are the topics presented in the next two sections, respectively.

1.2. Integrating environment and development: From Stockholm to the SDGs

In 1987, the World Commission on Environment and Development defined ‘sustainable development’ as “development that meets the needs of the current generation without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). Implicit in this definition is the notion that consideration must be given to the natural environment to ensure the long-term survival of humankind, and that this should be considered in combination with other aspects of human development. Although this idea may be somewhat commonplace among modern thinkers, its explicit acknowledgement among global governance agencies can be traced back only as far as the early 1970s, which saw the beginning of a series of processes led by the UN to explicitly link matters of environment and development at an international level.

The first of these processes was the UN Conference on the Human Environment, held in Stockholm, Sweden in June 1972. This conference culminated in the signing of the Stockholm Declaration (and its associated action plan) by 114 countries, formally marking the beginnings of dialogue between developed and developing nations on environmental issues, and on the links with economic growth, social development and human well-being (Handl, 2012). By the early 1980s, however, it was clear that environmental issues required greater attention on the global stage. In 1983 the UN responded by forming an independent organisation, the World Commission on Environment and Development (known informally as the ‘Brundtland Commission’), which was tasked with identifying long-term solutions to environmental issues based on co-operation among developing countries and between countries at different stages of economic and social development (World Commission on Environment and Development, 1987). The primary output from the Brundtland Commission’s analyses was a report titled ‘Our Common Future’ (World Commission on Environment and Development, 1987), also known ‘the Brundtland Report’. As well as providing the first working definition of ‘sustainable development’ (given above), the Brundtland Report proposed policy solutions that integrated matters of social equity, economic growth, and the environment.

The Brundtland Report laid much of the groundwork for the UN Conference on Environment and Development (often referred to as the “Earth Summit”), which took place in Rio de Janeiro, Brazil in 1992, and which made more explicit links between matters of environment and development than the Stockholm conference had done 20 years earlier (Handl, 2012). The Earth Summit brought together world leaders, NGOs, scientists and other influential groups from 179 countries, with the overarching objective to “produce a broad agenda and a new blueprint for international action on environmental and development issues that would help guide international cooperation and development policy in the twenty-first century” (United Nations, n.d.). The action plan that emerged from this conference, known as Agenda 21, was accompanied by a set of 27 guiding principles, known as the “Rio Declaration”. Principle 4 of this declaration states that “environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it", while Principle 25 states that "peace, development and environmental protection are interdependent and indivisible" (United Nations, 1992).

In 2000, the UN and its 191 (at the time) member states further committed to integrating matters of development and environment with the release of the Millennium Development Goals (MDGs), which all UN members agreed to help achieve. The MDGs comprised eight broad goals, made up of 18 targets, spanning matters of poverty, health, gender equality, education and the environment. Importantly, not only did the MDGs mark a greater coherence among the various UN agencies to deliver on a united vision (Kumar et al., 2016), but they also marked the first time that the UN adopted a target-driven approach to its development agenda (Kumar, 2013). The MDGs attracted criticism, however, for a number of reasons, including insufficient stakeholder involvement at the development stage, an absence of some important development topics previously agreed under other UN frameworks (e.g. matters of family planning), a bias towards developing countries over developed ones, a lack of measurability for many of the targets, and a general lack of attention to the interconnectedness of the goals (Attaran, 2005; Fehling et al., 2013; Waage et al., 2010).

Despite a generally poor performance of many countries to attain the MDGs (Waage et al., 2010), the conclusion of the timeframe covered by the goals in 2015 allowed an opportunity to revisit the overarching suitability and utility of such target-driven, multi-sectoral development frameworks in light of the criticisms given above. Consequently, the MDGs were succeeded by the SDGs, a more comprehensive list of 17 goals (Figure 1.3), developed through a much wider consultation of stakeholders than their predecessors, and with greater emphasis on the well-being of all countries, rather than just developing ones.

A further advancement of the SDGs was that they were purposefully created to integrate the wide range of themes and objectives embodied in the 17 goals through targets that overlap between goals (Le Blanc, 2015). The intention behind this is that the SDGs should be treated as an indivisible, unified whole (United Nations, 2015), which is an intentional response to a perceived lack of sectoral integration in previous development frameworks in terms of their strategies, policies and means of implementation (Le

Blanc, 2015). The implication of treating the global development agenda in this way, and one underpinning this whole thesis, is that interactions between the SDGs and their targets can and do occur, and that these should be purposefully identified, monitored and manipulated. The following section explores this idea in detail.

Figure 1.3. The 17 UN Sustainable Development Goals. Image is in the public domain and made freely available for use at: https://www.un.org/ sustainabledevelopment/news/communications-material/.

1.3. Interactions within and among the SDGs

The 2015 UN resolution on the SDGs makes clear that interactions between and within the 17 goals is fundamental to their design and achievement (United Nations, 2015). Underpinning this is the idea that achieving some aspects of the development agenda can actively facilitate the achievement of others, but in other cases, achievement of some aspects can constrain the achievement of others. For example, providing energy (SDG 7) can facilitate education (SDG 4) by providing light by which to study, power for computers, and so on, but limiting climate change (SDG 13) could also limit options to provide universal energy access (SDG 7) (Nilsson et al., 2016). Such interactions can be respectively termed ‘synergies’ and ‘trade-offs’, as is now common throughout much of the related literature. By identifying and better understanding the nature of synergies and trade-offs in the development agenda, it will be possible to develop cross-sectoral policies, strategies and interventions that promote the former and minimise the latter (Langou et al., 2019; Mainali et al., 2018; Nilsson et al., 2016).

Despite acknowledging the importance of SDG interactions, the original documentation associated with the SDGs does not provide guidance on the nature of these interactions. This leaves those tasked with helping to realise the goals at a potential disadvantage, as promoting synergies and avoiding trade-offs is not possible without first understanding them. Acknowledgement of this shortcoming soon prompted researchers to consider the topic in detail, with some of the earliest works being primarily theoretical in nature. For example, Waage et al. (2015) hypothesized interactions between three concentric ‘layers’ each containing sets of goals with similar attributes (Figure 1.4), and suggested that achieving infrastructure goals can help to facilitate the achievement of well-being goals, but may come at the expense of success in achieving natural environment goals.

In the subsequent years, and especially following a call to action by Nilsson et al. (2016) urging researchers to study SDG interactions, a productive area of research has emerged, seeking to identify, map, quantify and model SDG interactions. Such studies have varied widely in their level of focus (e.g. focusing on all SDGs or on specific pairs of components), their data sources, and/or their analytical approaches (Bennich et al., 2020), and in this section I aim to characterise and provide examples of each. Although the descriptions that follow are not exhaustive, they cover many of the methods most commonly encountered in the literature, and so provide a good primer on the subject. As it can be common practice to combine multiple methods and/or data sources when investigating SDG interactions, it is not always possible to describe the full complexities of each paper cited in the following summaries. However, I do aim to link some papers between sections in order to illustrate how different approaches can complement each other.

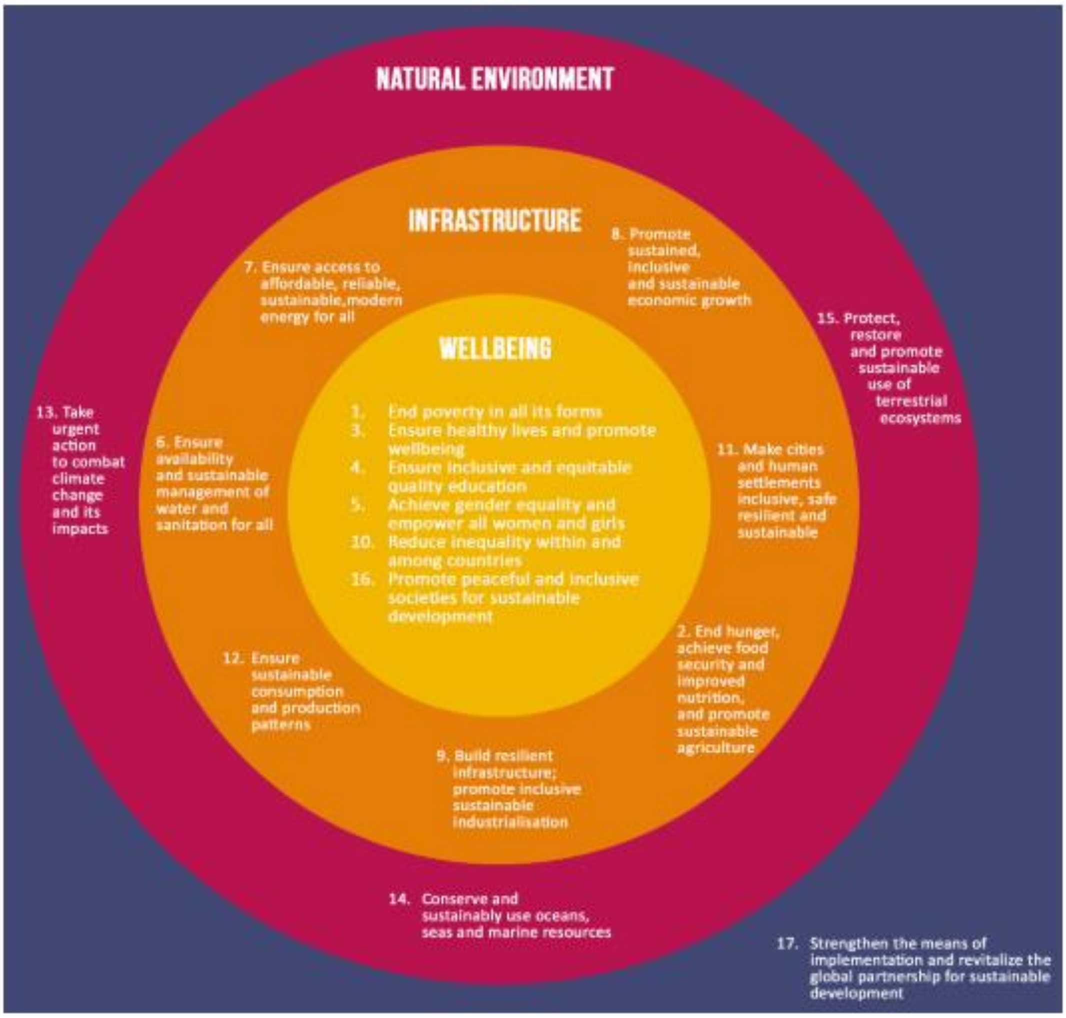

Figure 1.4. Waage et al. (2015) organised the SDGs into three 'layers' and described interactions within and between each. Source: Waage et al. (2015), licensed under CC BY-SA 4.0 (https://creativecommons.org/licenses/by/4.0/).

1.3.1. Establishing the level of focus when considering SDG interactions

A substantive literature review on the topic of SDG interactions by Bennich et al. (2020) applied a typology to studies based on the nature of the interactions being investigated. These can essentially be interactions between any combination of goal(s), target(s)/indicator(s), related policies, or external entities (i.e. themes or processes not covered by the SDGs). Throughout this thesis, the 'outcome' of interest (the conservation and restoration of forests) can be best aligned with the SDGs at the target level, and specifically, the following three targets (each of which overlap to some degree):

- *Target 15.1*: "By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands".

- *Target15.2*: "By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally".

- *Target 6.6*: "By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes".

This thesis is concerned with how the targets listed above are affected by changes in other areas of the development agenda, including at the target level (Chapters 2 and 4) and at the goal level (Chapter 3). As such, the following paragraphs predominantly cite examples of studies seeking to identify interactions at these levels, although readers should keep in mind that interactions can occur (and be studied) at other levels.

Interactions involving targets occur where progress towards achievement of one of the 169 SDG targets results in either a synergy or a trade-off with another aspect (i.e. a goal or another target etc.), or vice versa. In this thesis, I extend this definition to include cases where target-related indicators are used as a basis to explore interactions, although I note that some scholars (e.g. Bennich et al., 2020) make a distinction between target- and indicator-level interactions. Interactions involving goals occur where progress in a whole suite of targets pertaining to a single SDG results in either a synergy or a trade-off with another aspect (i.e. a target or another goal etc.) or vice versa. Although some investigations may choose to present their target-level findings grouped by goal (e.g. McCollum et al., 2018), I distinguish goal-level studies as those that combine target-level findings quantitatively in order to assess a goal's status, or changes therein.

Studies considering target-level interactions are more common than those considering goal-level interactions, and this is likely for three main reasons. Firstly, the 169 targets compared with 17 goals means that there is a greater variety of potential interactions to be explored to begin with. Second, because each SDG target has one or more associated indicators, they typically have a readily available data source and are inherently more quantifiable than whole goals. The third reason is that although the SDGs were developed around 2015, many of the indicators that support the SDG targets pre-date the SDGs, and so many target-level investigations had been conducted even before the data underpinning the research was actually placed into the context of the SDGs. One example of this (of countless possible) is the work of Kirigia et al. (2006), which investigated the influence of maternal mortality on gross domestic product (GDP). Although this work was published almost a decade before the advent of the SDGs, the data used correspond with SDG targets 3.1 (reduce maternal mortality) and 8.1 (sustain per capita economic growth), making the research and its findings still highly relevant in the context of modern sustainable development. SDG targets are more specific in nature than the composite goals that they are each a part of, which makes discerning interactions (including cause and effect) at this level, and subsequently prescribing specific interventions, conceptually more straightforward (Lusseau and Mancini, 2019; Weitz et al., 2018).

Goal-level investigations are inherently more methodologically challenging than those at the target level, mainly because the widely varying targets and indicators that comprise a given goal are not readily combined, and so consideration is required over how to characterise the goal(s) of interest. Also arising from the varied nature of each goal’s composite targets and indicators, a further challenge for goal-level studies is that they are typically unable to specify the mechanisms underlying (and therefore attribute cause and effect to) any relationships identified. Despite these challenges, identification of goal-level interactions can provide insights that can inform broader governance of whole thematic areas (Lusseau and Mancini, 2019). Furthermore, as interactions at the target-level do not necessarily scale up to reflect those at the goal level (Lusseau and Mancini, 2019), and vice versa, important relationships could be overlooked when only considering a single level of interaction. This point is pertinent to this thesis, which considers both target- and goal-level interactions with forests, as well as a comparison and a critical discussion of the similarities and differences in Chapter 5.

While some studies aim to consider all possible interactions between all goals or targets that comprise the SDGs (e.g. Hegre et al., 2020; Lusseau and Mancini, 2019), it is more common for studies to focus on a reduced set of components and/or a specific single component or theme. For example, Engström et al. (2019) considered interactions between goals on energy, climate, water and land, while Fader et al. (2018) considered interactions between targets relating to water, energy and food. Studies focusing on specific topics include Fuso Nerini et al. (2018), Cook et al. (2019) and Parikh et al. (2021), who respectively looked at interactions between energy, tourism and sanitation, and all 169 SDG targets.

Research into SDG interactions can be further distinguished as being either systemic or non-systemic (Langou et al., 2019). Systemic analyses attempt to capture interactions relating to the whole system (or at least a part of it), often including feedback loops and/or second-order interactions, whereas non-systemic analyses typically consider interactions between individual pairs of components only (Langou et al., 2019). Systemic techniques such as quantitative modelling or scenario analysis are more commonly used to project or forecast potential future outcomes than to actually identify interactions, and this topic receives specific attention in section 1.4. The exception to this is the use of network analysis, which is described shortly. One point to note is that systemic studies commonly use similar data and methods to non-systemic ones for the initial identification of interactions, before later considering them at the 'system' level, and so much of the information in the remainder of this section is relevant to both cases.

Lastly, studies of SDG interactions can be distinguished by their geographical scope, which may range from local (e.g. Engström et al. (2019) studied interactions at the level of Swedish municipality) to global (e.g. Hegre et al. (2020) studied interactions across all 193 UN member states). Intermediate levels of investigation can include national (e.g. Bisaga et al. (2021) studied interactions in Rwanda only) or regional (e.g. Allen et al. (2017) studied interactions within the Arab region). Geographical scope is an important consideration when interpreting the findings of a given investigation because interactions identified at one level may not necessarily scale up or down to another (De Neve and Sachs, 2020). Studies at smaller and greater geographical scales are analogous to target-and goal-level assessments, in the sense that the former are more typically able to provide highly context-specific insights and recommendations, and the latter more usually relevant to matters of high-level (e.g. international) governance and policymaking.

1.3.2. Sources of data for assessing SDG interactions

Bennich et al. (2020) noted that the most common data sources for studies of SDG interactions are direct observation, expert/stakeholder knowledge, official databases, and scientific literature, and the following sections discuss each of these.

(i) Direct observation

In some cases, SDG interactions are reported following direct observations, including by researchers or other actors that are witness to some kind of development-related change. At the simplest level, case studies (usually at a local scale) can report on observed interactions without use of complex analytical techniques, typically once some kind of intervention or change has resulted in a knock-on effect, be it intentional or otherwise. In other cases, observations can be made by individuals or groups of researchers specifically seeking to investigate one or more interactions.

Aiken and Leigh (2015) presented case studies of the impacts of large dams on indigenous communities in Malaysia. The dams were developed primarily to provide domestic energy and/or water, linking them to SDG targets 6.1 (access to water), 7.1 (access to energy) and 7.2 (renewable energies). Despite being ostensibly successful in achieving these aims, the authors describe a number of trade-offs with other key areas of development, mainly resulting from the resettlement of people and changes in land use. The forced relocation of indigenous communities represented an erosion of their ownership and control over land, property and natural resources (target 1.4), and presented issues surrounding food security (target 2.1: relocation sites were often not suitable to support the same levels of agriculture as the former sites) and unemployment (target 8.5: employment opportunities at the relocation sites were limited). Moreover, the loss and degradation of ecosystems (target 15.1) arising from the construction of the dams led to declining fish stocks that further jeopardized food security downstream from the actual sites.

Cluver et al. (2016) specifically sought to investigate whether improved social protection systems (target 1.3) facilitate improvements in a range of other targets (17 in total, spanning five goals) relating to adolescent health and well-being. To do so, they conducted research-specific surveys in two rural districts of South Africa, collecting data on 3,515 individuals. The authors concluded that improved social protection systems have synergistically positive relationships with most of the other targets included in their work.

Observational studies of this kind are useful insomuch as they can highlight specific interactions, often including the complex mechanisms through which they occur. However, because they are typically based on local-scale observations, their findings may not necessarily be reflective of the ways that interactions occur in different contexts and locations.

(ii) Expert and stakeholder elicitation

Elicitation of expert and stakeholder knowledge to identify SDG interactions is a relatively common approach (Bennich et al., 2020), typically involving focus groups, workshops, interviews or questionnaires. A report by the International Council for Science and the International Social Science Council (ICSU and ISSC, 2015), which was among the first efforts to identify linkages between the SDGs, was based on inputs from more than 40 selected experts. Subsequent assessments using expert elicitation have included Singh et al. (2018), who ran a series of expert workshops to evaluate the links between targets from SDG 14 (oceans) and those from 15 other goals (all except goal 17). Fuso Nerini et al. (2018) used a combination of expert elicitation and literature reviews to map synergies and trade-offs between energy targets (SDG 7) and all 169 SDG targets. The methods applied in this last study have since been repeated in other contexts, including urban ecosystems (Maes et al., 2019), off-grid solar energy in Rwanda (Bisaga et al., 2021) and sanitation (Parikh et al., 2021).

Expert elicitation has been used to apply semi-quantitative scales to known or expected interactions, the most commonly encountered of which is the framework proposed by Nilsson et al. (2016). This framework applies a seven-point scale ranging from ‘cancelling’ (i.e. achievement of both targets simultaneously is impossible), with an associated score of -3, through ‘consistent’ (i.e. no interactions, scored 0) to ‘indivisible’ (i.e. one target cannot be achieved without the other, scored +3), and takes into account matters of reversibility, directionality, strength and certainty (albeit based on the opinions of contributing experts). Perhaps the most comprehensive application of this framework to date was published by the International Council for Science (ICSU, 2017), which assessed interactions between targets from four SDGs (goals 2 (food security), 3 (health), 7 (energy), and 14 (oceans)) and those from all other goals, identifying 238 positive and 66 negative interactions overall.

One further use of expert elicitation is as a means to confirm the relevance or likelihood of suspected or anticipated interactions in a given context. For example, Allen et al. (2017) consulted experts and stakeholders from the Arab region to assess whether pre-identified interactions are relevant to that region.

Expert elicitation is considered useful when existing evidence or data is lacking, when underlying causal mechanisms are complex or poorly understood, and/or when apparent randomness in trends renders more quantitative techniques less appropriate (Dion et al., 2020; Knol et al., 2010). These advantages make the approach particularly appropriate for identifying SDG interactions, which can be highly context-specific and often poorly understood in many cases (ICSU, 2017; Nilsson et al., 2016; Weitz et al., 2019), and so can benefit from being considered by experts with a variety of backgrounds and expertise. It should be noted, however, that gathering information via expert consultations is not without some limitations, which can include a general lack of ability to consistently apply quantitative measures, and the potential for bias within assessments, especially if the composition of the experts consulted is not adequately representative (Morgan, 2014).

(iii) Indicator databases

For decades, multi-lateral agencies, national governments, and numerous NGOs have collected data to assess and support matters of development, and these can provide a rich source of data for studies of SDG interactions. Among the most suitable for such purposes, and especially for studies that concern themselves with multiple countries, are the UN's Global SDG Indicators Database (United Nations Statistics Division, 2022) and the World Bank's World Development Indicators Database (World Bank, 2022). Both databases are openly available to the public, and contain information that directly relates to the official SDG indicators, although it has been noted (Lusseau and Mancini, 2019) that the latter contains information for more countries and years, as well as data on additional indicators not used by the SDGs. These data have been used in a multitude of studies seeking to identify interactions between one more indicators (e.g. Anderson et al., 2021; Bali Swain and Ranganathan, 2021; Barbier and Burgess, 2019; Hegre et al., 2020; Lusseau and Mancini, 2019), and these studies almost always apply correlational approaches, which are described in the next section.

As well as data directly pertaining to the official SDG indicators, a wide range of other datasets providing national-level indicators for multiple countries are available, and can be used as proxies in cases where official indicator data are missing or incomplete. Among the most comprehensive and useful of these data sources is that provided by the United States Agency for International Development in the form of their Demographic and Health Surveys (DHS) (USAID, 2022), which collects and disseminates household-level data on population, health, and nutrition from more than 90 countries. Doku et al. (2020) used DHS data from 59 low- and middle-income countries to assess whether improving women's empowerment (SDG 5) is associated with reduced neonatal, infant and under-five mortality (target 3.2), and concluded that there are multiple synergies to be gained in this area.

In some cases, researchers mix official indicator data with proxy data sourced elsewhere. For example, the online 'SDG Interlinkages Analysis and Visualisation Tool' (Zhou et al., 2021), which maps and monitors target-level interactions for 27 countries, uses proxy data on the proportion of the eligible population receiving a pension to consider target 1.3, which relates to social protection floors/systems, as official indicator data are incomplete. Similarly, when investigating the impacts of corruption (target 16.5) on uptake of renewable energy (target 7.2), Amoah et al. (2022) sourced all data from the World Bank's Development Indicators Database apart from their measure of corruption, which was deemed too data poor in the official source, and instead used Transparency International's Corruption Perception Index (Transparency International, 2021). Although examples of potential data sources of this nature are too numerous to list here, the above examples illustrate the fact that it is common practice to employ proxy variables in some cases.

For researchers wishing to study SDG interactions at a (sub-)national scale, there are again a range of resources available, often deriving from national-level surveys and databases (including the DHS data mentioned above). The huge variety of such resources means that, again here, it is not possible to list them all, and so I instead provide illustrative examples only. Focusing on India, Jung et al. (2019) investigated whether the risk of cardiovascular disease (target 3.4) in India is linked to socioeconomic status (e.g. primary school completion rate (target 4.1), female literacy rate (target 4.6), and GDP per capita (target 8.1), among others). To do so, they used data from two government-led, nationally representative household surveys, which allowed them to draw conclusions at levels of both individual participant and district. Perhaps surprisingly, the authors found negative associations in many cases. Focusing on Ghana, Adamba (2018) used data from the Ghana Statistical Service (a government agency that collects and disseminates national data) to assess the links between access to electricity (target 7.1) and a range of learning outcomes (SDG 4), finding positive associations in most cases.

(iv) Scientific and grey literature

The wealth of existing studies and reports relevant to the topic of SDG interactions can provide a valuable source of information. Literature reviews are particularly useful where the aim is to synthesise and map interactions pertaining to multiple goals or targets. Doing so is considerably more practical than collecting first-hand data on such a broad range of subjects, and allows the researcher(s) to gain insights from studies conducted in a variety of contexts and locations.

Examples of studies using literature reviews to collate information on SDG interactions include the work of Vladimirova and Le Blanc (2016), who reviewed 37 UN flagship reports to assess links between education and all other goals, finding links with all goals except goal 14 (oceans). A further example is the work of Alcamo (2019), who used a series of key phrase searches to review the links between water quality (target 6.3) and targets from all other goals. The authors' findings suggest that the linkages that can be inferred from the wider literature significantly outweigh those that receive explicit mention in the supporting text of the SDG targets.

Literature reviews are often used in combination with other methods, most commonly expert/stakeholder elicitation, as a means to map interactions. Indeed, most of the studies cited in the section above on expert elicitation used these two approaches in combination. This includes all cited applications of the Nilsson et al. (2016) framework, and all cited applications of the methods developed by Fuso Nerini et al. (2018), which are two of the more common approaches to mapping SDG interactions.

Data gathered from published literature can also be used to assess SDG interactions in more quantitative ways. For example, after conducting a literature review of the links between energy technologies and land- and water-use impacts, Engström et al. (2019) used the findings as part of a systemic model (defined in section 1.4) to assess the possible impacts of different emissions reductions strategies in a Swedish municipality.

In this thesis, I make considerable use of the available literature to inform my work. In Chapter 2, I present a comprehensive systematic review of the links between non-environmental SDG targets and forests, and in Chapter 4, I review selected publications as a means to establish the development priorities and drivers of forest change for 48 countries, which I use as a basis to assess the possible impacts of the former on the latter.

1.3.3. Analytical techniques for assessing SDG interactions

Having established the scope and identified data sources for an investigation into SDG interactions, the remaining step is to determine an appropriate analytical approach.

Naturally, this will be guided by the specific aims of the study, which in most cases is either to verify/quantify the existence of an interaction and/or to synthesise information on a range of interactions in order to characterise an entire (or part of a) system. There are a range of analytical techniques at the disposal of researchers in this field, and in this section I describe the three most commonly encountered; namely (i) developing basic syntheses or maps; (ii) using correlational approaches; or (iii) performing network analysis. More complex systemic approaches have, in some cases, also been used to quantify SDG interactions (e.g. Scherer et al., 2018), but these are more commonly used to project anticipated or possible future interactions, and so I reserve this topic for section 1.4. Again, readers should keep in mind that many studies draw upon multiple analytical techniques, and so, for ease of presentation, the following examples may not convey the full complexities of the each study cited.

(i) Basic synthesis/mapping

Where the primary aim of a study is to determine the presence or absence of interactions in one aspect of the SDGs (e.g. selected themes, goals or targets) relative to others, and if data are collected via expert elicitation and/or literature review, it is often sufficient to simply present the results in a synthesized form, with few additional steps. The review of links between energy and all SDG targets by Fuso Nerini et al. (2018), and the subsequent publications that applied the same methodology (Bisaga et al., 2021; Maes et al., 2019; Parikh et al., 2021), all presented their findings graphically (Figure 1.5), grouping target-level findings by goal, and distinguishing between synergies and trade-offs, but with no further analysis. Both McCollum et al. (2018) and (Cook et al., 2019) used the framework devised by Nilsson et al. (2016) (see above), the former to assess interactions between energy (SDG 7) and non-energy SDG targets, and the latter to assess the links between the Icelandic tourism sector (relevant to SDG target 8.9) and all other SDG targets. In both cases, the authors present their results graphically with little additional analysis.

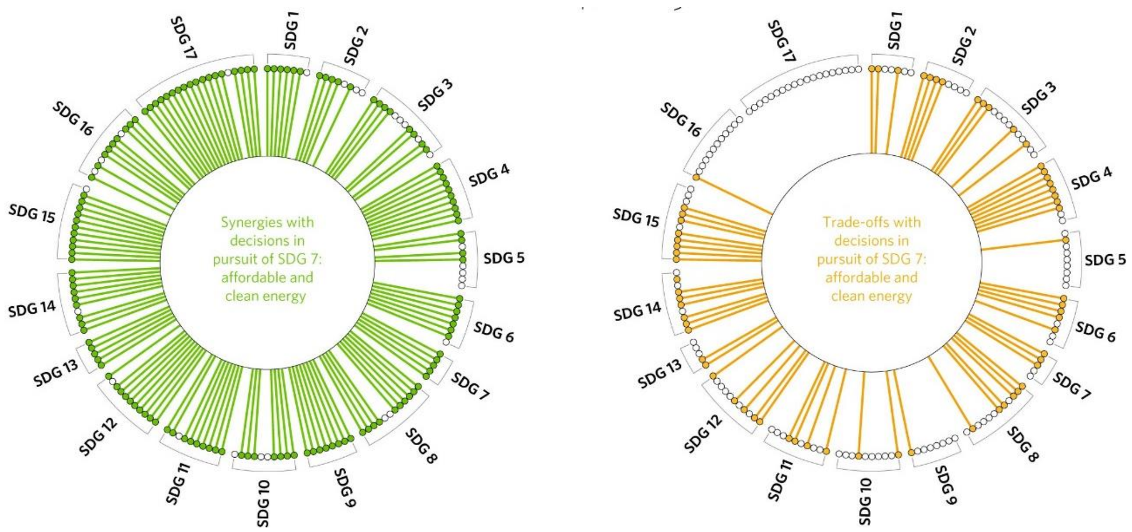

Figure 1.5. A simple way to map interactions was used by Fuso Nerini et al. (2018), here showing synergies (left) and trade-offs (right) between energy (SDG 7) targets and all other SDG targets. Source: Fuso Nerini et al. (2018). Image copyright: Springer Nature, used with permission.

The International Council for Science (2017) recommends application of the framework developed by Nilsson et al. (2016), followed by construction of a cross-impact matrix. A cross-impact matrix conveys the interactions between all possible pairs of targets (or goals, indicators etc.) considered in the assessment. By summing the row and column values is possible to gauge the extent to which each target influences, and is influenced by, all others included. Cross-impact analysis was used by Barquet et al. (2021) to summarise interactions between 36 selected targets in the context of Sri Lanka, by Weitz et al. (2018) to summarise interactions between 34 selected target (two from each goal) in the context of Sweden, and by Fader et al. (2018) to summarise interactions between all targets from goals on food, water and energy.

(ii) Correlational methods

Correlational methods mathematically identify/quantify relationships between two or more variables, and have been used on many occasions to explore SDG interactions. Being quantitative in nature, all correlational approaches require numerical data of some kind, and so, in the context of SDG interactions, they are most commonly used to analyse indicator (including proxy) data, including cases where indicators are merged to represent one or more goals.

Correlational methods used to assess SDG interactions have ranged from basic linear techniques (e.g. Pearson's correlation or ordinary least squares (OLS) regression) to more complex methods, including non-linear (e.g. polynomial regression) and dimensionality reduction (e.g. principal component regression) techniques. The choice of method for use is largely determined by the underlying research question(s) and by the nature of the data being analysed.

Correlational approaches can be used to explore specific hypotheses involving only a small number of predictors; for example the aforementioned work of Doku et al. (2020) used logistic regression to examine relationships between women's empowerment child mortality. Alternatively, they can be used in a more exploratory fashion to examine relationships between whole suites of variables. For example, Pradhan et al. (2017) used Spearman's rank correlation to assess relationships between all possible pairs of 122 different indicators spanning all 17 SDGs. They then calculated the proportions of significant positive (synergies), significant negative (trade-offs), and non-significant relationships identified for each goal. Their results suggest that indicators from SDGs 1 (poverty) and 3 (health) have proportionally more synergies with indicators from other goals than other SDGs, while indicators from SDGs 8 (economy), 9 (industry and infrastructure), 12 (responsible consumption and production), and 15 (life on land) have a greater proportion of trade-offs. Similarly, focusing on Spain, Ramos and Laurenti (2020) also used Spearman's rank correlation, in this case to assess relationships between all combinations of 34 indicators, and found that SDGs 4 (education), 5 (gender) and 7 (energy) provided the largest numbers of positive interactions.

Correlational approaches are commonly used to study goal-level interactions, including to derive useable goal-level metrics (i.e. from target/indicator data), as well as to assess their relationships. For example, Lusseau and Mancini (2019) ran linear mixed-effects models for each possible pair of 331 indicator variables, and then summarised the outcomes at the goal level by averaging the directions and strengths of any significant relationships identified for each of the respective goals involved. The resulting outputs were then used to perform network analysis (see next section).

In a novel approach to deriving goal-level data, Hegre et al. (2020) characterised each SDG by applying principal component analysis (PCA) to groups of indicators from each SDG. This provided ‘principal components’ for each SDG that were uncorrelated and captured known amounts of the variance present in all included indicators for each goal. By examining the strength and direction of the correlations between principal components for each goal, the authors were able to identify synergies and trade-offs at the goal-level. The authors found that SDGs 1 to 8, 11 and 17 (or at least the principal components that best characterise them) showed consistently strong and positive correlations (indicating synergies) with each other, while SDG 10 showed negative correlations (indicating trade-offs) with most other goals.

De Neve and Sachs (2020) examined relationships between each of the 17 SDGs and a single variable of interest - subjective well-being[4]. In this case, the authors made use of a freely available index, the Sustainable Development Goal Index (SDGI), which combines a range of relevant indicators to provide country-level scores from 0 (worst possible) to 100 (best possible) for each SDG for 193 countries (Sachs et al., 2019). Using standard univariate correlations, this analysis found significant positive relationships (indicating synergies) between subjective well-being and all goals apart from goals 12 (consumption and production) and 13 (climate), which both had significant negative relationships, and goals 14 (oceans) and 15 (life on land), neither of which were significant. The authors followed this up by performing dominance analysis, a technique to assess the relative importance of each of a set of predictors in explaining an outcome, on the same dataset. Their finding suggested that SDGs on health, economy, industry/infrastructure and sustainable consumption are most important in in explaining subjective well-being. In Chapter 3 of this thesis, I draw upon the methods used in this study, and use both the SDGI and dominance analysis to examine goal-level interactions with forests.

Because correlational studies are typically based on standardised indicators, they are more easily reproduced and are less subject to bias than methods based on expert-derived assessments (unless some bias exists in the underlying data). Furthermore, their

[4] Subjective well-being is not an explicit component of the SDGs, but rather an overarching indicator that can be considered relevant to multiple goals. Nevertheless, I make reference to this work here as its methodological approach directly informed parts of this thesis.

quantitative nature makes them better suited to drawing inferences about a given relationship (e.g. strength, probability etc.), as well as for the development of predictive models. Nevertheless, correlational approaches can be limited by data availability, and may require specialised knowledge on the part of the researcher if highly advanced techniques are required. Ultimately, such methods can only reflect mathematical relationships insofar as they exist within the underlying data, and as such, may be unable to identify a given interaction if the relationship is inconsistent and/or varies in specific contexts or circumstances. In such cases, qualitative assessments may be more appropriate.

(iii) Network analysis

Network analysis refers to a group of methods that seek to map the overall structure of complex inter-relationships between a group of variables (Hevey, 2018). In the context of SDG interactions, network analysis is the only systemic approach encountered in this review that was used in an exploratory, rather than a 'predictive' or scenario modelling sense (these are described in section 1.4). The types of data used in network analysis can vary, and I explore this shortly, but first I introduce a few basic concepts.

A network is comprised of nodes (the entities that make up the network) and edges (links between the nodes that convey some relationship). Edges can be characterised in terms of their direction (indicating whether the relationship is mutual or one-directional) and/or weight (the strength or size of the relationship) (Weitz et al., 2018). Nodes can be assigned values from the underlying data, and can be further characterised by measures of 'centrality', which are values describing the position of each node in the network relative to all others. Commonly used measures of centrality include 'degree' (the number of links going into and/or out of the node), 'strength' (similar to degree, but also includes the degree values of all other connected nodes), 'closeness' (a measure of all direct and indirect connections with all other nodes; note that more connected nodes are usually placed more centrally in the overall network), and 'betweenness' (a measure of a node's importance in the average pathway between all other pairs of nodes) (Hevey, 2018; McGowan et al., 2019). Depending on the data used to construct a network, each of the above have different implications, and it is beyond the scope of this thesis to discuss these in detail. As a general rule, however, high strength and degree values suggest a greater tendency to affect or be affected by other individual components, and high closeness and betweenness values suggest a higher capacity to exert (or receive) influence over (or from) the entire network (Hevey, 2018; Yan and Ding, 2009).

Le Blanc (2015) made what was likely the first attempt at mapping of the SDGs as a network of related targets, based on similarities in the wording of the supporting documentation for each target. From 107 targets considered, Le Blanc found that 60 contained wording that linked them to at least one other goal. Although informative, this approach has limitations; as noted by the author himself, use of the wording alone to infer links is likely to miss some important relationships, such as between energy and climate change. A later paper by Lim et al. (2018) also used a keyword approach to infer target-target relationships, but in this case the authors developed five separate networks pertaining to different shared aspects (challenges, topics, stakeholders involved, enabling/constraining characteristics, and actions required for achievement) of each target. Comparing centrality measures across each of these networks, the authors concluded that goals on peace, climate, economic growth and energy have proportionally more targets that can exert significant influence on the wider network.

Earlier, I described how Weitz et al. (2018) used the framework devised by Nilsson et al. (2016) to develop a cross-impact matrix for 34 selected targets in the context of Sweden. This matrix was then translated into an overall network, as well as several sub-networks, for example conveying only the strongest synergies or trade-offs, allowing easy identification of the targets that most influence, and are most influenced by, other targets in both positive and negative ways (Figure 1.6). The authors further proceeded to factor in second-order interactions (i.e. subsequent effects on a third target) before recalculating the relative degrees of influence for each target. The authors conclude that, among the 34 targets considered, those on climate change adaptation, energy efficiency, effective institutions, woman’s participation, and unpaid/domestic work can exert the greatest positive influences, while those on exports from developing countries and renewable energies can exert the greatest negative influences.

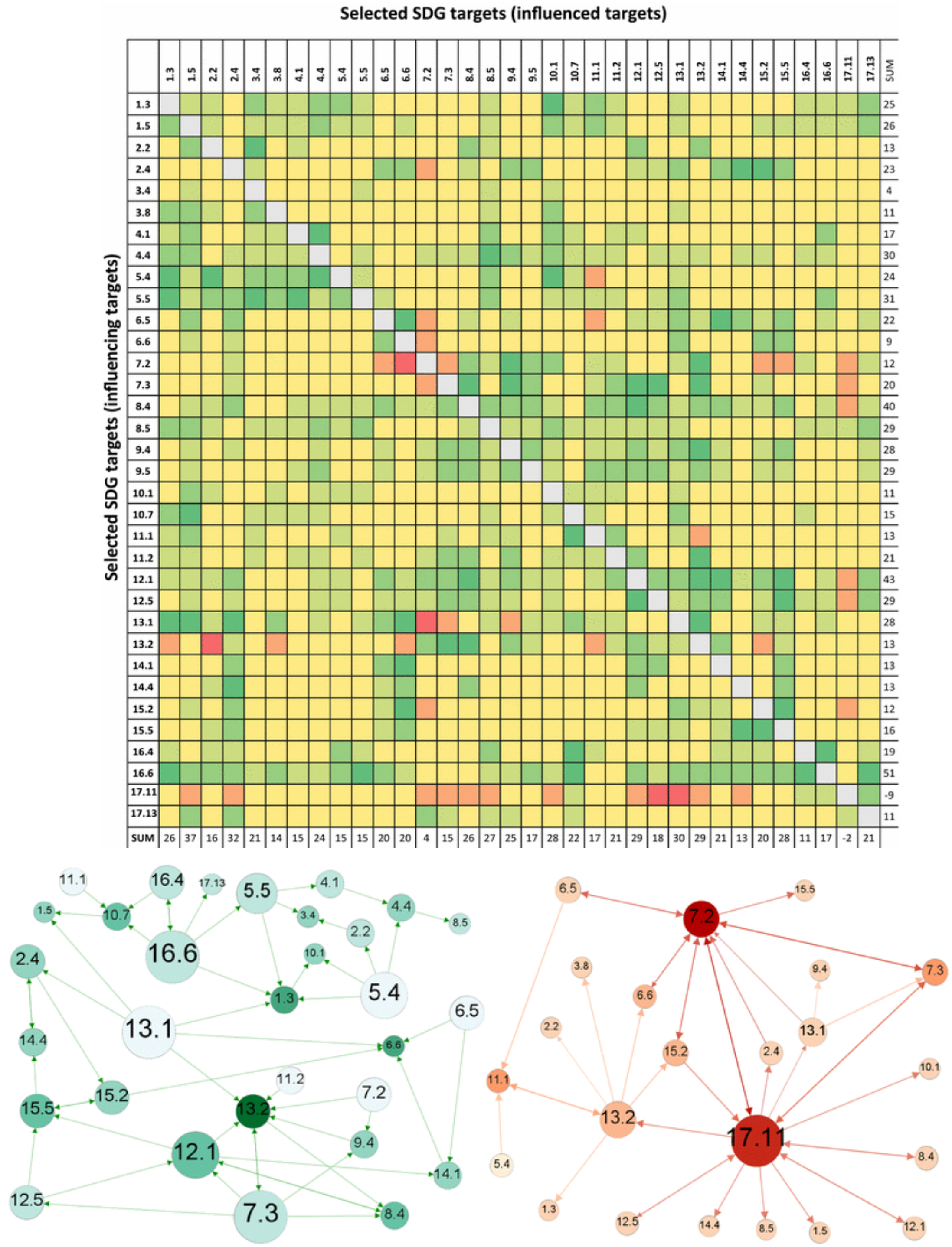

Figure 1.6. Cross-impact matrix (above image) showing synergies (green), trade-offs (red) and no interactions (yellow) between 34 SDG target pairs in Sweden, based on the scoring system of Nilsson et al. (2016). Row and column values show net influence over and from all other targets, respectively. Lower images show network analysis performed using these values, including the highest-scoring synergies (lower left) and trade-offs (lower right). In these images, numbers are SDG target numbers, arrows show direction of relationships, larger circles indicate more influence over other targets, and darker colours indicate more influence from other targets. Adapted from: Weitz et al. (2018) licensed under CC BY-SA 4.0 (https://creativecommons.org/licenses/by/4.0/).

McGowan et al. (2019) also used data collected through expert elicitation on target-level relationships to perform network analysis, this time at the goal level. Using the target-level interactions identified by ICSU and ISSC (2015), the authors considered each goal as a node in the network and determined edge weights by counting the number of targets that link any two goals. Based on this, they next assessed all four of the centrality metrics listed at the start of this section, and ranked the 17 goals. Their results showed that SDG 4 (education) occurred in the top three goals for three of the four metrics, SDGs 2 (hunger) and 7 (energy) occurred in the top three goals for two metrics; and SDGs 6 (water and sanitation), 9 (industry and infrastructure) and 15 (life on land) occurred in the top three goals in one metric.

Lusseau and Mancini (2019) developed a network of SDG interactions (which they refer to as the 'sustainome') based on statistical relationships between pairs of indicators. The authors used the outcomes (beta values and standard errors) of linear mixed-effects models between 331 indicators pairs spanning all 17 goals to construct their network, and investigated a single measure of centrality. Findings suggested that major trade-offs are associated with goals on climate change, inequalities and responsible consumption, while synergies are associated with goals on poverty reduction and inequalities. This process was repeated for subsets of countries based on their level of income, demonstrating that this alters the structure of the sustainome. The authors also found that the target-level sustainome does not scale up to the goal level, which, as noted elsewhere, is relevant to this thesis, which considers SDG interactions with forests at both of these levels.

Network analysis is a powerful tool for assessing and visualising SDG interactions in a systemic manner, however, as noted by Weitz et al. (2018), being a 'bottom up' process, its findings can only be as reliable as the information that it is based upon. This is especially true for analyses that consider higher-order interactions, as confidence surrounding the strength or likelihood of an interaction is likely to decline with each additional step across the network. This underscores the importance of developing robust techniques to identify individual (i.e. non-systemic) interactions, so that subsequent systemic investigations can be conducted with confidence and provide maximum utility. Because network analysis requires assessment of linkages between all possible pairs of a chosen set of features (e.g. SDG targets), its applicability in the context of this thesis (which focuses on a single outcome – forests) is limited. Nevertheless, in Chapter 5, under section 5.4 (Future work), I make a case for employment of network analysis in this context, and suggest steps for doing so.

1.4. Beyond mapping interactions – what next?

So far, this introduction has described the importance of understanding synergies and trade-offs within the development agenda, and has provided examples of studies aiming to do so. However, from the perspective of those tasked with realising the SDGs (e.g. politicians, development agencies etc.), it is desirable to know which interactions are of greatest relevance to their specific context, including the likelihood that a given interaction will (or will not) occur, and the potential magnitude of any associated impact(s). With such knowledge, responsible parties will be better equipped to adjust their development policies and interventions so as to avoid undesirable trade-offs and to facilitate desirable synergies.

The most commonly encountered group of methods used for such purposes is what I refer to collectively as 'systemic models', including integrated assessment models, system dynamics models, agent-based models, computable general equilibrium models, and input-output models, among others. Fundamentally, each of these methods works by linking multiple features from a whole system (or at least part of it) in a quantitative and dynamic way, so as to reflect how changes in one part of the system will manifest as changes in another, including through both direct and indirect effects. These models can contain elements pertaining to economics and trade, societal progress, populations and demographics, technology, land/resource use, and natural processes, among others (e.g. see Hughes, 2001). Systems modelling techniques can be applied at most scales, from very local to global, though the challenges of scaling models up or down are well acknowledged, and are in large part due to issues of data availability and the inherent variability of between-variable relationships at increasingly large scales (Creutzig et al., 2012; Rounsevell et al., 2012; van Wijk, 2014).

Underpinning any systems model is a conceptual model, which is essentially a flow diagram that links together the various system components via observed or hypothesized relationships, including causal feedback loops. Researchers typically aim to quantify individual relationships present in the conceptual model mathematically before consolidating them all into a single unified model, and this itself is usually an iterative process requiring fine-tuning of the equations linking system components (or revision of the links themselves) following testing and validation based on observed changes (Zhang et al., 2016). Once the final model is developed, researchers can use scenario analysis to explore how different components of the model react following changes in others.

A relatively simple example of systems modelling in the context of the SDGs is the work of Engström et al. (2019), who explored how efforts to achieve SDGs 7 (energy) and 13 (climate change) could affect goals 6 (water) and 15 (life on land) in a specific Swedish municipality. The authors used specialised planning software to assess future options for supplying energy to the municipality, including associated carbon emissions. Using information derived from a literature review on how different energy sources/technologies impact upon land resources, the authors modelled a series of scenarios in which the municipality aimed to achieve zero carbon emissions by 2030, and quantified the predicted direct and indirect water and land impacts associated with each.

Focusing on coastal Bangladesh, Hutton et al. (2018) made use of an established integrated assessment model (the Delta Dynamic Integrated Emulator Model, or ΔDIEM (Lazar et al., 2019)) to assess future interactions between economic growth (goal 8), poverty (goal 1), environmental degradation (goals 14 and 15), inequality (goal 10) and food production (goal 2). Data and functions for the underlying model were gathered from a range of sources, including analyses of demographic and economic trends, census-derived poverty indicators, and household surveys (Nicholls et al., 2016), and the scenarios used in the model were developed through stakeholder consultations. Among other conclusions, the authors reported high potential for trade-offs between economic growth and natural resources.

Arguably the most sophisticated and ambitious systems modelling tool from an SDG perspective, and one that is endorsed by the UN Development Programme (UNDP, 2020), is the International Futures (IFs) integrated model (Hughes, 2001). IFs contains

12 sub-models relating to agriculture, demographics, economics, education, energy, environment, government finance, governance, health, infrastructure, international politics and technology (Figure 1.7), and provides readily available data for 186 countries. There have been a number of efforts to use IFs to explore possible SDG interactions, including that of Moyer and Bohl (2019), who modelled three alternative pathways (characterised by consumption change, decentralised solutions and technological change) to achieving nine targets (spanning six goals), and considered the synergies and trade-offs likely to emerge from each. Among the numerous findings from this work, was the authors' conclusion that achieving maximally in all considered targets will require a combination of aspects from all three scenarios.

Systems modelling, whether in the context of SDG interactions or otherwise, has a number of important limitations. By their very nature, systems models are complex, which not only limits their overall reproducibility (specialised knowledge is usually required to do so), but also their interpretability by end-users such as policymakers and stakeholders (Alcamo and Henrichs, 2008). Reproducibility of systems models may be further limited by data availability, as, by design, they require data pertaining to a range of different topics and sectors, which increases the likelihood that one or more sources may be unavailable for those wishing to apply an established model in a different setting. Lastly, but of no less importance, one must question the overall capability of these models to realistically capture the often subtle dynamics of highly complex systems (Niet et al., 2022; Price and Keppo, 2017; van der Zwaan and Seebregts, 2004). As with network analysis, any missing elements or wrong assumptions about the nature of the linkages between two or more model components will be amplified throughout the model, including in any feedback loops, ultimately producing erroneous outputs (Niet et al., 2022; van der Zwaan and Seebregts, 2004). Scenario models are undoubtedly useful, but, as with network analysis, they require sound understanding of the underlying relationships in order to function well. Once again, this highlights the importance of first applying non-systemic methods before attempting more complex analyses.

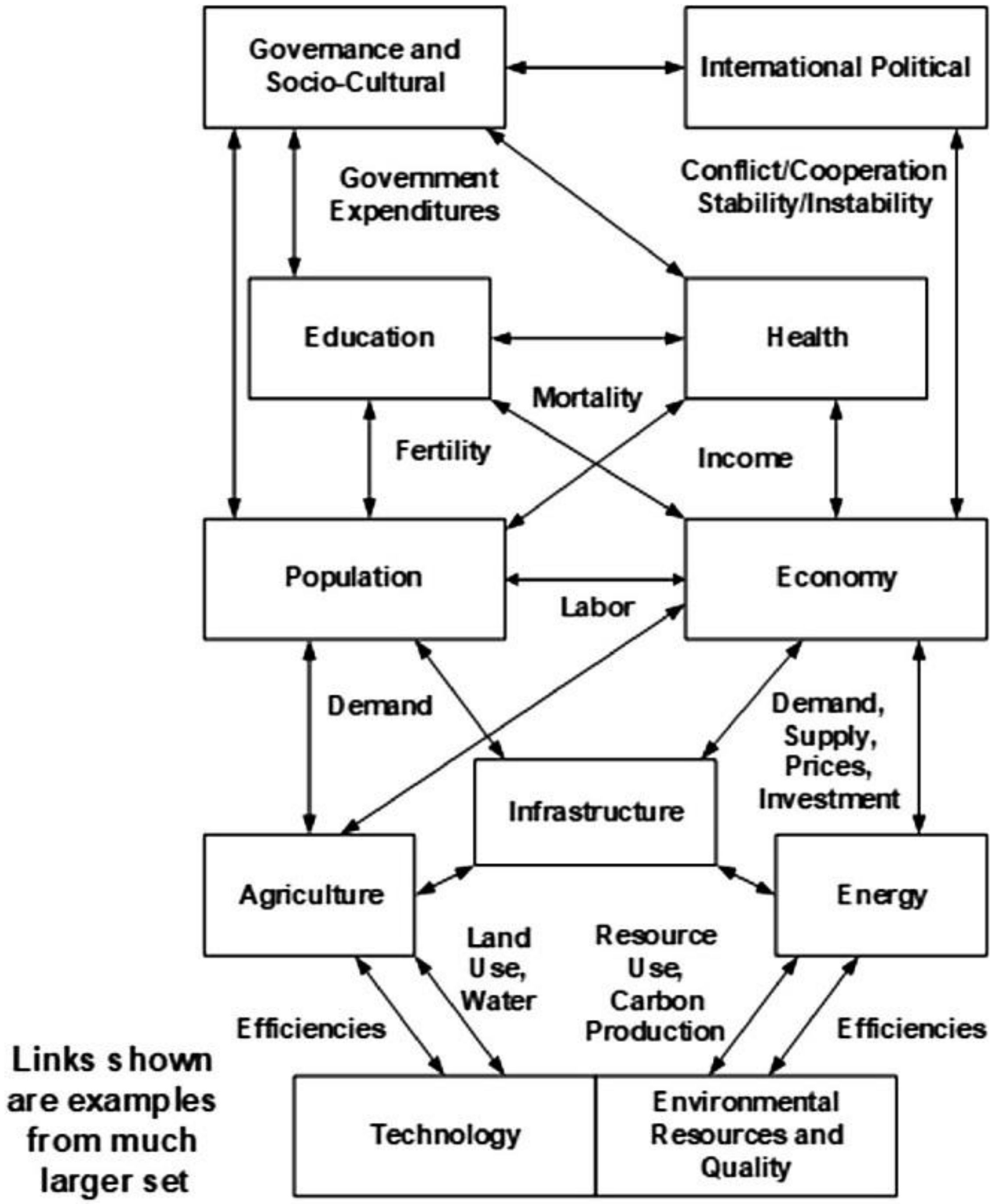

Figure 1.7. Conceptual model showing sub-models and their linkages, as used in the International Futures (IFs) integrated model, a sophisticated modelling tool used to explore possible future SDG interactions by Moyer and Bohl (2019), among others. Source: Moyer and Bohl (2019). Image copyright: Elsevier, used with permission.

1.5. SDG-forest interactions: Research gaps addressed in this thesis

The burgeoning body of literature on SDG interactions has naturally covered matters of the environment since the field of enquiry began, and examples have been provided throughout this introduction. In some cases, work on the topic has been comprehensive (e.g. Scharlemann et al., 2016), providing syntheses of evidence of environment-human interactions that apply across the SDGs. Such work makes it clear that impacts on the environment arising from sustainable development are highly complex, involving both synergies and trade-offs, and may vary according to context, location and a range of other factors (ICSU, 2017; ICSU and ISSC, 2015; Scharlemann et al., 2016). In order to distil such complexity, and to help make it more readily interpretable by stakeholders, policymakers and other relevant parties, it can be helpful to consider specific aspects of the environment individually. To this end, and for reasons explained in section 1.1, the focus of this thesis is forests.

As already alluded to in this chapter, researching how matters of sustainable development can affect forests is not a new line of enquiry, and various studies, many of which pre-date the advent of the SDGs, have considered the topic. Particularly well-covered topics in this area include food production and infrastructure expansion (especially roads), which are commonly associated with damaging impacts (Benhin, 2006; Laurance et al., 2015, 2014), and energy provision and economic growth, which can have mixed impacts depending on the context and other specifics (Crespo Cuaresma et al., 2017; Gibson et al., 2017; Tanner and Johnston, 2017). Despite such a wealth of available information on development and forests, much of this remains poorly consolidated, and there have been fewer efforts to analyse and present this in the specific context of the SDGs. Given the significant importance of the SDGs in shaping the development objectives and trajectories of much of the world (all 193 UN member states), work to help fill this gap is likely to be of great utility in helping to ensure that the topic of forest conservation is adequately and appropriately considered by parties seeking to achieve the SDGs.

This is not to imply that there has been no effort in this area at all, however, and some publications have explicitly considered how achieving the SDGs could affect forests. For example, Swamy et al. (2018) provided a rapid overview and qualitative assessment of the literature on SDG-forest interactions, giving examples of potential synergies and trade-offs in the process. Although informative, the brevity and qualitative nature of this work means that it could not cover the subject from all possible angles. Moreover, although the paper does link impacts to specific targets in some cases, this is non-systematic in nature, meaning that the relative implications for forests of each target, as well as the goals under which they sit, remain unclear, and the authors themselves note the requirement for a more comprehensive and systematic consideration of the topic. The book by Katila et al. (2019) also considers, on a chapter-by-chapter basis, the implications of achieving each SDG on forests and the people they support. Although comprehensive, the book does not systematically consider all targets for each SDG, nor does it provide an overall synthesis of the impacts described to allow a comparison of impacts within and between goals.

To complement and build upon the work of Swamy et al. (2018) and Katila et al. (2019), Chapter 2 of this thesis presents a systematic review that considers, on a target-by-target basis, the observed and anticipated impacts on forests of achieving the SDGs. The intention is that this work should provide a more structured and methodical review of the topic than the works that have preceded it, including by emphasising the variation in potential impacts that exists between and within the individual goals. Additionally, beyond indicating areas where existing knowledge and confidence about target-level impacts is good, which appears to have been the focus of earlier reviews of the topic, this study makes a point of highlighting targets for which possible impacts are less well understood, indicating where further research is required. I see this as an important step towards developing a more holistic picture of how progress towards achieving the SDGs could affect forests, which will ultimately help to promote more fully integrated development planning that considers the consequences for forests from all possible angles.

At the goal level, there appears to have been no efforts to date to quantitatively assess the links between achievement of the SDGs and matters of forest change, yet past work linking high-level metrics of sustainable development to changes in forests provide good reasons to expect that this would be a useful line of enquiry. For example, higher scoring countries on the UN’s Human Development Index (HDI), which combines measures of life expectancy, education and gross national income per capita into a single metric (UNDP Human Development Report Office, 2022), have been shown as more likely to have lower levels of deforestation or net forest gains (Jha and Bawa, 2006; Kauppi et al., 2018). Given this finding, it is relevant to ask whether similar relationships apply when examined through the lens of the SDGs, and if so, to ask which goals are most responsible for this.

In Chapter 3 of this thesis, I address this research gap by conducting a quantitative, exploratory analysis to examine goal-level relationships between the SDGs and changes in forest cover. Looking at 122 countries, I follow De Neve and Sachs (2020) by using country-level SDGI scores (as well as calculated changes in these scores) as predictors of forest change between 2017 and 2020, and use appropriate methods (given high multicollinearity between the goals) to determine the relative importance of each. I also group the SDGs thematically, and compare the relative importance of these themes in shaping changes in forest cover between regions of the world. This work represents the first high-level, quantitative analysis of the relative importance of the SDGs in terms of their influence on forest cover, The intention behind this work is that it should stimulate thinking, dialogue and further research across the major sectors and thematic areas represented within the SDGs, in order to better integrate matters of forest conservation.

Examples of systemic models that have included a component on forests are numerous, including as a means to predict changes in a system component other than forests (e.g. climate or the economy (e.g. Eriksson, 2015; Rogelj et al., 2018)), or where the specific purpose is to predict changes in the forest itself (e.g. see den Herder et al. (2014) for a review). In the case of the latter, which is most relevant to this thesis, a number of reviews, critiques and model comparisons have been published, providing useful insights into the general utility and limitations of these methods for usefully informing forest-relevant policy decisions. While most sources generally agree that these approaches have broad utility, and that their robustness continues to improve with time, they invariably all also describe important limitations, which largely align with those for systems model applications in other contexts.

Acknowledged limitations of systemic models as a tool to inform forest policy and decision-making include an inherent trade-off between model complexity and robustness of the results obtained (Castro et al., 2018). Models with reduced complexity may fail to integrate all relevant sectors (often instead focusing on a specific one, e.g. energy), which will limit robustness (Aggestam and Wolfslehner, 2018). Conversely, with increasing complexity comes reduced interpretability, which has been noted as a common concern among stakeholders wishing to make decisions based on model outputs (Castro and Lechthaler, 2022; den Herder et al., 2014). All forest modelling tools inherently rest on assumptions of one form or another, for example about the ways that humans will behave at a future time (Trubins et al., 2019), and these assumptions, if incorrect, will inevitably lead to errors in the wider model (Aggestam and Wolfslehner, 2018; den Herder et al., 2014). Work comparing models that differ in their assumptions and/or composition has shown that small changes can notably alter the model outputs (Blujdea et al., 2021; Schmitz et al., 2014), which again raises question over the level of faith that should be placed into such models for informing decision-making around important subjects.

Collectively, these viewpoints highlight a need (especially among non-specialist stakeholders) for an easy-to-interpret method of evaluating the potential impacts on forests of anticipated development changes, which rests on as few assumptions as possible. In Chapter 4 of this thesis, I present a novel framework for assessing how the anticipated development trajectory of a given country could interact with matters of forest conservation, and demonstrate its application using data relating to 24 SDG targets across 48 tropical countries. This assessment framework is straightforward to apply and interpret, and uses data that is readily available for most countries, meaning that it can be replicated in a standard manner. Importantly, the method does not rest on assumptions that a change in a given aspect of the development agenda will be guaranteed to result in a specific outcome, but instead highlights areas for which anticipated development could provide risks, opportunities or enabling conditions for the conservation of forests. My hope is that this framework will help overcome some of the shortcomings of systemic approaches to anticipating changes in forests, and will help users to confidently consider how imminent progress towards achieving the SDGs could affect forests, and to act accordingly.

1.6. Summary and Motivation

The ongoing global crisis of deforestation and forest degradation has been acknowledged now for well over half a century, and has motivated a dedicated research community, along with numerous governmental and non-governmental agencies, to seek solutions to the problem. Research on the topic has been successful in identifying the direct and underlying drivers that are resulting in the decline of forests, including at scales ranging from local to international, yet in many cases this knowledge alone has proved insufficient to result in meaningful change.

At the root of this problem is the fact that conserving forests (along with other natural ecosystems) is only one of a great many desirable outcomes that human societies seek to achieve, not all of which are mutually compatible (commonly termed ‘trade-offs’). However, in some cases two desirable outcomes may actively support or facilitate each other (commonly termed ‘synergies’). Identifying desirable outcomes that present trade-offs and synergies with the conservation of forests, and subsequently mitigating against the former while promoting the latter, is now acknowledged as an important part of the process to help better conserve forests while simultaneously improving in a range of other areas.

The advent of the UN’s SDGs provided a framework that explicitly embedded the conservation of natural systems among other development goals and targets. Fundamental to the SDGs is the notion that their constituent goals and targets should be treated as unified whole, taking into account the fact that interactions (synergies and trade-offs) can occur between the SDGs and their targets, which can either help or hinder the mutual achievement of goals/targets in question. While the theory behind these interactions is relatively straightforward, in practice the SDGs provide no guidance on their nature, nor on how to identify them (Bennich et al., 2020). Acknowledgement of this shortcoming soon prompted efforts to identify and map interactions between the SDGs and their targets.

Work seeking to identify interactions has been conducted at multiple levels, ranging from assessments of thematically-grouped sets of goals (e.g. social and environmental goals (Scherer et al., 2018)), through assessments at the goal level (e.g. De Neve and

Sachs, 2020), to assessments at the target/indicator level. Assessments have applied a range of techniques and covered a variety of focal themes (e.g. subjective well-being, energy, sanitation and so on), yet assessments focusing specifically on environmental outcomes (including forests) have been relatively few in number. Concerning forests specifically, past assessments of impacts associated with achievement of the SDGs include Swamy et al. (2018) and Katila et al. (2019), both of whom provide qualitative assessments of the ways in which achievement of the SDGs could potentially affect forests. However, neither of these works attempted to summarise impacts at the target level, nor to assess relationships statistically, and in Chapters 2 and 3 of this thesis I explicitly address these research gaps.

Having identified potential synergies and trade-offs among the SDGs and their targets, a logical next step is to assess where and to what extent these are likely to manifest, which can allow governments and planning agencies to act accordingly. To date, most work of this nature has involved the use of complex systemic models, which, although informative, have drawbacks that limit their ability to effectively inform policy. In Chapter 4 of this thesis, I present a conceptual framework that provides a simple metric designed to convey the potential risks, opportunities and enabling conditions that could affect forests as a result of a country’s anticipated development trajectory, and demonstrate its application using data for 48 tropical countries.

This thesis is motivated by an urgent need to assess, synthesize and better communicate the nature of interactions between the SDGs and matters of forest conservation, in order to facilitate the successful achievement of both. The work presented in the following chapters builds upon an extensive body of research on the topics of sustainable development and forest conservation, but provides novelty by investigating the nexus of both topics through the application of appropriate methods and techniques never before used in this context. It is my aspiration that this body of work will stimulate discussion, further research and, ultimately, action to ensure that both the environmental and non-environmental aspects of the development agenda are achieved efficiently and harmoniously.

1.7. Aims and Objectives

The aim of this research is to provide a comprehensive assessment of the roles that the SDGs and their constituent targets play in shaping the dynamics of deforestation and forest degradation, including an assessment of where these interactions could be most impactful across the tropics. To achieve this, Chapters 1, 2 and 3 of this thesis each investigate one overarching research question (1 to 3 below) through the achievement of associated objectives (a to i below), as follows:

1. Which non-environmental SDG targets are associated with impacts on forests, whether damaging, beneficial, or both, and how do these vary between and within the individual Goals?

    a. Systematically review the scientific literature to collate published evidence of impacts on forests arising from achievement of (or progress towards) individual SDG targets not directly related to matters of the environment.

    b. Synthesize the information collected through the above process to assess (i) the nature (i.e. damaging, beneficial or mixed) and (ii) levels of confidence associated with each impact identified.

    c. Compare and contrast the findings from the above two steps between each of the SDGs.

2. How does achievement of the SDGs relate to changes in forest cover globally, and which goals are most important in shaping this relationship?

    d. Regress national-level measures of forest cover change against measures of (i) levels of achievement in all SDGs, and (ii) recent progress towards achieving all SDGs, to assess the relationships, including the significance of the interaction between both predictors.

    e. Apply novel techniques to determine the relative contributions of each individual SDG in shaping the relationships identified in objective d.

f. Group the SDGs thematically and use the same methods applied in objective e to assess whether the relative importance of each group (i.e. theme) in shaping changes in forest cover varies between major regions of the world.

3. Based on findings from research question 1 (objectives a to c) above, which SDG targets might we expect to result in risks, opportunities or enabling conditions for the conservation of tropical forests in the short- to medium term?

   g. Collate evidence on national-level drivers of deforestation and forest degradation for selected tropical countries, and use these data to identify the SDG targets that are most relevant to ongoing or emerging threats to forests.

   h. For those SDG targets identified through objective g, use appropriate indicator data and other resources to assess (i) the potential magnitude of any impacts on forests that may arise through progress towards their achievement, and (ii) the likelihood that progress will occur.

   i. Use findings from objectives g and h to compare (between countries and regions) the relative risks, opportunities and enabling conditions for forests that are likely to emerge as a result of progress towards the SDGs.

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Chapter 2 Anticipated impacts of achieving SDG targets on forests - a review

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Abstract

Successful sustainable development will require knowledge of trade-offs and synergies between environmental and non-environmental goals and targets. Understanding the ways in which positive progress in matters of development not directly concerned with the environment can affect the natural environment, whether for better or for worse, can allow policymakers and development agencies to avoid the negative impacts of their actions, while capitalising on mutually beneficial opportunities. Through a systematic review of the literature, we consider the impacts of UN Sustainable Development Goal (SDG) targets on forest ecosystems, and identify 63 targets associated with potentially beneficial, damaging or mixed (i.e. damaging and/or beneficial depending on context or location) impacts. Types of impact are not uniform within SDGs, nor necessarily within individual targets. Targets relating to energy and infrastructure are among the most damaging and best studied, while targets expected to potentially result in beneficial outcomes, typically associated with social progress and well-being, have been investigated to a much lesser degree, especially in the context of external interventions. Thirty-eight targets have some variation in the direction of their impacts (i.e. at least one record with mixed impacts, or two or more records with different directions), suggesting the potential to achieve beneficial over damaging impacts in many cases. We provide illustrative examples of a range of impacts and use our findings to provide recommendations for researchers, development agencies and policymakers.

2.1. Introduction

Achieving universal well-being and prosperity whilst conserving the natural environment is the central tenet of sustainable development. To best achieve this, policymakers and development agencies must understand how certain aspects of development present trade-offs that can undermine efforts to conserve biodiversity and ecosystem services, while conversely, other aspects can result in synergies that benefit the environment or facilitate its conservation. The 17 United Nation’s (UN) Sustainable Development Goals (SDGs) (Figure 2.1) and their 169 constituent targets, which comprise a detailed, sector-specific breakdown of the current development agenda, provide a policy-relevant framework through which to explore such complexities. Indeed, shortly after publication of the SDGs, Nilsson et al. (2016) called for researchers and practitioners to identify and quantify the relationships between SDGs, recognising this as an important first step towards maximizing positive interactions and minimizing negative ones. A number of research efforts have since responded to this call, including Pradhan et al. (2017), who assessed synergies and trade-offs between SDGs at the level of goal, and Scherer et al. (2018), who analysed interactions between selected social and environmental goals. In the following review, we aim to contribute to this growing field of research by assessing the impacts of meeting non-environmental SDG targets on forest ecosystems. This work responds to research question 1 of this thesis, which asks "which non-environmental SDG targets are associated with impacts on forests, whether damaging, beneficial, or both, and how do these vary between and within the individual Goals?".

Forests are of particular interest in this regard, as they support a significant proportion of global terrestrial biodiversity and provide important climatic and hydrological regulating services. Globally, around 1.6 billion people live in close proximity to forests (Newton et al., 2020), and hundreds of millions of these depend on forest products, in the form of fuel, food and timber, to help meet their needs (FAO, 2018). Although the roles that forests can play in helping to achieve non-environmental targets are relatively well understood (FAO, 2018; Scharlemann et al., 2016), this is often less so for interactions occurring in the opposite direction. Katila et al. (2019) describe impacts of the SDGs on both forests and people and how these impacts may, in turn, enhance or undermine the contributions of forests to climate and development, but a systematic review of the literature on SDG targets is missing.

To address this, our approach focused on two main questions: (i) is there published literature that suggests or demonstrates that achieving a given target can have implications for forests?; and (ii) what is the strength of this evidence? We use our findings to characterize identified impacts, making comparisons both between and within individual goals and targets. We consider a subset of our data that focuses on external development interventions (i.e. governments, development agencies or NGOs seeking to achieve one or more SDG targets), which represent intentional (and therefore indicative) efforts to achieve development objectives. We also describe impacts on forests that arise via interactions between two or more targets, providing illustrative examples of these and discussing their importance in future research efforts. Finally, we summarise the key implications of our findings.

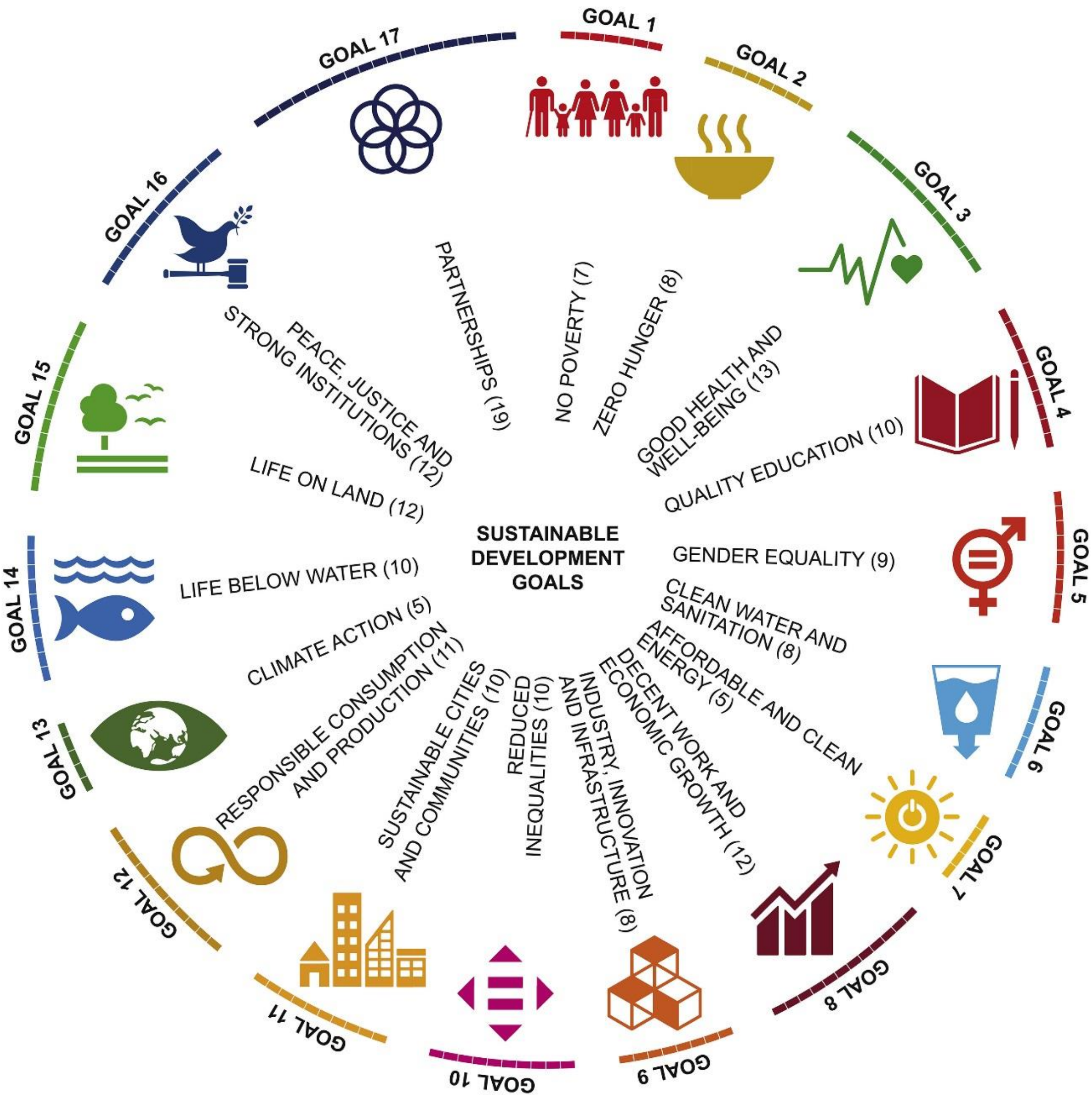

Figure 2.1. The 17 UN Sustainable Development Goals (SDGs). Numbers following goal names indicate numbers of targets for each.

2.2. Methods: Identifying the impacts of SDG targets on forests

We conducted a systematic search of three literature databases (Web of Science, CAB Abstracts and Google Scholar) to identify peer-reviewed and grey literature relevant to our questions (details of our search protocol and other methods are provided in the Appendix A). Searches were based on 489 key words and phrases taken from the SDG targets and indicators developed by the Inter-Agency and Expert Group in Sustainable Development Goal Indicators (2016). Searches did not include terms from SDGs considered environmental (Goals 12, 13, 14 and 15) (Bengtsson et al., 2018; Waage et al., 2015), nor from targets from the remaining goals that have an environmental focus (Figure 2.2a). We also did not include terms from Goal 17, which is considered 'cross-cutting' in nature (i.e. containing elements pertaining to all other goals (Waage et al., 2015)). Consequently, our investigation focused on a total of 104 of the 169 SDG targets.

We focused on natural forests only, and did not include any work focusing on forest plantations, agroforestry plots or altered habitats. We otherwise used a broad definition of forest, which extends to include woodlands and mangroves. While we endeavoured to follow the established definition of a forest developed and used by the Food and Agriculture Organization of the United Nations (i.e. a tree canopy cover of >10%, an area >0.5 ha and a minimum height of ≥5 m, but noting that their definition includes plantations (MacDicken, 2013)), in practice few papers give such specific details, and so a certain degree of subjectivity was required. Nevertheless, literature for which the term forest was ambiguous and did not suggest that the habitat under investigation was both natural and an appropriate structure were excluded. The definition of impacts on forests (hereafter 'impacts') was left intentionally broad, so as to capture a wide range of interactions. Types of impact included any changes in forest size, structure or composition (including changes in non-plant taxa), including changes in the rate of change of any of the above, as well as changes in policy, protection status or human behaviours with implications for forests. Based on the above, the 'direction' of each impact recorded was classified as either 'damaging', 'beneficial' or 'mixed' (i.e. damaging and/or beneficial depending on context or location).

Impacts were also scored according to their associated confidence as follows: Impacts based on speculative theories or notable assumptions (e.g. that an acknowledged driver of forest loss would result in forest gains if reversed), as well as changes in policy or human behaviour that were expected (but had not been demonstrated) to affect forests, were considered *low confidence*; impacts based on first-hand evidence, but with notable confounding factors, and impacts based on qualitative reports or proxy measures of forest change (e.g. quantity of fuelwood extracted) were considered *fair confidence*; and impacts based on direct observation of forest change arising from progress made towards a given target were considered *high confidence*.

For comparative and graphical purposes, each impact was assigned a score based on its confidence rating, with low, fair and high confidence impacts scoring 0.01, 0.1 or 1, respectively. For each target, confidence scores for each of beneficial, mixed or damaging impacts were summed, and the direction of those impact(s) with the highest level of confidence (within at least one order of magnitude) used as the final impact category. In cases where the best evidence comprised two or more impacts with different directions and the same level of confidence, the category of 'mixed' was given.

While conducting our searches we earmarked papers that made reference to impacts associated with external interventions, allowing these records to be analysed as a standalone subset and compared with the full dataset. We also kept notes of any impacts encountered that involved interactions between two or more SDG targets, although this last component cannot be considered exhaustive.

2.3. Results and discussion

From a total of 466 sources, we collected 963 records of impacts spanning 63 SDG targets. Summarising these findings at the target level, we identified 29, 15 and 19 targets with potentially beneficial, damaging and mixed impacts, respectively, of which 36 have a high level of associated confidence and 27 a low level (Figure 2.2). No impacts were identified for 41 targets, and although these receive little attention in the remainder of this article, we do not dismiss the possibility that some forest impacts may exist, despite these not being evident in the literature encountered in our searches.

The following sections present and discuss different aspects of our findings, including how the predominant directions of target-level impacts vary between individual SDGs (section 3.1), how impacts can vary in direction at the individual target level (section 3.2), the knowledge biases observed between certain targets and goals (section 3.3), and, finally, a summary of our findings relating to the impacts of external development interventions (section 3.4). We illustrate our findings using examples spanning a range of goals and targets, but nevertheless direct readers to Table A.1 (Appendix A), which provides a breakdown of findings for all targets.

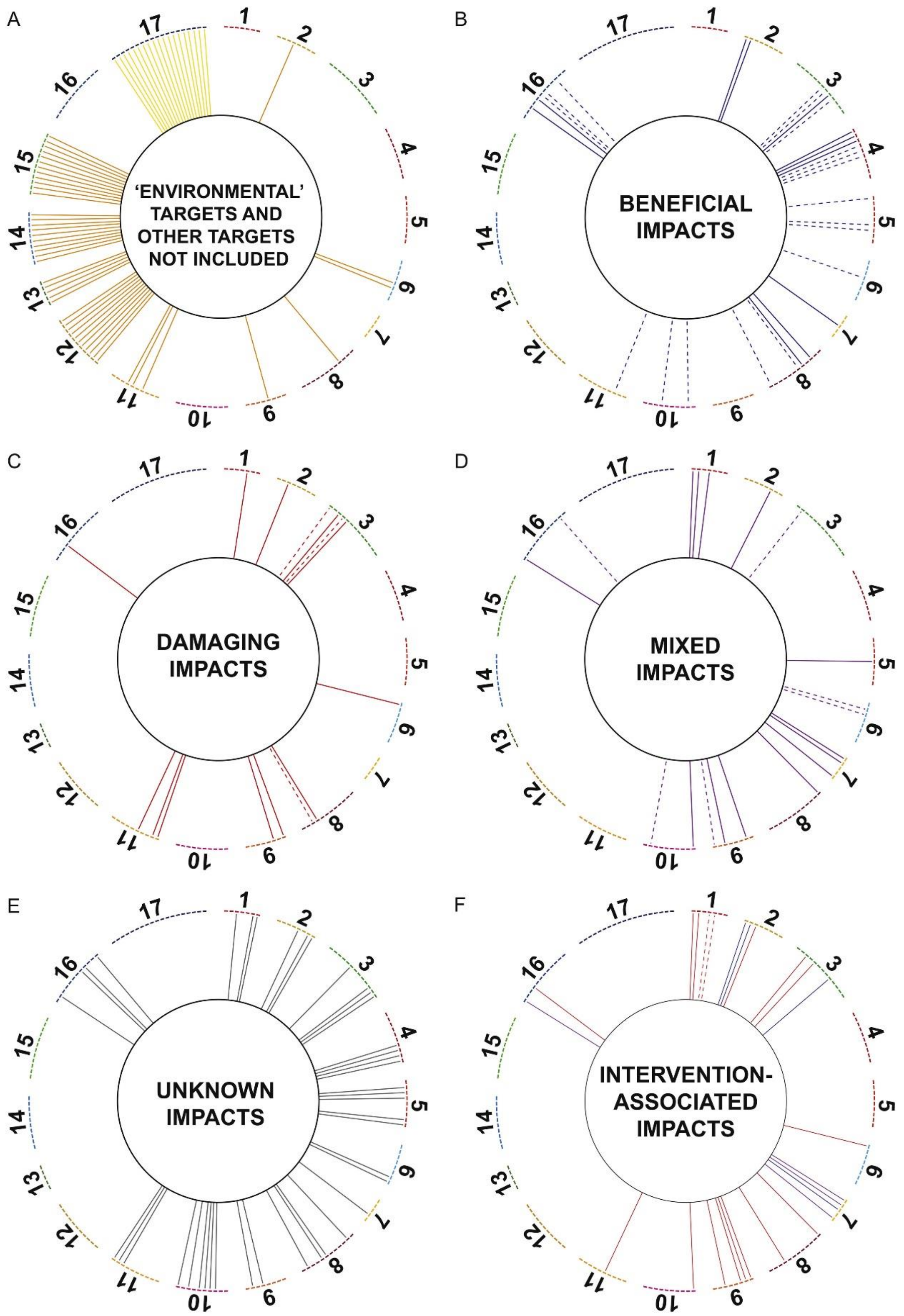

Figure 2.2. Forest impacts associated with each of the 169 SDG targets. In Figure 2.2A, orange lines are 'environmental targets' and yellow lines are 'cross-cutting'. Solid and dashed lines indicate impacts with and without a confidence score of greater than or equal to one, respectively. Figure 2.2F shows intervention-associated impacts only, using the same colour schemes for beneficial, damaging and mixed impacts as in other diagrams. Targets are ordered clockwise within each SDG.

2.3.1. Variation in impacts within and between SDGs

Almost all of the SDGs considered .contain a mixture of impacts of different types among their targets, though the predominant direction of these varies between goals. While some goals have predominantly beneficial potential impacts (e.g. SDGs 4 (quality education), 5 (gender equality) and 16 (Peace, justice and strong institutions)), some have mostly damaging and/or mixed potential impacts (e.g. 9 (industry and infrastructure) and 11 (sustainable cities and communities)), and the remainder have varying combinations of the three categories.

Six of SDG 4's ten targets were identified as having impacts, and all were evaluated as beneficial. Empirical observations (Godoy et al., 1998; Godoy and Contreras, 2001) suggest that improving access to all levels of education, including from pre-primary to university (targets 4.1, 4.2 and 4.3, all high confidence) can result in a reduced tendency to clear forests. Mechanisms by which this occurs are not always clear, but are often related to one or more of the following associated outcomes: a higher proportion of people working in the service sector; an increased tendency to migrate from rural to urban areas; increased knowledge of new farming techniques/technologies resulting in agricultural intensification over expansion into new areas (although we acknowledge that agricultural intensification does not always result in land sparing (e.g. see Gutiérrez-Vélez et al., 2011)); or in an increased awareness of the 'Western' environmental movement (Burns et al., 1994; Ehrhardt-Martinez, 1998; Godoy et al., 1998; Godoy and Contreras, 2001). Targets relating to technical and vocational skills for employment (4.4), gender disparities in education (4.5) and literacy and numeracy (4.6) are also all suggested as having potentially beneficial impacts on forests (Arnold et al., 2011; Getahun et al., 2017; Singh et al., 2017), although the available evidence for these is less robust, and each was assessed with low confidence. Across this goal more broadly, the links with targets 8.3 (beneficial, high confidence), 8.5 (beneficial, high confidence) and 8.b (beneficial, low confidence), which are all concerned with increasing [off-farm] employment, are thought to have important implications for reducing encroachment into forests (Angelsen and Kaimowitz, 2001; Parés-Ramos et al., 2008; Schmook and Radel, 2008).

Four of SDG 5’s nine targets were identified as having impacts on forests. Of these, three were assessed as potentially beneficial (targets 5.1 (end all forms of gender discrimination), 5.6 (increase access to sexual and reproductive health and reproductive rights) and 5.a (equal female rights to economic, financial and natural resources, and land/property ownership)), although none were supported by robust evidence (all beneficial, low confidence), and only 5.6 was supported by more than a single source. Records for target 5.6 were identical to those for the overlapping target 3.7 (ensure access to sexual and reproductive health-care services and family planning), and the overarching suggestion of these records is that increasing [female] access to family planning and reproductive health services can help address issues of rapid population growth, and hence the demand for land and other natural resources (Bryant et al., 2009; Starbird et al., 2016; Wan et al., 2011). We note here, however, that the links between human population growth and environmental quality remain unclear, and much contested. Target 5.5 (female participation in leadership and decision-making) was evaluated as mixed overall (high confidence), supported by four empirical observations of beneficial outcomes and one with mixed outcomes. It is worth noting that all evidence found for this target was specific to participation in decision-making bodies related to forests, and hence provides a somewhat biased insight into how achieving this target in a wider, more holistic sense would affect forests, if at all.

Impacts relating to SDG 16 (peace, justice and strong institutions) were identified for eight targets, including five beneficial, two mixed and one damaging. When considering these impacts, it is important to keep in mind that the political economies and legal/regulatory frameworks of the countries in question, including whether these tend to favour large or small scale actors, can be of critical influence on the resulting outcomes; a point which holds true for many targets under other goals. Records for targets 16.3 (promote the rule of law) and 16.5 (reduce corruption), which were the most numerous within SDG 16, suggest near-unanimously that progress towards achieving these targets is potentially highly beneficial for successful forest conservation (Assa, 2018; Ifrani and Nurhayati, 2017; Koyuncu and Yilmaz, 2009; Tegegne et al., 2016). Although much of this literature on these topics is of a theoretical nature only, a few empirical records meant both were assessed with high confidence. Targets 16.1 (reduce violence) and the related 16.a (strengthen institutions to combat violence, combat terrorism and crime) both have mixed impacts (high and low confidence, respectively). The implications for forests of ending civil or international armed conflicts can be highly complex, requiring consideration of a multitude of factors. For example, while ending a conflict may alleviate forest pressures relating to displaced peoples (Ordway, 2015), armed groups residing in forests (Nackoney et al., 2014), exploitation of resources to supply funds to armed groups (Johnston, 2004) and/or the breakdown of the rule of law, it may concurrently allow for other damaging activities to begin or resume, including agricultural expansion (Murillo-Sandoval et al., 2020) or increased exploitation of forest resources from formerly hostile environments (Ordway, 2015). Target 16.4 (reduce organized crime) was assessed as having potentially damaging impacts (high confidence), with all empirical records pertaining to efforts to combat coca-associated crime in Colombia (which overlaps with target 3.5 (damaging, high confidence) on preventing narcotics abuse). Despite having some forest benefits, coca crop eradication has been shown to result in cultivators simply moving their damaging activities elsewhere or switching to agricultural practices that are more damaging themselves (Bradley and Millington, 2008; Rincón-Ruiz et al., 2016). The remaining three SDG 16 targets with identified impacts were all assessed as beneficial and with low confidence. Targets 16.6 (effective, accountable and transparent institutions), 16.7 (inclusive, participatory and representative decision-making) and 16.10 (public access to information) (all beneficial, low confidence) are all thought to have mediating effects on other targets, particularly those relating to law enforcement and corruption (Ceddia et al., 2014; Jorgenson and Burns, 2007; Suwarno et al., 2015).

SDGs 9 and 11 have five and four targets, respectively, with identified impacts, with two and three targets respectively assessed as damaging. In most cases damaging impacts were associated with hard infrastructure (including roads, railways, dams, housing and industrial areas (Doyle and Havlick, 2009)). Regarding roads, there is good evidence to suggest that roads designed to boost access to markets (target 9.3: high confidence) are especially damaging (Perz et al., 2008). Despite this, occasional records suggest potentially mixed or even beneficial impacts of roads (Kaczan, 2020), but such evidence is relatively weak. Possible exceptions to this include the process of industrialisation (target 9.2: mixed, high confidence), which, although often associated with damaging impacts due to infrastructure, industrial pollution and influxes of workers (De Castro et al., 2017), can result in agricultural abandonment leading to forest expansion (Parés-Ramos et al., 2008). The presence of communication networks and infrastructure (linked to target 9.c: mixed, low confidence) has been shown to correlate positively with forest declines (Lim et al., 2017; Wheeler et al., 2013), though the mechanisms are not well understood and the source materials do not provide information on the specific types of infrastructure. Moreover, there are arguments to suggest that better access to communication technologies can help develop and enforce rules around forest use (Poteete and Welch, 2004). Although some of the impacts mentioned here seem almost unavoidable, it is often suggested that a more inclusive and participatory approach to planning (target 11.3 and the overlapping 16.7, both beneficial, low confidence) shows promise as a way to help minimize the damage (Suwarno et al., 2015; Valencia-Sandoval et al., 2010). However, few robust empirical observations to support this suggestion were encountered in this review, and one study (Feintrenie and Levang, 2011) suggests that in some cases local communities may favour development over forest conservation.

Four of SDG 2's (end hunger and increase food security) eight targets were identified as having forest impacts. Targets 2.1 (end hunger) and 2.2 (end malnutrition) had largely overlapping records, and were both evaluated as beneficial (high confidence). Despite some (non-empirical) suggestions (often pertaining to agricultural expansion) of potentially damaging or mixed impacts from these targets, final evaluations were based on a single empirical record of a food aid program in Ethiopia which demonstrably reduced the need for agricultural expansion (Belay et al., 2015). Target 2.3 (double agricultural productivity and food producer incomes) was assessed as damaging (high confidence). While noting that there are arguments suggesting that agricultural intensification can in some cases reduce encroachment into forests (Pope et al., 2016; Shively and Pagiola, 2004), records largely reported damaging impacts associated with agricultural expansion and irrigation schemes (Bélanger and Grenier, 2002; Franks et al., 2017). Target 2.a (investment into agriculture) was evaluated as mixed (high confidence). Records for this target all relate to agricultural technologies, a topic comprehensively reviewed by Angelsen and Kaimowitz (2001), who conclude that although damaging impacts are more common than beneficial ones (especially in the context of export crops), positive forest outcomes can occur, for example, when technological changes occur away from forested locations and attract workers that would otherwise engage in forest-damaging activities.

2.3.2. Differential impacts within targets

To compare the variation of directions within the evidence collated for each target, damaging impact scores were converted to their equivalent negative values (i.e. -0.01, -0.1 or -1) and mixed impact scores divided by two, and one resulting half converted to its negative equivalent (e.g. a mixed record with high associated confidence would result in two values: 0.5 and -0.5). This process allows the summed values of for each category (damaging, beneficial, mixed positive and mixed negative) to be more easily represented visually, as in Figure 2.3. Figure 2.3 shows that 38 targets have some variation in the direction of their impacts (i.e. at least one mixed record, or two or more records with different directions). This occurs for one of three main reasons, as follows.

Firstly, achievement of a particular target may have genuinely mixed impacts depending on context and other factors. Improving ownership and control over land (a component of target 1.4: mixed, high confidence), for example, may lead landowners to either exploit or conserve their forest resources, depending on, inter alia, exposure to market forces and immigration, local governance conditions, and starting forest condition (Graziano Ceddia et al., 2015; Hayes, 2007; Katila et al., 2020; Larson and Dahal, 2012; Naughton-Treves and Wendland, 2014; Travers et al., 2015). Similarly, forest impacts relating to economic growth, as measured by GDP per capita (target 8.1: mixed, high confidence), can be mediated by a range of factors to potentially result in beneficial or damaging impacts. Among others, mediating factors are thought to include: the relative stage of economic development (Crespo Cuaresma et al., 2017) (although this remains a topic of much debate (Choumert et al., 2013)), the nature of the economy (closed vs. widely trading) (Foster and Rosenzweig, 2003), and levels of income inequality (Koop and Tole, 2001).

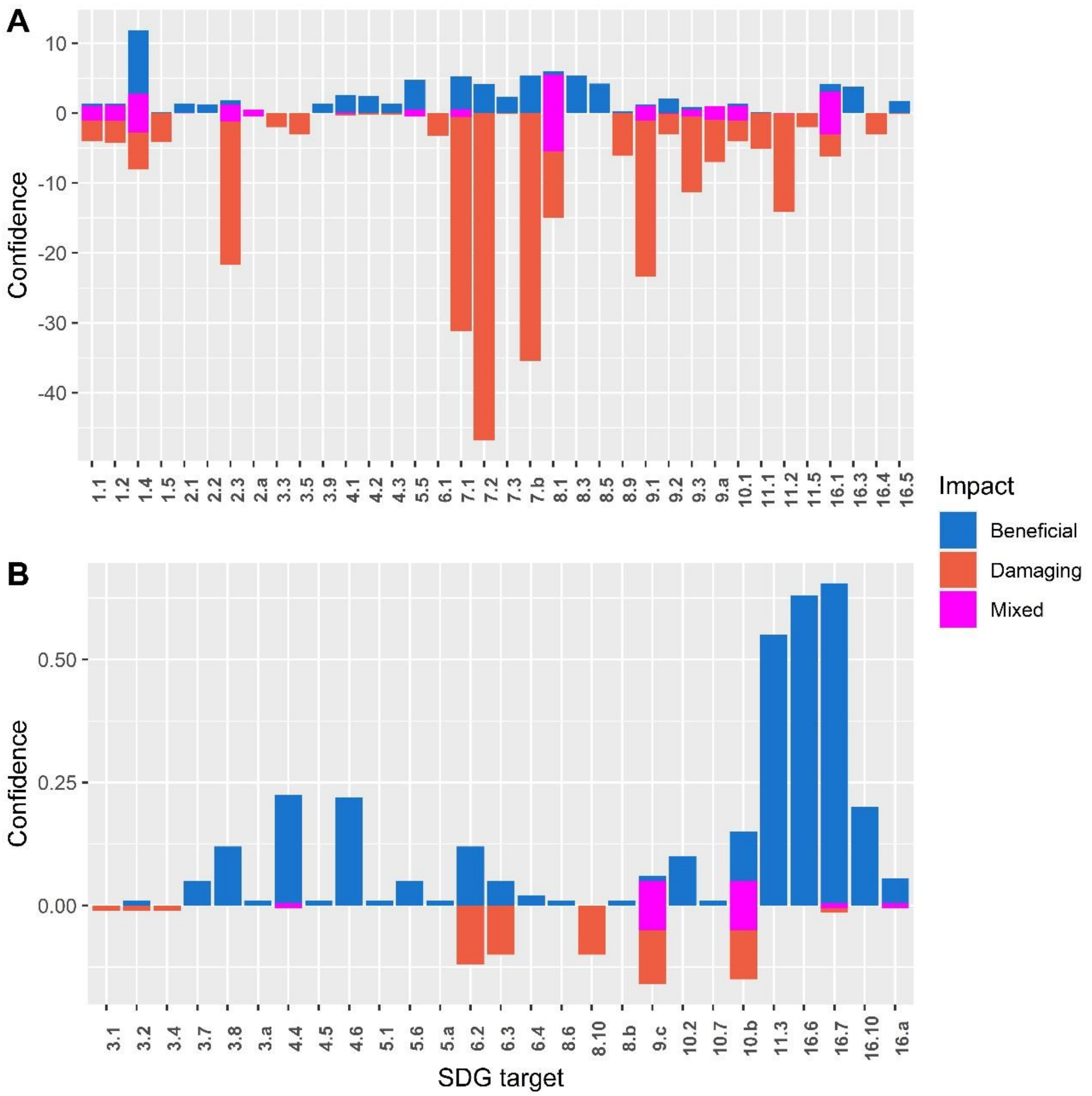

Figure 2.3. SDG targets with identified impacts with high (above) and low (below) associated overall confidence. Bars show cumulative scores for all records found based on the confidence of each. Scores for mixed impacts contribute equally to positive and negative values.

Second, a target's impact may vary in direction if there are different options available as to how it might be addressed. We note, for example, that records collected for targets 7.1 (access to affordable, reliable and modern energy), 7.2 (renewable energies) and 7.b (energy infrastructure and technology) (all mixed, high confidence) encompass topics ranging from the deployment of large-scale energy generation plants (predominantly hydroelectric schemes (Jolli, 2012; Urruth et al., 2017), and to a lesser extent other renewable energies such as solar, wind (Gibson et al., 2017) and geothermal (Shortall et al., 2015)), which are typically damaging (Gibson et al., 2017), to papers looking at clean fuel options, including household-level initiatives relating to biogas or improved cookstoves (incidentally, the topic with most records for target 7.3 on energy efficiency (beneficial, high confidence)), which are acknowledged as having the potential to reduce the exploitation of forests for fuel (Agarwala et al., 2017; Dresen et al., 2014; Meeks et al., 2019). Though the example above implies that decision-makers working on such targets can simply choose the most environmentally sound option available, we acknowledge that, in practice, contextual and practical factors will limit some options.

Lastly, targets whose specifics are highly varied, or are perhaps ambiguous, may show mixed impacts depending on specific interpretations. Target 1.5 (reduce exposure and vulnerability to shocks) (damaging, high confidence) covers economic, social and environmental matters, and, depending on which of these one considers, impacts can vary. In this review we found mixed impacts associated with reducing economic shocks (Chibwana et al., 2013; Klepeis and Vance, 2003), but damaging impacts relating to the use of hard infrastructure to reduce exposure to extreme weather events such as flooding (Doyle and Havlick, 2009; Irving et al., 2018). Similarly, target 1.2 calls for the reduction of poverty according to 'national definitions', and provides little guidance beyond this. Our assessment of this target, therefore, being unable to explore all national definitions, included factors spanning wealth (Alix-Garcia et al., 2013) and household assets (Illukpitiya and Yanagida, 2008), among others, which in part explains the mixed (high confidence) impacts identified.

2.3.3. Knowledge-bias among target-level impacts

In terms of research effort, we note that more than 50% of all records (486 of 963) were associated with just eight targets (all detailed elsewhere in this article): 7.2 (increased renewable energy, 83 records); 7.1 (modern and clean energy, 71 records); 1.4 (access to basic services, 70 records); 2.3 (double agricultural productivity, 58 records); 16.5 (reduce corruption, 48 records); 8.1 (per capita economic growth, 46 records); 9.1 (develop infrastructure, 44 records); and 16.3 (promote the rule of law, 41 records). Conversely, 26 targets contained five records or less, and a particularly striking observation is that 16 of these were assessed as beneficial overall (albeit mostly with low confidence). As described in the following paragraphs, areas that seem particularly poorly researched include matters of health (SDG 3), between- and within-country equality (SDG 10), and water and sanitation (SDG 6). Matters of gender equality (SDG 5), and aspects of education (SDG 4), both discussed earlier in the article, also appear to be relatively poorly researched.

Matters of health provide an interesting case, as the links with forests are not necessarily obvious, yet, despite relatively few overall records, there is indication of a mixed range of impacts. Potentially damaging impacts of improving human health mostly relate to the idea that reduced mortality leads to population increases, and hence greater demand for land and natural resources (de Jong et al., 2010), but we note that this is not well substantiated, and that other findings have shown a negative correlation between child mortality and deforestation (Redo et al., 2012). Nevertheless, this underscores the importance of family planning (targets 3.7 and 5.6) in helping to mitigate population-related impacts (Bryant et al., 2009; Starbird et al., 2016; Wan et al., 2011). We also found damaging impacts arising from vegetation removal used to control tsetse flies (Nash, 1948) and onchocerciasis (Baldry et al., 1995), although such impacts are unlikely to be commonplace. Beneficial impacts associated with health targets relate to environmental benefits of improved cookstoves (as a means to improve household air quality; target 3.9: beneficial, high confidence) (Agarwala et al., 2017; Bensch and Peters, 2013; Dresen et al., 2014); the beneficial land-use implications associated with reduced tobacco cultivation (Jew et al., 2017) (target 3.a: beneficial, low confidence); and the (uncorroborated) suggestion that providing rural communities with access to healthcare (target 3.8: beneficial, low confidence) can improve people's perceptions of conservation activities, where the two are integrated (Chapman et al., 2015).

Records associated with SDG 10 (reduced inequality), all but one of which have low confidence, include the suggestion that reducing both economic inequalities (Andersson and Agrawal, 2011; Koop and Tole, 2001) (target 10.1: mixed, high confidence) and social inequalities (target 10.2: beneficial, low confidence) (in particular, inequalities between ethnic groups (Matin et al., 2014)) are important factors in minimizing negative effects on forests (Matin et al., 2014). We acknowledge, however, that Andersson and Agrawal (2006) tested the relationship between wealth inequality and three forest condition variables at the between-country level and found no relationships.

Urban to rural migration, including that concerning refugees or migrants locating in rural areas has been implicated in deforestation, suggesting that better planned migration (target 10.7) will result in less impacts on forests (Hugo, 2008), though this assumption does not appear to have been well tested (low confidence). We acknowledge, however, that in some cases deforestation was a problem before refugees arrived, and other writers point to positive impacts of refugees in, for example, reforestation schemes.

We also note that financial development assistance (including foreign direct investment, FDI) (target 10.b) is thought to have potentially mixed impacts on forests (low confidence), which are mediated by governance factors such as corruption (Assa, 2018). FDI can potentially be damaging when used for primary industries, but may facilitate forest transitions (i.e. a change from net forest loss to net gain) when not (Li et al., 2017).

Concerning SDG 6, impacts associated with water infrastructure (e.g. dams, treatment plants, pipelines) can be damaging (Benfield et al., 2005; Doyle and Havlick, 2009; Perry and Praskievicz, 2017), but can often be avoided with appropriate planning (Maughn and Harris, 2009). Other impacts within this goal include suggestions that reducing open defecation (target 6.2: mixed, low confidence) and the release of hazardous chemicals and materials (target 6.3: mixed, low confidence) will reduce forest-damaging pollution (to which mangroves are particularly vulnerable) (Rakotomavo et al., 2018; Yim and Tam, 1999), and that improvements in water-use efficiency (target 6.4: beneficial, low confidence) will help ameliorate impacts to hydrological systems (which can affect forests) that result from over-extraction of water (Pittock and Lankford, 2010).

2.3.4. Impacts of development interventions on forests

As noted earlier, the intentionality of external development interventions means that they can provide ‘real-world’ case studies from which to assess the impacts of achieving specific development targets. Our review identified 55 sources that specifically considered the impacts of development interventions (which could be readily linked to

SDG targets) on forests. Intervention types were predominantly large-scale initiatives (i.e. with intended beneficiaries at the regional level or above), including two international projects (the Onchocerciasis Control Programme in West Africa (covering parts of Burkina Faso, Cote d'Ivoire and Mali) and the paving/completion of the Inter-Oceanic High- way in Peru and Brazil (two papers). Almost half of the sources (27 of 55) looked at energy/fuel projects, which ranged from large hydroelectric projects (17 papers, mostly projects led by national governments and/or the private sector) through projects to install biogas plants and disseminate cookstoves, as well as more policy-focused initiatives, such as the Indonesian Presidential Decree to establish the National Energy Policy. Other types of initiatives recorded included coca eradication schemes in Colombia and Bolivia (involving national and US governments); efforts to end civil conflicts (e.g. in Angola, Colombia and Mozambique, among others); provision of credit to small farmers (e.g. the En Nahud Cooperative Credit Project in Sudan); the Oportunidades Program, which aims to increase school attendance and health care among poor families in Mexico; the formalization of land rights in Brazil and China; agricultural development programs in Brazil and the Philippines; and the provision of food aid in Ethiopia.

From the 55 sources, we extracted 142 impacts relating to 25 SDG targets (as well as nine cases where impacts were deemed negligible, and four cases where findings were inconclusive). Impact directions were recalculated for targets based on this subset (Figure 2.2f), and seven targets (1.1, 1.2, 1.3, 8.1, 9.2, 9.a and 10.1) differed from the full dataset in this regard, all changing from mixed to damaging when considered in the specific context of interventions.

Possible reasons for this difference include that either (a) in the context of interventions, researchers have tended to focus on negative outcomes, possibly because their aim is to highlight damaging forest impacts with a view to reducing these in future, or (b) that impacts are simply more damaging when associated with an intervention than when changes occur autonomously. Explanation (a) is supported to some degree by the observation that only four (16%) of the 25 targets investigated in the context of interventions were evaluated as potentially beneficial in the full dataset (compared with a possible 29 (or 46%) of the 63 available for consideration). This suggests a research bias towards damaging interventions, implying that many (currently theoretical) positive impacts, and lessons that might be learned from these, are being overlooked.

This subset, similar to the full dataset, showed signs of bias towards only a few targets, with 88 (62%) of the 142 records covering just four (16%) of the 25 targets (7.1, 7.2, 7.b and 2.3). Targets 16.1 and 9.3 also received moderate amounts of attention with seven and five records each. We compared information compiled by AidData (Sethi et al., 2017) on Official Development Assistance (ODA) Commitments to the SDGs between 2000 and 2013 (a rough proxy for interventions) to our own findings and observe that some goals are reasonably well aligned in terms of commitments and research attention in the context of forests, but also see some notable mismatches. For example, SDG 16 (peace, justice and strong institutions), which is by far the most well-funded of the SDGs, received US$342.5 billion (26%) of the approximately US$1.3 trillion commitments to goals considered in this work, and was accordingly well-represented in our data with 10 (7% of the 142 total) records. SDGs 5 (gender equality) and 10 (reduced inequality) both received less than 1% of all ODA commitments, and accordingly account for zero and three (2% of the total) records in our data, respectively. Conversely, SDG 7 was the focus of 83 (58%) our 142 records, yet received only US$93.9 (7%) of all commitments. SDGs 4 and 11 accounted for zero and one of our 142 records, respectively, yet received relatively large amounts of ODA commitments (US$147.4 billion (11%) and US$144.3 billion (11%), respectively). In light of the impacts described throughout this article, and given the relatively low amount of ODA directed towards terrestrial conservation (US$19.1 billion, or 1.2% of the total for all SDGs), this imbalance clearly warrants attention.

2.4. Multi-target impacts

Although not an explicit aim of this review, we identified a number of ways in which two or more non-environmental targets may interact to result in forest impacts, and which highlight an additional layer of complexity in this topic. A non-exhaustive list of such interactions is provided in Table 2.1. Such interactions can be thought of as either facilitating (i.e. achievement of one target permits achievement of a second, which has subsequent impacts), mediating (i.e. achievement of one target mediates the expected impacts of a second) or synergistic (i.e. achievement of two or more targets results in impacts that are greater than those expected from a single target). We note that, of the examples given in Table 2.1, the greater proportion are facilitating or mediating in nature, and that fewer synergistic examples are given. While this is reflective only of our findings, and we do not necessarily expect this to be the case in practice, it does highlight the fact that such interactions are less considered, possibly because of the practical difficulties of designing counterfactual research that quantifies multiple target impacts with and without the influence of each other.

We also acknowledge that such complexities can extend beyond interactions between only two targets, and, in practice, diverse ranges of facilitating, mediating and synergistic factors likely interact to result in forest impacts. Identification of such interactions, even when specific mechanisms or other complexities are not fully understood, will provide useful insights that can help achieve multiple targets in the most sustainable manner possible.

2.5. Implications of our findings

2.5.1. Implications for researchers

This review has highlighted a number of research gaps, which, with some investigation, would help facilitate a more integrated approach to sustainable development that avoids damage to forests and capitalises upon mutual benefits wherever possible. The 41 targets evaluated as ‘unknown’ in this work may nevertheless still have roles to play in affecting the natural environment, and would be worthy of investigation in this regard. The 27 targets identified as having forest impacts, but with low confidence, are particularly interesting from a research standpoint as they represent potential trade-offs or synergies that may be being overlooked by policymakers and development agencies. It is worth noting again here that more than two thirds of low confidence impacts are thought to be potentially beneficial. In all cases we encourage studies across a range of contexts (especially external interventions), locations and scales, so as to fully elucidate the complexities surrounding those impacts identified, including the mechanisms through which they arise.

Table 2.1. Examples of inter-target interactions with implications for forests.

Interaction type	Goals or targets involved	Impact mechanism	Expected direction of impact
Facilitating	**16.10** (Ensure public access to information) **16.5** (Reduce corruption and bribery)	Greater access to information, in particular through freedom of the press, helps to expose and reduce corruption (Ehrhardt-Martinez et al., 2002). Corruption is a key determinant of forests loss (Sommer, 2017).	Beneficial
	16.1 (End violence and related deaths) **1.4** (Equal rights to ownership and control over land and property)	Cessation of war and conflict is typically required for land rights to be recognised (de Bremond, 2013). Increasing local and individual land rights has mixed impacts on forests.	Mixed
	SDG 4 (Access to education and learning opportunities) **8.3** (Promote job creation and entrepreneurship)	Increasing levels of education allows individuals a more diverse range of job options, including non-agricultural employment, resulting in less encroachment of agriculture into forests (Baland et al., 2006).	Beneficial
	11.3 (Inclusive and sustainable urbanization) **7.1** (Access to modern energy services)	Evidence suggests that urban households are more likely to use more modern, and less forest-degrading fuel types (DeFries and Pandey, 2010).	Beneficial
	9.3 (access to markets and financial services, including credit) **2.3** (Double agricultural productivity)	Access to credit provides the capital required for farmers to expand agricultural operations into new areas, but can also allow investment into new technologies that promote intensification (Angelsen and Kaimowitz, 2001).	Mixed

Table 2.1. (Continued from previous page).

Interaction type	Goals or targets involved	Impact mechanism	Expected direction of impact
Mediating	**16.6** (effective, accountable and transparent institutions) **10.b** (increase official development assistance and foreign direct investment)	Effective governance can help mitigate the negative impacts that often arise from foreign direct investment (Assa, 2018).	Beneficial
	10.1 (Achieve in-country wealth equality) **8.1** (Sustain per capita economic growth)	Some evidence to suggest that reducing wealth inequalities can have a mediating effect on the damaging aspects of economic growth (Koop and Tole, 2001).	Beneficial
Synergistic	**8.9** (Promote sustainable tourism) **9.1** (Develop infrastructure)	Tourism typically requires increased infrastructure, and better infrastructure attracts more tourists. Damaging impacts of both are likely to be greater in combination than in isolation (Gaughan et al., 2009).	Damaging

Gaining a deeper understanding of multi-target interactions will be especially useful for developing integrated approaches to achieving non-environmental development without jeopardising the environment. Numerous multivariate studies (e.g. Crespo Cuaresma et al., 2017; Koop and Tole, 2001; Wang et al., 2019) have already made some progress in this area, highlighting key factors that can interact to result in forest outcomes (notably changes in deforestation rates). However, these are often limited to macro-level analyses that can fail to (a) identify forest degradation, or (b) uncover the specific mechanisms through which change occurs, especially when it involves subtle changes in social contexts, such as those relating to equality or health. Studies that combine local-level measures of changes in a range of development indicators with on-the-ground measures of forest change could be particularly insightful in this regard.

Finally, though many of our findings will apply to natural systems other than forests, many will not, and many other important interactions are likely to exist. As such, we recommend similar target-level reviews to this one to investigate other ecosystem types. In particular, work focusing on marine and coastal systems, wetlands, mountains and drylands, which are all mentioned in the SDG targets (Inter-Agency and Expert Group in Sustainable Development Goal Indicators, 2016), should be seen as priorities.

2.5.2. Implications for policymakers and development agencies

Institutions seeking to help achieve one or more non-environmental SDG targets must remain aware of the implications of their actions for natural biological systems and resources (illustrated here in the case of forests). Although our findings are broadly generalizable across locations, we remind readers that contextual factors (especially legal frameworks and political economies, relevant particularly to SDG 16) are of great importance in determining the consequential impacts of development progress. While for some forms of development, such as those relating to infrastructure or agriculture, avoiding negative environmental impacts presents a seemingly huge challenge, damage may be minimized by capitalising on some of the potentially beneficial (and perhaps less conspicuous) impacts identified in this review. In particular, evidence suggests that widespread promotion of quality education to support environmental awareness and a diverse job market in the non-agricultural sectors would support forest conservation.

Actions to support transparent and effective governance institutions, free from corruption and able to effectively implement the rule of law will be particularly useful in providing a background for successful achievement of environmental goals. Similarly, and although the evidence is less robust, creating a world with significantly reduced wealth and resource inequalities (including for women), as well as access to medical treatments and family planning services, could yield beneficial outcomes for the natural environment.

In cases where infrastructural developments seem likely to cause unavoidable negative environmental impacts, the evidence here suggests these might be minimized by adoption of participatory planning which is inclusive of diverse members of society. Roads in particular require careful consideration, and where increased market integration results from new roads (whether intentionally or otherwise) well-enforced policies, laws and other safeguards should be used to prevent overexploitation of nearby natural resources. For practitioners and policymakers working in the energy sector, evidence here also suggests the need for careful consideration of the environmental impacts that can result from their work (especially from the associated infrastructure) and supports the need for development of alternative options that provide clean, reliable energy in ways that minimize environmental damage.

Countries or development agencies wishing to invest in forest protection or restoration need to look beyond the conservation sector and address other competing and potentially conflicting development priorities while capitalising on those that can provide indirect benefits. A long-term solution for forests will necessitate a holistic approach where, among other factors, health, education, equality, and transparent and effective governance are treated as essential enabling conditions. To achieve this, a development planning landscape that is not only inclusive, but is, as best possible, free from silos that discourage dialogue and planning across sectors (and indeed across cultures and geographical boundaries) is important to avoid or capitalise upon the types of cross-target interactions described in this work (Nilsson et al., 2016; Timko et al., 2018). While this review has highlighted some of the most important sectoral silos that should be avoided (e.g. urban planning, deployment of energy infrastructure, agriculture), it seems reasonable to assume that even less obvious inter-sectoral dialogues, such as between matters of health and environment, will yield benefits. The removal of silos will not only facilitate well integrated planning and implementation of development interventions, but will also allow for better monitoring and research of cross-sectoral synergies and trade-offs, as described in the previous section. Continued interdisciplinary dialogue and research will yield an increasingly better understanding of ways to achieve the SDGs in a manner that is truly sustainable.

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Chapter 3 Identifying synergies and trade-offs between forests and the Sustainable Development Goals using relative importance analysis

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Abstract

Understanding how non-environmental UN Sustainable Development Goals (SDGs) are associated with changes in forest cover can facilitate pre-emptive measures that mitigate against forest-damaging activities and facilitate mutually beneficial development pathways. We use open access data for 122 countries to explore the relationships between achievement of the SDGs and changes in forest cover between 2017 and 2020 at global and regional levels. We overcome multicollinearity present in the SDG data by using two methods: partial least squares regression and dominance analysis. We find that higher levels of achievement for most goals is associated with reduced forest loss, with goals on health, education, energy, economy and industry appearing to have the most important relationships. Progress towards the achievement of many SDGs appears to affect forests negatively, and this may be of particular concern in countries with lower pre-existing levels of development. In this case, goals on economy and climate change mitigation appear to play the most important roles. Heterogeneity in our regional-level results underscores the need for consideration of contextual matters when interpreting and acting upon result such as these. We discuss the possible mechanisms underlying our findings, and suggest relevant policy measures and avenues for future research.

3.1. Introduction

This chapter responds to research question 2 of this thesis, which asks "How does achievement of the United Nations Sustainable Development Goals (SDGs) relate to changes in forest cover globally, and which goals are most important in shaping this relationship?". While various studies have examined relationships between specific components of the development agenda (e.g. targets or indicators) and forests, a knowledge gap remains around the net impacts of achieving goals comprising multiple targets, and around the relative importance of these in shaping (un)desirable outcomes for forests. In responding to this knowledge gap, we present the first ever global-level attempt to explore the empirical relationships between achievement of the SDGs and changes in forest cover, and to identify which of the major development 'themes' (i.e.

grouped goals with similar focal topics) are most closely associated with forest losses or gains.

The SDGs, which comprise 17 goals and 169 associated targets spanning matters of well-being, prosperity and the natural environment, were developed with the intention of providing the most comprehensive and integrated framework to date through which to guide and monitor development around the world. The original supporting documentation of the SDGs (United Nations, 2015) stresses the importance of interlinkages (now more commonly referred to as interactions) between the goals. Implicit in this is the notion that achieving some goals or targets will help to facilitate achievement of others (i.e. provide synergies), but in other cases, achieving a given goal or target can constrain the achievement of others (i.e. present trade-offs) (Nilsson et al., 2016). Despite stressing the importance of these interactions, the supporting documentation of the SDGs provides no guidance on their nature (Bennich et al., 2020), which has since motivated a growing field of inquiry to explore and map interactions between the SDGs. It is now widely acknowledged that such studies can help to take advantage of mutually reinforcing goals and targets, while targeting mitigating measures in cases where achieving a goal or target might hinder progress in another (Nilsson et al., 2016).

Waage et al. (2015), who were among the first to consider SDG interactions, grouped the SDGs into three broad categories; those relating to well-being, infrastructure and the natural environment, and suggested that links between the first two are typically conspicuous and often mutually reinforcing, but that the links between natural environment and other categories are less well understood. The authors further suggested that without careful planning and sound governance, goals relating to well-being and infrastructure could be treated with greater priority than environmental goals, potentially compromising achievement of the latter. A number of subsequent studies have suggested that environmental risks could emerge if inter-sectoral dialogue and careful planning does not take into account the links between the environmental and non-environmental aspects of the SDGs, but have also highlighted the potential for synergies that could benefit the natural environment (Messerli et al., 2019; Schleicher et al., 2018; Tiba and Frikha, 2019). Numerous studies have highlighted how a healthy natural environment can facilitate achievement of non-environmental aspects of the

SDGs (Omisore, 2018; Scharlemann et al., 2020; Weitz et al., 2019), yet relatively fewer have considered this from the reverse perspective, examining the consequences of attaining non-environmental SDGs for the natural environment. In this work, we seek to address this imbalance.

We focus specifically on forests, a critical ecosystem whose conservation presents one of the most pressing of today's environmental challenges (IPBES, 2019). Between 2010 and 2020, the world's forests shrunk by an estimated 4.74 million hectares (or 0.12%) per year (FAO and UNEP, 2020). However, this decline has been geographically unequal, with rates of forest loss slowing or even reversing in some countries in recent years, while increasing in others (FAO and UNEP, 2020; IPBES, 2019). Forests receive notable attention within the SDGs, with targets 6.6, 15.1 and 15.2 all calling for their conservation and restoration, and indicator 15.1.1 requiring the monitoring of 'forest area as a proportion of total land area' as a means to track progress in target 15.1 (Inter-Agency and Expert Group in Sustainable Development Goal Indicators, 2016). Forest conservation will be key to achieving a number of SDGs, including those relating to climate, water, health and economic growth, among others (Sayer et al., 2019), and so understanding the factors that help prevent and reverse forest loss is essential not only for achieving the SDG's environmental components, but also the myriad non-environmental components that they support.

Past research provides support for the idea that matters of human development can underpin the drivers of both forest losses and gains. The work of Jha and Bawa (2006), for example, showed that higher levels of development, as typified by the UN's Human Development Index, are associated with lower levels of deforestation. Given the importance of the SDGs in shaping the development objectives and trajectories of much of the world (all 193 UN member states), it is relevant to ask whether this same relationship applies when examined through the lens of the SDGs. If indeed it does, then it is also pertinent to ask which specific aspects of the SDGs are most responsible for this. There are reasons to expect that elements from all SDGs can have implications for forests in one way or another (Carr et al., 2021; Katila et al., 2019), yet understanding of these relationships is much better in some cases than in others (Carr et al., 2021). Moreover, for some SDG elements, for example those relating to health or education, forest impacts have been most commonly investigated at local scales, and it remains unclear whether the observed impacts apply more widely. Holistic studies that investigate the impacts of all elements of modern sustainable development on forests at a global scale are, therefore, likely to be of significant interest and utility.

The mechanisms through which achievement of the various SDGs can affect forests are numerous and often complex, although some commonly described processes can be identified from past literature. Trade-offs for forests can occur, for example, where forestlands are converted for alternative purposes, such as for agriculture (relevant to SDG 2) (Laurance et al., 2014) or the development of new infrastructure (relevant to several SDGs, including those on energy, industry and housing) (Doyle and Havlick, 2009; Laurance et al., 2015). If some aspect of the SDGs is achieved through the direct use and/or sale of forest resources (e.g. for manufacturing (SDG 9) or to achieve economic growth (SDG 8)) then increased extraction could potentially reach unsustainable levels (Rodrigue and Soumonni, 2014). More subtle trade-offs can occur if achievement of (or progress towards) some component of the SDGs increases desire/ability to procure forest resources, products, or lands. This could occur, for example, if individuals or households have increased access to monetary resources (perhaps through reduction of poverty (SDG 1) or improved equality (SDG 10) (Alix-Garcia et al., 2013; Wunder, 2001)), or where formerly inaccessible areas become accessible, perhaps following infrastructure improvements (SDG 9) (Laurance et al., 2009) or the cessation of conflict (SDG 16) (Murillo-Sandoval et al., 2020).

Synergies for forests may occur where high levels dependence on forestlands or forest resources are reduced. At the subsistence level, examples could include improvements in access to energy (SDG 7) leading to a reduced dependence of wood-based fuels (Tanner and Johnston, 2017), or reduced poverty (SDG 1) reducing the need to harvest forest products in times of severe hardship (Delacote, 2012). Beyond matters of subsistence, examples could include cases where improved education (SDG 4) and/or better employment opportunities (SDG 8) result in a reduced proportion of a population being reliant on forest-damaging activities, such as agriculture, to provide their livelihoods (Godoy and Contreras, 2001; Kaimowitz and Angelsen, 1998). Synergies may also arise if some aspect of the SDGs helps to prevent the illegal or unregulated use of land or resources, for example through improved law enforcement of reduced corruption (SDG 16) (Brunner et al., 1999; Sommer, 2018; Sundström, 2016). There are also cases where improvements in a given aspect of the SDGs can potentially result in positive and/or negative outcomes for forests. For example, in cases where land ownership rights are improved (SDG 1), or where decision-making powers become more inclusive (components of SDGs 5, 10 and 16), beneficiaries may face a choice of either conserving or exploiting forests, and there is no guarantee that they will choose the former over the latter (Naughton-Treves and Wendland, 2014; Villamor et al., 2014).

The above examples are not exhaustive, yet they serve to illustrate two key points. Firstly, we see that impacts arising from a given goal can be either positive or negative under different circumstances. It is of great interest therefore to know whether, at the goal level, a predominant net outcome is evident. A second key feature to note is that for some aspects of the SDGs, impacts may arise specifically as a result of higher levels having been achieved (e.g. illegal logging reduces once better law enforcement is achieved), yet for others, additional impacts may occur through the processes of actually attaining higher levels (e.g. as land is converted to improve infrastructure). Consequently, when examining matters of development as they relate to forests (or indeed other matters of the environment), we feel it is important to consider both aspects.

In the context of forest change, most work to date pertaining to development-related impacts has been focused at the target/indicator level, and we are not aware of any analyses that have so far attempted to relate forest change to the SDGs at the level of goal. While target/indicator-level analyses are helpful in identifying highly specific interactions and informing possible interventions, goal-level analyses can help to stimulate thinking, dialogue and further research that promotes sound governance of whole thematic areas (De Neve and Sachs, 2020; Lusseau and Mancini, 2019). A likely underlying reason for the relative dearth of assessments of goal-level interactions is that characterisation and quantification of the SDGs at any level above that of indicator presents methodological challenges. The indicators that underpin the SDGs and their targets, and which by definition each have their own associated metrics, can vary widely in their nature, and so combining them in a quantitative manner is not straightforward. One notable effort to overcome this challenge is the Sustainable Development Goal Index (SDGI) (Sachs et al., 2021). The SDGI (details of which are given in our methods section) provides an indicative score from zero to 100 on the performance of countries for a suite of indicators, which can be averaged to assess a country's status at the level of goal or above. The nature of the SDGI is such that it can be readily compared between countries, goals and/or years. In a recent paper, De Neve and Sachs (2020) used the SDGI to assess how levels of attainment in each of the SDGs is associated with subjective well-being (finding positive relationships in most cases). In this paper, we draw upon their methodology to examine associations between SDGI scores and changes in forest cover.

A further challenge when considering how achievement of the SDGs affects a given outcome of interest is the high degree of multicollinearity that exists between many of the goals (see Methods and Appendix B). This limits the applicability of many of the more commonly applied techniques, such as multiple regression, to identify relationships, as the relative roles of each predictor becomes clouded, along with any ability to confidently infer causality. In the presence of multicollinearity, it is often suggested to exclude one or more predictors. However, as noted above, there are reasons to believe that all SDGs are likely to have at least some influence on forest cover change, and so we do not feel that this solution is appropriate. Instead, to overcome this issue, we employ relative importance analysis, which is a term used to describe methods that partition the explained variance among a set of (typically collinear) predictors, and assess the relative roles played by each (Tonidandel and LeBreton, 2011).

In our exploration of the empirical relationships between achievement of the SDGs and changes in forest cover, we specifically seek to answer the following research questions: (i) is achievement of the SDGs (as typified by the SDGI for all goals combined) associated with higher or lower levels of forest cover change? (ii) Which specific goals are most important in explaining the observed variance in forest cover change around the world? (iii) Which of the broad themes encompassed by the SDGs (in our case well-being, social issues, economy, infrastructure or sustainability) are most important in explaining changes in forest cover, and does their relative importance vary between different regions of the world? Our hope is that the work will stimulate thought, discussion and further research on the focal topic, and ultimately contribute to a widespread effort to better integrate matters of environmental conservation into development planning around the world.

3.2. Methods

3.2.1. Data sources and processing

To explore the research questions stated above, we analysed secondary, quantitative data from three well-established sources. We considered a total of 122 countries, and the inclusion criteria used establish the list of countries included are provided in the following paragraphs.

To compare changes in forest cover at a national level, several datasets are made freely available, and each has its own advantages and limitations. The Global Forest Resources Assessment (GFRA) dataset (FAO, 2022) has been compiled annually since 1990, providing measures of both forest losses and forest gains for 234 countries and territories, which can be compared to derive a measure of net change (FAO and UNEP, 2020). These data have received criticism, however, due to inconsistencies in the way that they are collected, including between time periods and between countries (Grainger, 2008), particularly as country-level data are self-reported, and in some cases based on desk studies (conducted by the FAO) rather than direct observation. Although these data remain imperfect, their quality is thought to have improved over time; since 2000, consistency in the definitions use (e.g. of forest) has been improved between reporting countries, and since 2015, efforts have been made to ensure greater accuracy of the reports submitted (MacDicken, 2015; Nesha et al., 2021).

Since 2013, the data hosted on the website Global Forest Watch (GFW) (Hansen et al., 2013) have arguably been the most commonly utilised resource for comparing changes in forest area between countries. These data are seen as an improvement on the GFRA, as they are collected in a more standardised and robust way, using Earth observation satellite data at a spatial resolution of 30 metres. Data are provided as separate measures of tree cover losses (annually, from the year 2000 to the present) and tree cover gains (over two 10-year periods; 2000 to 2010, and 2010 to 2020), as well as measures of total tree cover in the years 2000 and 2010. Limitations to these data arise from the fact that, due to methodological differences, tree cover losses and gains cannot be compared to derive an overall net value. Moreover, the 10-year time periods over which tree cover gains are reported means that these data cannot be used for analyses wishing to consider changes over shorter timeframes. Both the GFRA and the GFW data have received criticism due to a limited ability to distinguish between natural forests and certain other habitats (notably plantations) (Tropek et al., 2014), as well as a poor consideration of forest degradation.

The recently released dataset by Vancutsem et al. (2021) overcomes many of these issues, as it provides annual measures of net forest change that are consistent in their underlying methodology, accounts for both deforestation and forest degradation, and is better able to distinguish between forests and plantations. However, these data pertain exclusively to tropical moist forests, and as such, only provides data for 54 countries.

Because our intention was to conduct a global analysis, the Vancutsem et al. data were deemed not suitable for our purposes, and we instead chose to use both the GFRA and the GFW data as individual response variables, repeating all analyses using both datasets separately. In the case of the GFRA data, we calculated each country's net change in forest cover between the years 2017 and 2020, expressed as percentage change of its total percentage forest cover in 2017. In the case of the GFW data, we calculated each country's total loss of tree cover (with a canopy density >30%) between the same period, again expressed as a percentage change in total cover in 2017. In this case, to derive the 2017 values against which to compare changes we subtracted total tree cover loss during the preceding years (2010 to 2016) from the total forest cover values for the year 2010. Because these calculations do not account for forest gains, our estimates of percentage tree cover losses may be overestimates in some cases. Moreover, these values should not be treated as a measure of net forest change, which is the intention behind our use of the GFRA dataset. We excluded countries with less than 10% forest cover in 2017 (based on the GFRA data), as we feel it is reasonable to assume that changes in a given SDG would have less relevance to forests in countries with little or no forest to begin with.

As shown in Figure 3.1, the differing nature of our two response variables is such that values derived from the GFRA data include cases of both net losses and gains in forest cover, while those derived from the GFW data contain measures of tree cover loss only. When interpreting our results, therefore, readers should keep in mind that negative and positive coefficients in the case of the GFW data are indicative of lower and greater levels of tree cover loss, respectively, but in the case of the GFRA data, negative coefficients can be indicative of greater levels of forest loss as well as lower levels of forest gains, while positive coefficients can be indicative of lower levels of forest loss as well as higher levels of forest gains.

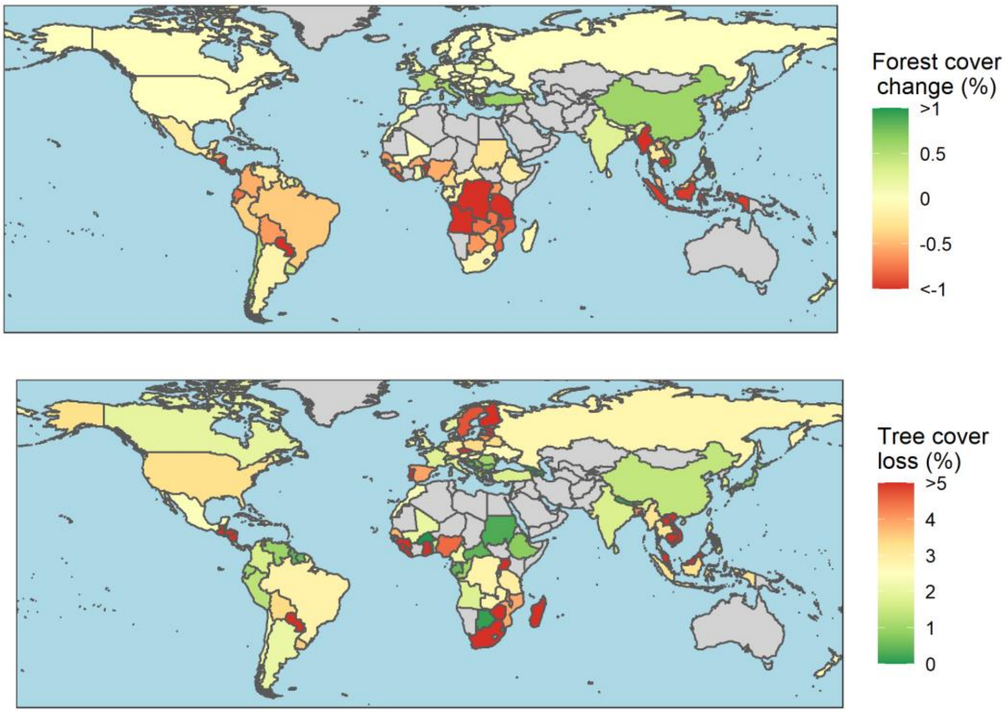


Figure 3.1. Percentage net change in forest cover based on GFRA data (above) and percentage tree cover loss based on GFW data (below) between 2017 to 2020 for the 122 countries included in this work. Countries not included are shown in grey. Source: Author's own work based on data from FAO (2022) and Hansen et al. (2013).

All predictors were based on data underlying the official Sustainable Development Reports of 2017 (Sachs et al., 2017) and 2020 (Sachs et al., 2020), which track the performance of all 193 UN Member States on the 17 SDGs. These assessments employ the Sustainable Development Goal Index (SDGI), which synthesises data from a suite of indicators, and summarises these in terms of status and recent trends (ranging from ‘on track’ to ‘decreasing’). To allow direct comparison between indicators, countries and years, the SDGI applies a normalisation process which standardises each indicator using a scale from zero (worst possible) to 100 (best possible) (see source for methods). Use of this scale also allows the status and trend of each country to be assessed, following a process of averaging, at the level of goal. The SDGI also provides a single combined metric of achievement across all SDGs.

Predictors in our analyses included the 2017 values for both the overall SDGI scores (i.e. for all goals combined) and for the individual goals. We also calculated changes in each of the above between the years 2017 (the year in which the SDGI began to provide disaggregated assessments to reflect the individual goals) and 2020 (the most recent year for which GFRA forest data were available), which were also used as predictors. Values for all predictors used are shown in Figure 3.1. Following De Neve and Sachs (2020), missing score values were imputed based on average regional scores, including three for SDG 1, one for SDG 4, and eight for SDG 10. For all goal-level analyses, we did not include data for goal 14 (life below water), which was deemed too data poor, goal 15 (life on land), which is not independent from the response variable, or 17 (partnerships for the goals), which is cross-cutting, and contains elements pertaining to all other goals (Waage et al., 2015). We excluded all countries with SDGI values missing for two or more goals.

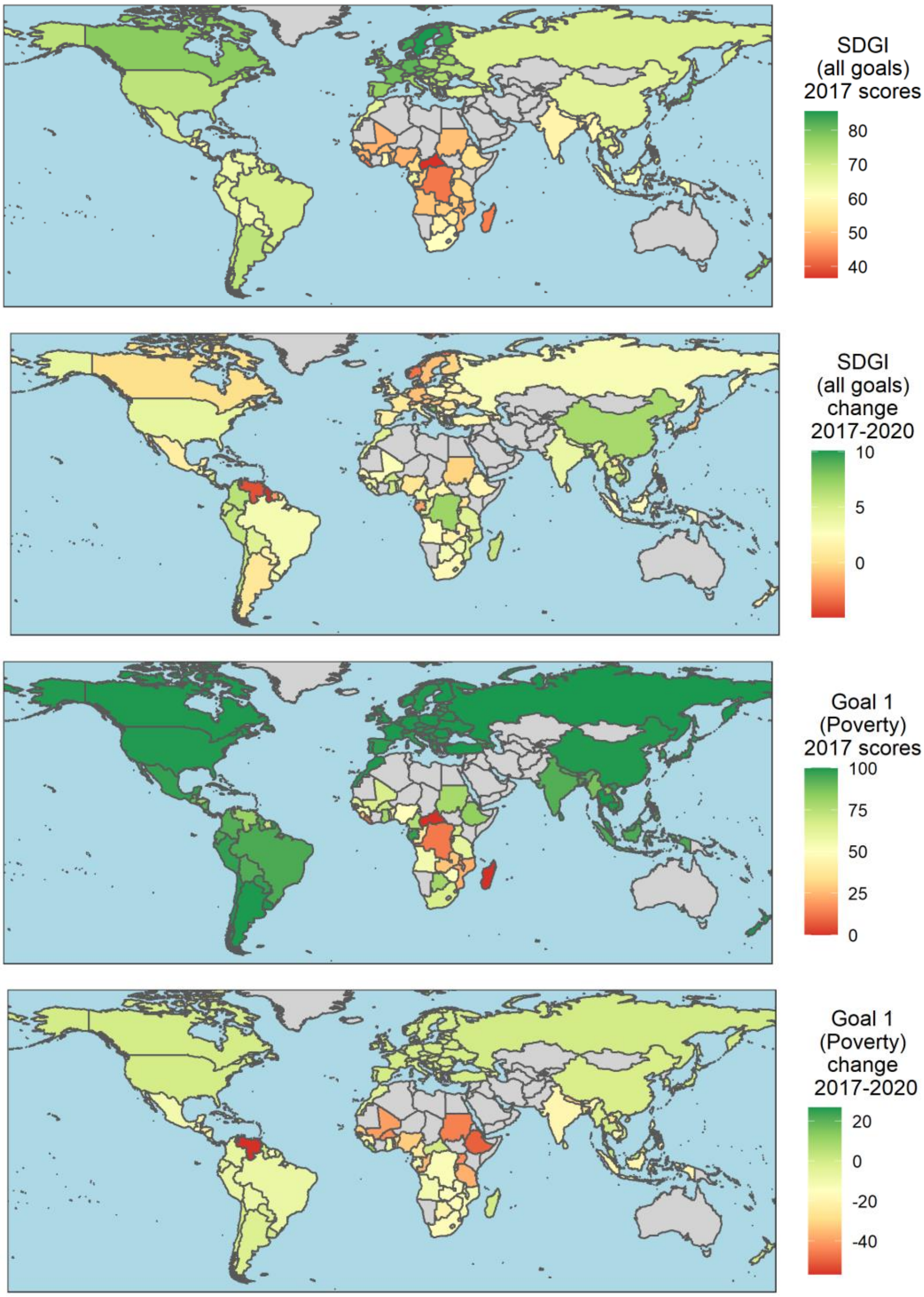
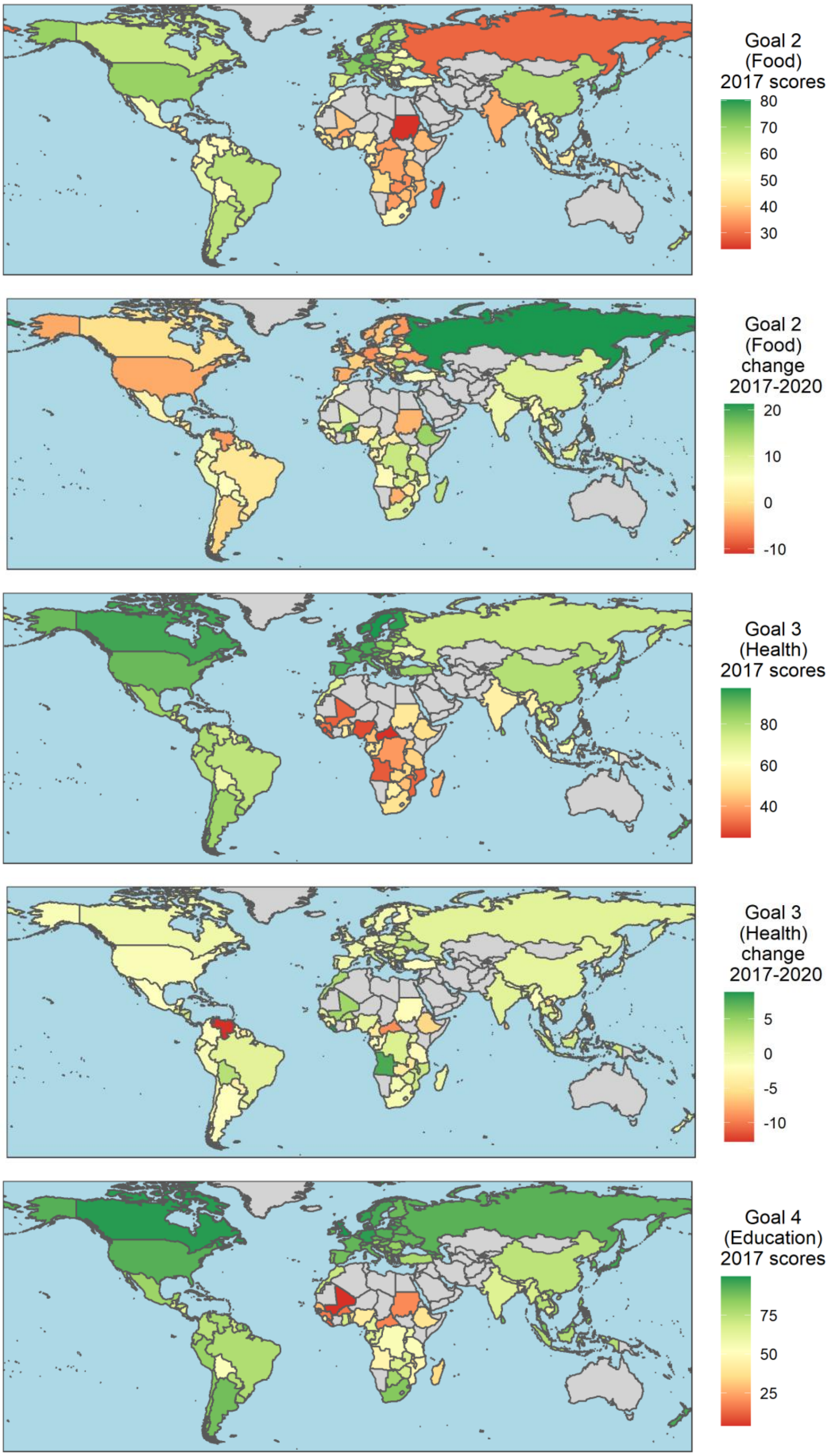


Figure 3.2. Maps depicting national values of all predictors used in this work, including 2017 values of the overall SDGI score (first image), changes in this score between 2017 and 2020 (second image), and 2017 scores and 2017 to 2020 changes in the SDGI for goals 1 to 13 and 16. Figure continues over multiple pages.

Figure 3.2. Continued from previous page.



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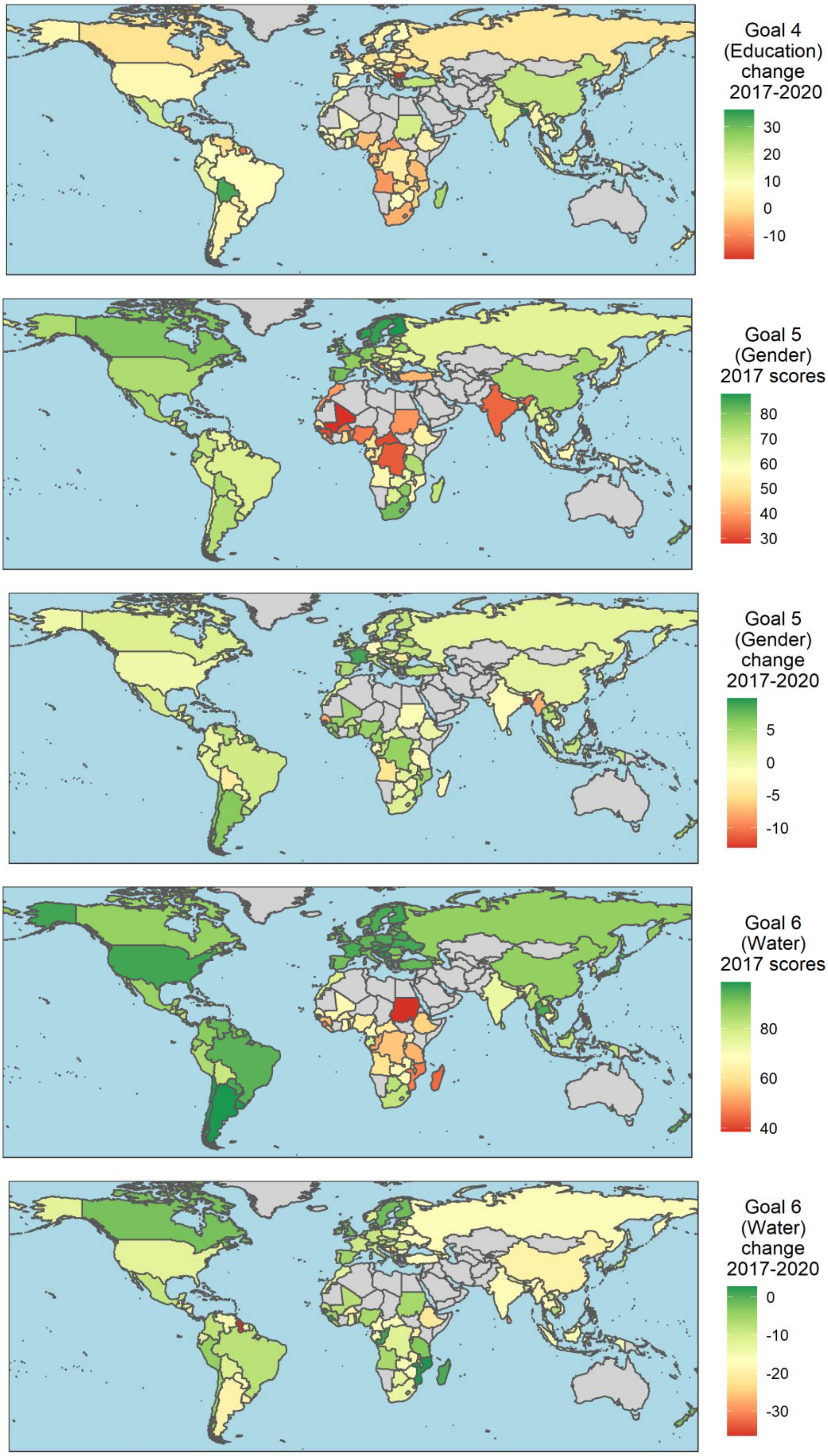

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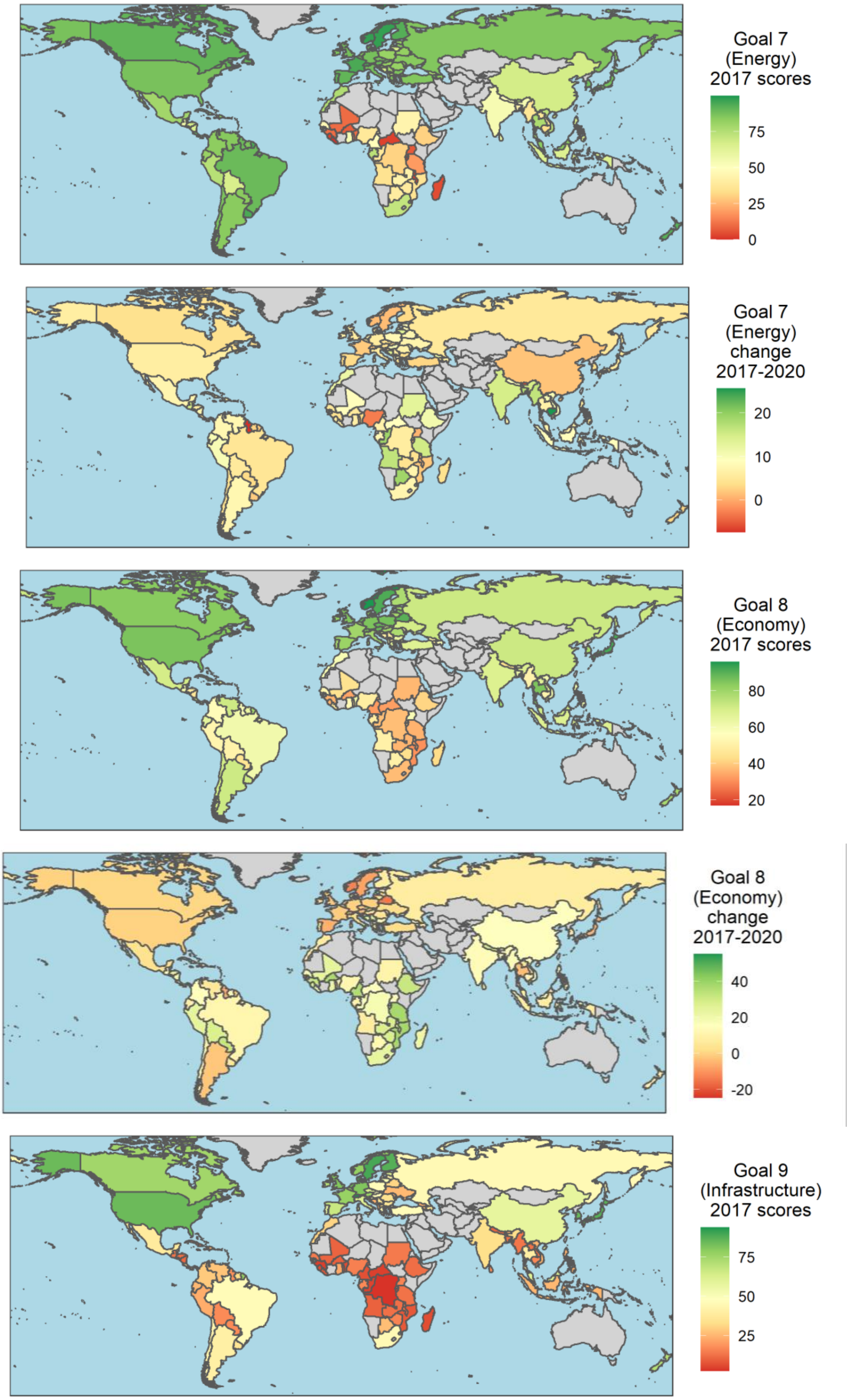

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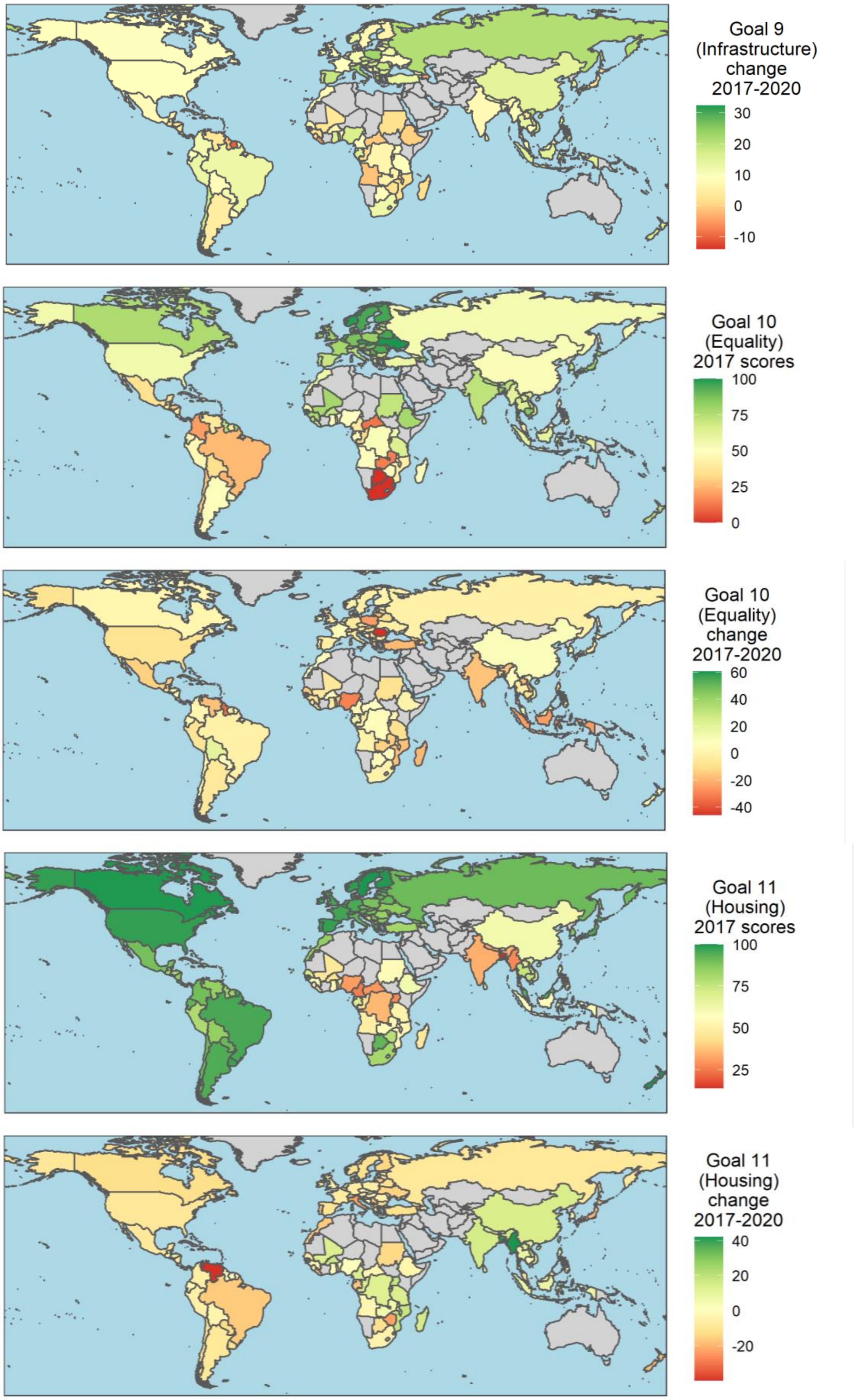

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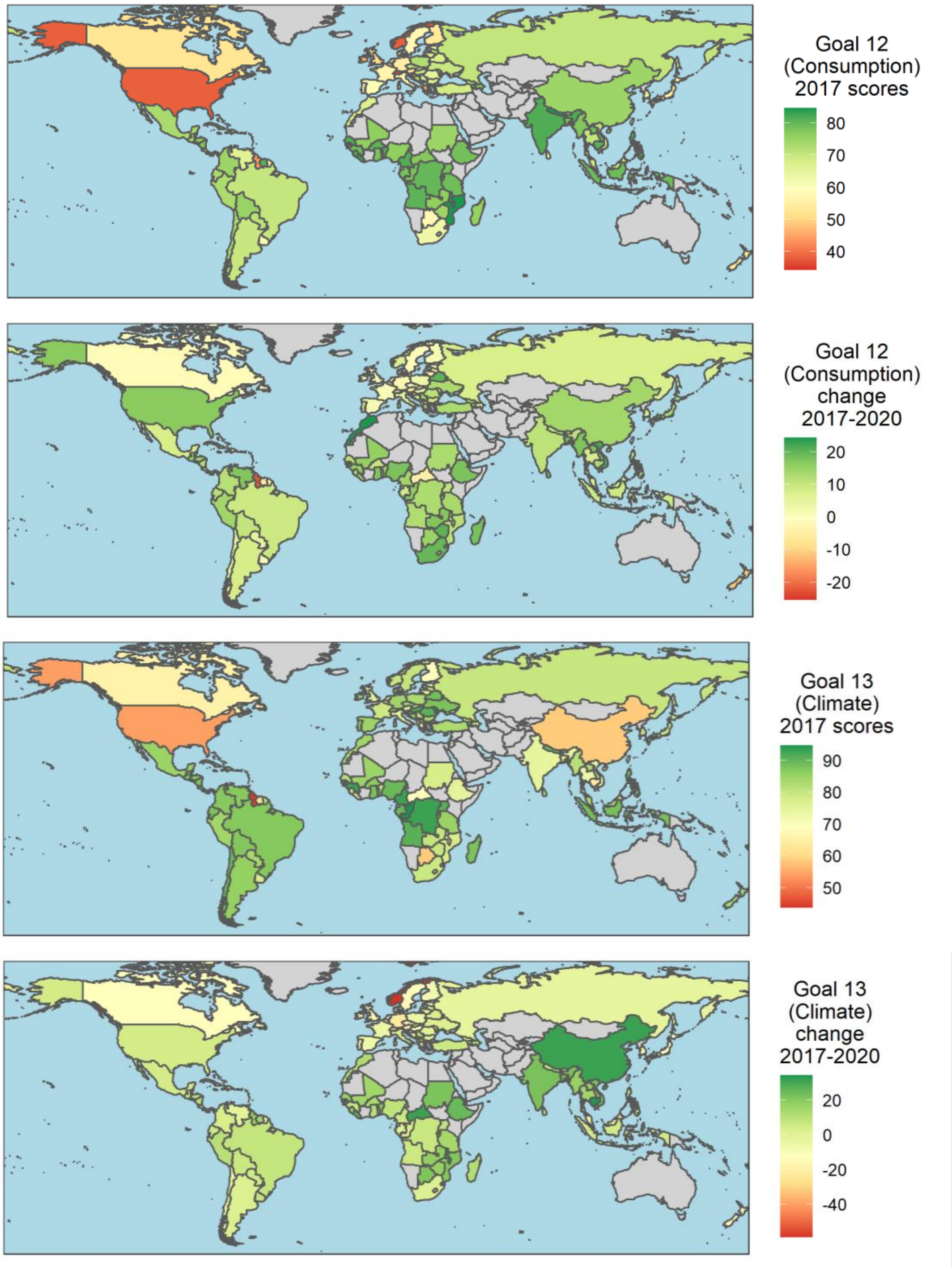

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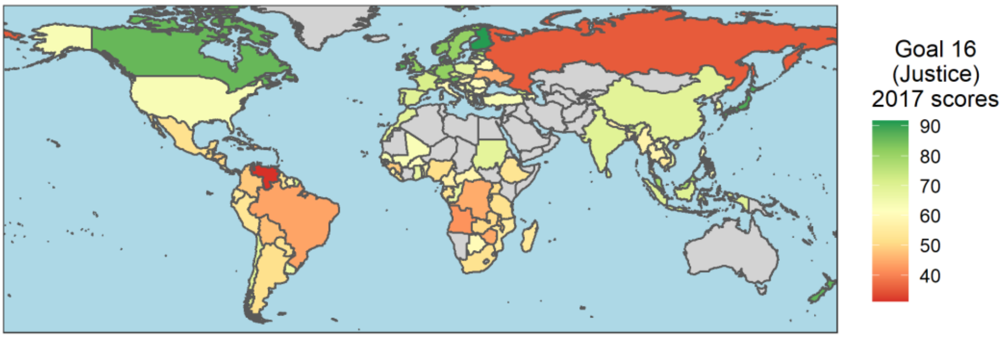

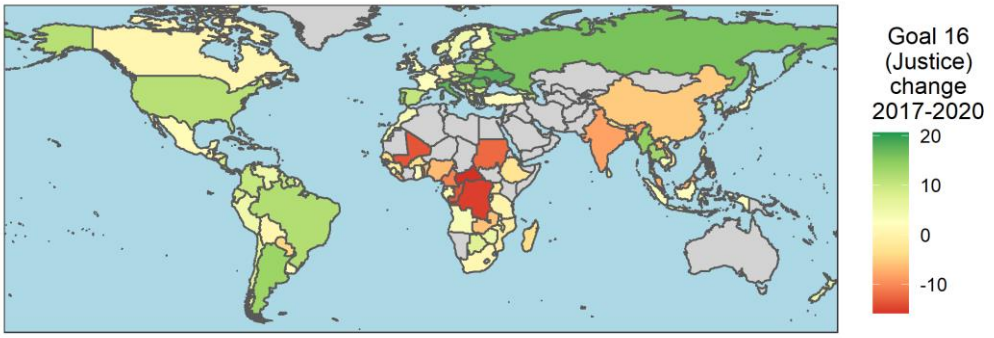

3.2.2. Analytical approach

For the first part of our analysis, we were interested to know if changes in forest cover are associated with overall levels of development prior to changes occurring (i.e. the 2017 overall SDGI score) and/or with subsequent changes in that score. We were also interested to know whether the former has a moderating effect on the latter (i.e. does the effect of change in SDGI on forest cover vary depending on the initial SDGI score of the country in question?). To investigate these questions, we ran ordinary least squares (OLS) regression models, first with each of the two predictors separately, and second with both predictors together, including an interaction term between the two. These models satisfied all standard assumptions of OLS regression. This analysis, along with all others, was run in R version 4.0.2 (R Core Team, 2021).

Preliminary analyses indicated high levels of multicollinearity between many of our goal-level predictors (see Figure B.1 in Appendix B), meaning that OLS regression was not appropriate for analysis of these variables. To overcome this issue we employed two types of relative importance analysis: partial least squares regression (PLSR) and dominance analysis (DA). Both approaches are able to overcome issues of multicollinearity (along with, to some extent, small sample sizes and non-normal data) to assess the relative contributions of a set of predictors in explaining a given outcome of interest (Carrascal et al., 2009; Goodhue et al., 2012; Tonidandel and LeBreton, 2011).

PLSR can be thought of as a hybrid between multiple linear regression and principal component analysis (PCA). As with PCA, PLSR reduces the predictors to a smaller set of orthogonal (or uncorrelated) components, but unlike PCA, the components produced using PLSR are based on covariance with a given response variable, rather than on variance within the predictors alone (Hubert and Vanden Branden, 2003; Tobias, 1995). The orthogonal components identified through PLSR, which account for successively lower proportions of the covariance, can be assessed through a process of cross-validation to determine the optimum number that provides the best predictive power (prediction being the more common application of PLSR) (Hubert and Vanden Branden, 2003; Tobias, 1995). Having identified the optimum number of components, the relative contributions of each predictor can then be assessed through examination of its variable importance in the projection (VIP) score (Galindo-Prieto et al., 2014). The sum of the squared VIP values will always be equal to the total number of candidate predictors (Galindo-Prieto et al., 2014), making it straightforward to convert these into more readily interpretable percentage values. Predictors with VIP values >1 explain a greater proportion of the variance in the outcome than would be expected if all predictors contributed equally.

We ran PLSR using the R package ‘pls’ (Liland et al., 2021), and applied a ‘leave one out’ method of cross-validation. This method calculates all potential models excluding one observation at a time, and uses these to calculate the root mean squared error of the prediction (RMSEP) for each number of components (up to a maximum of 10 in our case). Following standard procedure (see Mehmood et al. 2012), we report on models with a given number of components that provides the lowest RMSEP value. Predictor coefficients derived from our PLSR models using the GFRA data as the outcome variable can be interpreted such that negative values indicate a relationship in which higher predictor values are associated with higher levels of net forest loss/lower net forest gains, while positive values indicate that higher predictor values are associated with lower levels of net forest loss/higher net forest gains. Predictor coefficients derived from our PLSR models using the GFW data as the outcome variable can be interpreted such that negative values indicate that higher predictor values are associated with lower levels of tree cover loss, while positive values indicate that higher predictor values are associated with higher levels of tree cover loss. As described above, we convert VIP scores to percentages, and focus much of our reporting on predictors that explain more variance than would be expected if all predictors contributed equally. For example, in our goal-level analyses, we included 14 predictors at any one time, and so were particularly interested where percentage values exceeded 7.14%.

DA is designed to assess the individual contributions of predictors relative to each other within a pre-selected model (typically a multiple regression model) (Azen and Budescu, 2003). To achieve this, it calculates R^2 values for subset models using every possible combination of the available predictors, and, in each case, conducts pairwise comparisons of the additional contribution to R^2 made by adding a given predictor (Azen and Budescu, 2003; Budescu, 1993). By averaging these contributions for each predictor, it is then possible to calculate (and express as a percentage) the relative contributions of each to the variance explained by original, 'full' model (a good example of this is the aforementioned work of De Neve and Sachs (2020), who also used DA in the context of the SDGI). We ran DA using the R package 'dominanceanalysis' (Bustos Navarrete and Coutinho Soares, 2020), using a standard multiple linear regression model containing all candidate predictors, with no interactions, as the basic model from which to assess relative contributions. By default, DA does not provide coefficients, and so we determined these using individual OLS regressions, and these may be interpreted in the same manner as described for PLSR above. As with PLSR, we were again interested in predictors that explain more variance than would be expected if all predictors contributed equally.

While PLSR identifies the subset of a given dataset that best describes the variance of a given outcome, which can then be studied in terms of its composition (i.e. the relative contribution of each predictor to that subset), DA first assesses the maximum variance in the outcome that can be explained by inclusion of all data from all predictors, and then decomposes this to explain the relative contributions of each. As such, PLSR may inherently overlook some aspects of a given relationship (those present in the data from any of any excluded components) in favour of the most parsimonious model, while DA may tend to over-explain given relationships, as it essentially forces the predictors to explain all of the variance in the outcome. By applying (and comparing) both of these approaches in our examination of the relative contributions of each SDG in explaining forest cover change, we hope to achieve higher confidence in our findings. Cases where the methods agree that a predictor is (or is not) of high relative importance can be interpreted with greater certainty than cases where models disagree, which provide subject matter for discussion towards the end of this paper.

Our analyses do not attempt to combine predictors relating to 2017 SDGI scores and those relating to changes between 2017 and 2020, as doing so would push our predictor to sample size ratio beyond a reasonable limit. Nevertheless, we note that levels of collinearity are much lower between these two different predictor groups than within the individual groups (see Appendix B), and so the findings from each may be considered as having reasonable independence. Exceptions to this include goals 2 (food security), 8 (economic growth) and 11 (cities and communities), for which the 2017 values and the subsequent changes in these values show high collinearity (Pearson's $r = -.61$, $-.86$ and $-.67$ for the three goals, respectively). The negative correlation coefficients given above suggest that, for these three goals, the better a given country is already performing, the less likely it is to make further positive changes. We discuss the implications of these relationships as they become relevant to our findings.

3.2.3. Thematic and regional analyses

The effects of a given SDGI score (or change therein) on a country's forests may not necessarily be uniform at all locations around the world, and it is therefore of interest to investigate whether relationships vary between the world's major regions. Accounting for this in our models is difficult, however, as there currently exists no established method through which to include both continuous and categorical variable in either PLSR or DA. To overcome this, we used the following two processes.

First, we ran individual OLS regressions for each predictor (and for both response variables) including an interaction term with the categorical variable 'region'. This variable comprised the following four groups: Africa (N = 32); the Americas (including the Caribbean) (N = 28), Asia (N = 23); and Europe (which includes Russia and New Zealand) (N = 39). In these models Africa was used as the reference category, as in the majority of cases SDGI scores are typically lower in many African countries than in countries elsewhere in the world. We highlight significant interaction terms, including the sign of the coefficient, which can be interpreted such that a positive coefficient indicates that higher predictor values are associated with reduced forest losses/forest gains (for the GFRA data) and higher rates of loss (for the GFW data) compared with the reference category, while negative coefficients indicate the opposite.

Second, following De Neve and Sachs (2020), we repeated our analyses based on thematically-linked groups of goals, including for four regional subsets using the groupings listed above. Our thematic groupings deviated somewhat from those used by De Neve and Sachs, and are as follows: Well-being (goals 1, 2 and 3); Economic (goals 4 and 8); Social (goals 5, 10 and 16); Sustainability (goals 6, 12 and 13); and Infrastructure (goals 7, 9 and 11). In each case, we repeated the above PLSR and DA processes with few deviations.

There are a number of important limitations to our analyses, which we consider more fully in our discussion section. These include a limited numbers of observations, particularly in the case of our regional analyses, and a general lack of variance in the data for some of our predictors, which can limit the power of the variance decomposition analyses used herein. Suffice to say, at this stage, our findings should be considered with due caution, keeping in mind that they portray past correlational relationships from a specific timeframe, and so do not necessarily have predictive utility. This is particularly relevant to certain predictors, including goals pertaining to poverty, hunger, health and economy, which underwent notable declines during the period of our investigation, largely as a result of the Covid-19 pandemic (Sachs et al., 2020), and so are not necessarily characteristic of the preceding time periods, nor, one hopes, those of the future.

3.3. Results

3.3.1. Relationship between overall SDGI score and forest change

We found a significant positive relationship between SDGI score (all goals combined) in 2017 and changes in net forest cover (GFRA data) between 2017 and 2020 (β = .025, SE = .004, p < .001, R^2 = .213), suggesting that higher levels of development are associated with lower levels of forest loss, and ultimately forest gains. Conversely, we found a significant negative relationship between change in SDGI score (all goals combined) and net changes in forest cover between 2017 and 2020 (β = -.057, SE = .019, p < .01, R^2 = .065). In contrast to our findings on SDGI scores, this suggests that progress towards achieving higher SDGI scores is associated with declines in forest cover (or smaller forest gains). Analyses to investigate whether these relationships vary between regions found no significant interactions (α = .05) between either 2017 SDGI scores nor scores changes between 2017 and 2020 and any of the regions, compared with the reference category (Africa). Detailed outputs from these models are provided in Appendix B. Regression analysis combining 2017 SDGI scores and subsequent changes in these scores by 2020 and using the GFRA data as the response variable found a significant positive interaction term between the two predictors (Table 3.1). This suggests that the impacts of progressing towards an improved SDGI score become less negative (i.e. cause less severe forest losses, and ultimately gains) where countries' initial SDGI scores are greater.

Table 3.1. OLS regression outputs for model regressing net forest cover change (GFRA data) against 2017 SDGI scores, changes in SDGI scores between 2017 and 2020, and the interaction between the two. The following alpha values apply: * = <.05, * = <.001.**

	Coefficient	Std. error
Intercept	-1.103*	0.455
SDGI	0.014*	0.006
Change in SDGI	-0.292*	0.115
SDGI * Change in SDGI	0.004*	0.002

R^2 = .254
Adj. R^2 = .235
*F(3, 118) = 13.38****

We also found a significant negative relationship between SDGI score (all goals combined) in 2017 and percentage tree cover loss (GFW data) between 2017 and 2020 (β = .067, SE = .020, p < .01, R^2 = .084), suggesting that higher levels of development are associated with lower levels of tree cover loss. We found a significant positive relationship between change in SDGI score (all goals combined) and percentage tree cover loss between 2017 and 2020 (β = .225, SE = .085, $p < .01$, $R^2 = .056$), suggesting that progress towards achieving higher SDGI scores is associated with increased tree cover loss. These findings largely align with those using the GFRA data as a response. However, in this case we found a significant positive interaction between 2017 SDGI scores and the Europe category of the Region variable, suggesting that higher SDGI scores in Europe are associated with a higher rate of tree cover loss than in the reference category (see Appendix B for full results of these models). In contrast to analyses using the GFRA data, we did not find a significant interaction between 2017 SDGI scores and changes in these scores between 2017 and 2020 when using the GFW data as a response (Table 3.2).

Table 3.2. OLS regression outputs for model regressing percentage tree cover loss (GFW data) against 2017 SDGI scores, changes in SDGI scores between 2017 and 2020, and the interaction between the two. The following alpha values apply: * = <.05, ***** = <.01*****.**

	Coefficient	Std. error
Intercept	3.808*	1.089
SDGI	-0.021*	0.029
Change in SDGI	1.027*	0.328
SDGI * Change in SDGI	-0.014	0.008

$R^2 = .218$
Adj. $R^2 = .196$
*$F(3, 118) = 5.215$***

We were also interested to know whether these findings are the result of lower existing forest cover in more highly developed countries, which could have been depleted during the process of developing, leaving less forest left to remove. To examine this, we regressed percentage forest cover in 2017 (GFRA data) against 2017 SDGI scores (all goals combined), and found no significant relationship between levels of development and percentage forest cover (β = .203, SE = .159, $p = .204$). We acknowledge that this is an imperfect method of addressing this question, given that different countries would not have had the same proportion of forest to begin with, but the finding nevertheless refutes the idea that lower rates of forest loss among more developed countries is a consequence of having less forests to be exploited.

3.3.2. Goal-level analyses

Individual OLS regressions for each of our predictors suggest a greater number of significant relationships between 2017 SDGI values and changes in forest cover than subsequent changes in these values between 2017 and 2020. This applies both for net change in forest cover (GFRA data, Table 3.3) and percentage tree cover loss (GFW data, Table 3.4), although the numbers of significant predictors were fewer for the GFW data than for the GFRA data in both cases.

In the case of the GFRA data, 2017 SDGI values of all goals showed significant positive relationships with net change in forest cover, with the exceptions of Goal 12 (production and consumption), which was not significant, and Goal 13 (climate change) which had a significant negative relationship. Concerning interactions with the region variable, the only significant interaction found was that for SDG 16 (peace and justice) with the Europe category; the negative sign indicating that higher 2017 values for this goal are associated with lower net changes in forest cover in Europe compared with the reference category (Africa). For changes in SDGI scores between 2017 and 2020, goals 1 (no poverty), 9 (industry, innovation and infrastructure) and 16 each had significant positive relationships with net change in forest cover, while goals 7 (energy), 8 (economic growth), 11 (cities and communities), 12 and 13 each has significant negative relationships. Again here, only one significant interaction with the region variable was identified; in this case for goal 7, where a negative interaction between change in SDGI score and the Asia category suggests that greater improvements in this goal are associated with lower net changes in forest cover there compared with the reference category.

Using the GFW data as the response, we found significant negative relationships (indicating lower levels of tree cover loss) with 2017 SDGI scores for goals 1, 3 (health), 4 (education), 6 (water and sanitation), 7 and 11. These included significant positive interactions with the Europe category of the region variable for goals 3 and 11, suggesting that higher SDGI scores for these goals are associated with higher rates of tree cover loss in Europe compared with the reference category. For changes in SDGI scores between 2017 and 2020, goals 8 and 13 showed significant positive relationships with percentage tree cover loss, while goal 16 showed a significant negative relationship. In the case of the goal 8, a significant negative interaction with the Americas category of the Region variable suggests that progress in this goal is associated with lower levels of tree cover loss in this region compared with the reference category. In the case of goal 13, a significant positive interaction with the Asia category of the Region variable suggests that progress in this goal is associated with higher levels of tree cover loss in this region compared with the reference category.

Despite large numbers of significant predictors in some cases, we note that in many cases the explained variance remains low when using predictors individually in this way. Also, as was noted earlier, the high levels of multicollinearity between many of our predictors means that these results should be interpreted with due caution.

PLSR using the 2017 SDGI scores to predict net change in forest cover (GFRA data) identified a one-component model as having the lowest RMSEP value (0.548). This one-component model used 66% of variation in the predictors to explain 30.6% of change in forest cover, and identified goals 1, 3, 4, 7, 8 and 9 (which all had positive coefficients) as making contributions greater than would be expected if all goals contributed equally. DA using these same data identified goals 3, 4, 7, 8, 9 and 16 as making greater contributions to the 40.6% of explained variation in the original model than would be expected if all goals contributed equally, again with positive coefficients in all cases. PLSR using the 2017 SDGI scores to predict percentage tree cover loss (GFW data) identified a two-component model as having the lowest RMSEP value (2.47). This two-component model used 74.1% of variation in the predictors to explain 29.1% of change in tree cover, and identified goals 1, 3, 4 and 7 (all with negative coefficients) as making contributions greater than would be expected if all goals contributed equally. DA using these same data identified goals 1, 3 and 7 as making greater contributions to the 38.8% of explained variation in the original model than would be expected if all goals contributed equally, again with negative coefficients in all cases.

PLSR using the SDGI score changes between 2017 and 2020 to predict net change in forest cover (GFRA data) also found a one-component model to have the lowest RMSEP value (0.566). This one-component model used 32.9% of variation in the predictors to explain 27.7% of change in net forest cover, and identified goals 1, 8, 9, 11 and 13 as making contributions greater than would be expected if all goals contributed equally. In this case, goals 1 and 9 had positive coefficients, while goals 8, 11 and 13 had negative coefficients. DA using these same data identified goals 7, 8, 9, 10 and 13 as making greater contributions to the 34.7% of explained variation in the original model than would be expected if all goals contributed equally. In this case, all predictors had negative coefficients except goal 9, which had a positive coefficient.

Table 3.3. Outputs from OLS regressions for all goal-level predictors used in this work, with net forest cover change from 2017 to 2020 (based on GFRA data) as a response. The following alpha values apply: * = <.05, ** = <.01, * = <.001. Table also indicates regions that showed a significant interaction (alpha = .05) with the predictor in question (based on separate models), including the sign of the coefficient. Detailed outputs from these models are provided in Appendix B.**

	SDGI score (2017)				Change in SDGI (2017 – 2020)			
Predictor	**Coefficient**	**SE**	**R^2**	**Significant regional interactions**	**Coefficient**	**SE**	**R^2**	**Significant regional interactions**
Goal 1 (No poverty)	**.0087*** **	.002	.135		**.0084***	.004	.036	
Goal 2 (Hunger and food security)	**.0149*** **	.004	.087		-.0182	.009	.030	
Goal 3 (Health)	**.0131*** **	.003	.180		-.015	.019	.005	
Goal 4 (Education)	**.0114*** **	.002	.166		-.0002	.006	-.008	
Goal 5 (Gender)	**.0092***	.004	.049		.0188	.016	.011	
Goal 6 (Water)	**.0157*** **	.004	.139		-.0021	.008	<.001	
Goal 7 (Energy)	**.009*** **	.002	.184		**-.0273***	.011	.047	Asia (-)
Goal 8 (Economic growth)	**.015*** **	.003	.193		**-.0173*** **	.004	.130	
Goal 9 (Industry, innovation and infrastructure)	**.0094*** **	.002	.154		**.0274*** **	.007	.104	
Goal 10 (Equality)	**.0067** **	.002	.068		-.0068	.004	.024	
Goal 11 (Cities and communities)	**.008** **	.002	.087		**-.0089***	.004	.034	
Goal 12 (Production and consumption)	-.0151	.004	.092		**-.0141***	.006	.042	
Goal 13 (Climate change)	**-.0123*** **	.004	.090		**-.0123*** **	.004	.090	
Goal 16 (Peace and justice)	**.0168*** **	.004	.129	Europe (-)	**.0148***	.007	.037	

Table 3.4. Outputs from OLS regressions for all goal-level predictors used in this work, with total tree cover loss from 2017 to 2020 (based on GFW data) as a response. The following alpha values apply: * = <.05, ** = <.01, * = <.001. Table also indicates regions that showed a significant interaction (alpha = .05) with the predictor in question (based on separate models), including the sign of the coefficient. Detailed outputs from these models are provided in Appendix B.**

	SDGI score (2017)			Significant regional interactions	Change in SDGI (2017 – 2020)			Significant regional interactions
Predictor	**Coefficient**	**SE**	**R^2**		**Coefficient**	**SE**	**R^2**	
Goal 1 (No poverty)	**-.0349*** **	.001	.125		-.002	.017	<.001	
Goal 2 (Hunger and food security)	-.0203	.019	.009		-.0192	.041	.002	
Goal 3 (Health)	**-.0429*** **	.011	.109	Europe (+)	.0934	.079	.019	
Goal 4 (Education)	**-.0303** **	.011	.066		.0185	.027	.004	
Goal 5 (Gender)	.0085	.016	.002		.0867	.069	.013	Asia (-)
Goal 6 (Water)	**-.0568*** **	.015	.102		.0331	.018	.027	
Goal 7 (Energy)	**-.0319*** **	.008	.126		.0251	.049	.002	Asia (+)
Goal 8 (Economic growth)	-.0235	.013	.027		**.1024** **	.034	.072	Americas (-)
Goal 9 (Industry, innovation and infrastructure)	-.0161	.009	.025		-.0332	.031	.009	
Goal 10 (Equality)	-.0062	.01	.003		.0129	.017	.005	
Goal 11 (Cities and communities)	**-.0242* **	.011	.041	Europe (+)	.0233	.019	.013	
Goal 12 (Production and consumption)	.0428	.019	.041		.0469	.026	.026	Europe (-)
Goal 13 (Climate change)	.0259	.023	.01	Asia (-)	**.0221* **	.016	.056	Asia (+)
Goal 16 (Peace and justice)	-.0265	.018	.018	Europe (+)	**-.0681* **	.029	.044	

PLSR using the SDGI score changes between 2017 and 2020 to predict percentage tree cover loss (GFW data) identified a one-component model as having the lowest RMSEP value (2.554). This one-component model used 29.9% of variation in the predictors to explain 17.2% of percentage tree cover loss, and identified goals 8, 13 and 16 as making greater contributions than would be expected if all goals contributed equally. In this case, goals 8 and 13 had positive coefficients, while goal 16 had a negative coefficient. DA using these same data identified the same three goals as making greater contributions to the 19.8% of explained variation in the original model than would be expected if all goals contributed equally, and again here, goals 8 and 13 had positive coefficients, while goal 16 had a negative coefficient.

Comparisons of the findings from both methods are shown in Figures 3.3 (GFRA data) and 3.4 (GFW data). Here we see that the outputs from the two methods are largely well aligned, albeit with some notable exceptions. Also, notable similarities and differences are evident between analyses using the two different response variables. In the case of 2017 SDGI scores, both methods using both response variables identified goal 7 as being of greatest relative importance. Also in all cases, goal 3 was identified as being of high relative importance. Goals 1 and 4 were highlighted as having high relative importance in three of the four cases (all but DA for the GFRA and the GFW data, respectively). Goals 8 and 9 were identified as important predictors of the GFRA data, but this was not the case for analyses using the GFW data.

Analyses of SDGI score changes between 2017 and 2020 show agreement on the relatively higher importance of goals 8 and 13 in explaining forest cover change in all cases. However, few other similarities are evident. In the case of the GFRA data, both methods identified goal 9 as having high relative importance, whereas this was not the case for the GFW data. Conversely, both methods identified goal 16 as an important predictor of the GFW data, but this was not the case for the GFRA data. Disagreements between the two methods were evident in the analysis of the GFRA data, including in their assignment of importance to goals 1 and 11 (identified as important in PLSR, but not DA) and goals 7 and 10 (identified as important in DA, but not PLSR).

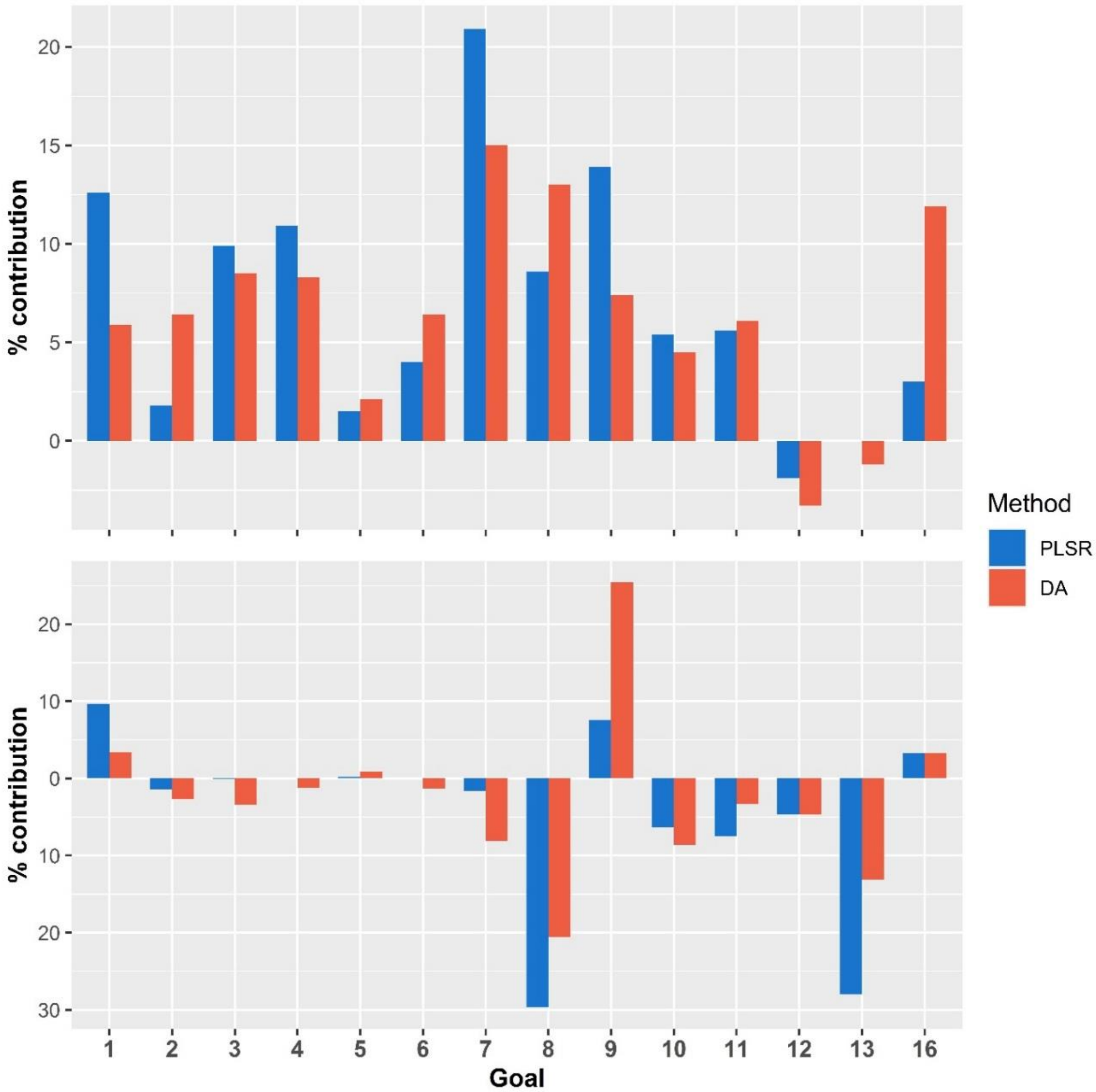

Figure 3.3. Partial least squares regression (PLSR) and dominance analysis (DA) assessments of the relative percentage contributions of the SDGs in explaining net forest cover change between 2017 and 2020 based on GFRA data. Upper plot is based on 2017 SDGI scores, and lower plot is based on changes in SDGI scores from 2017 to 2020. Direction of bars indicates sign of coefficients (upward = positive, downward = negative).

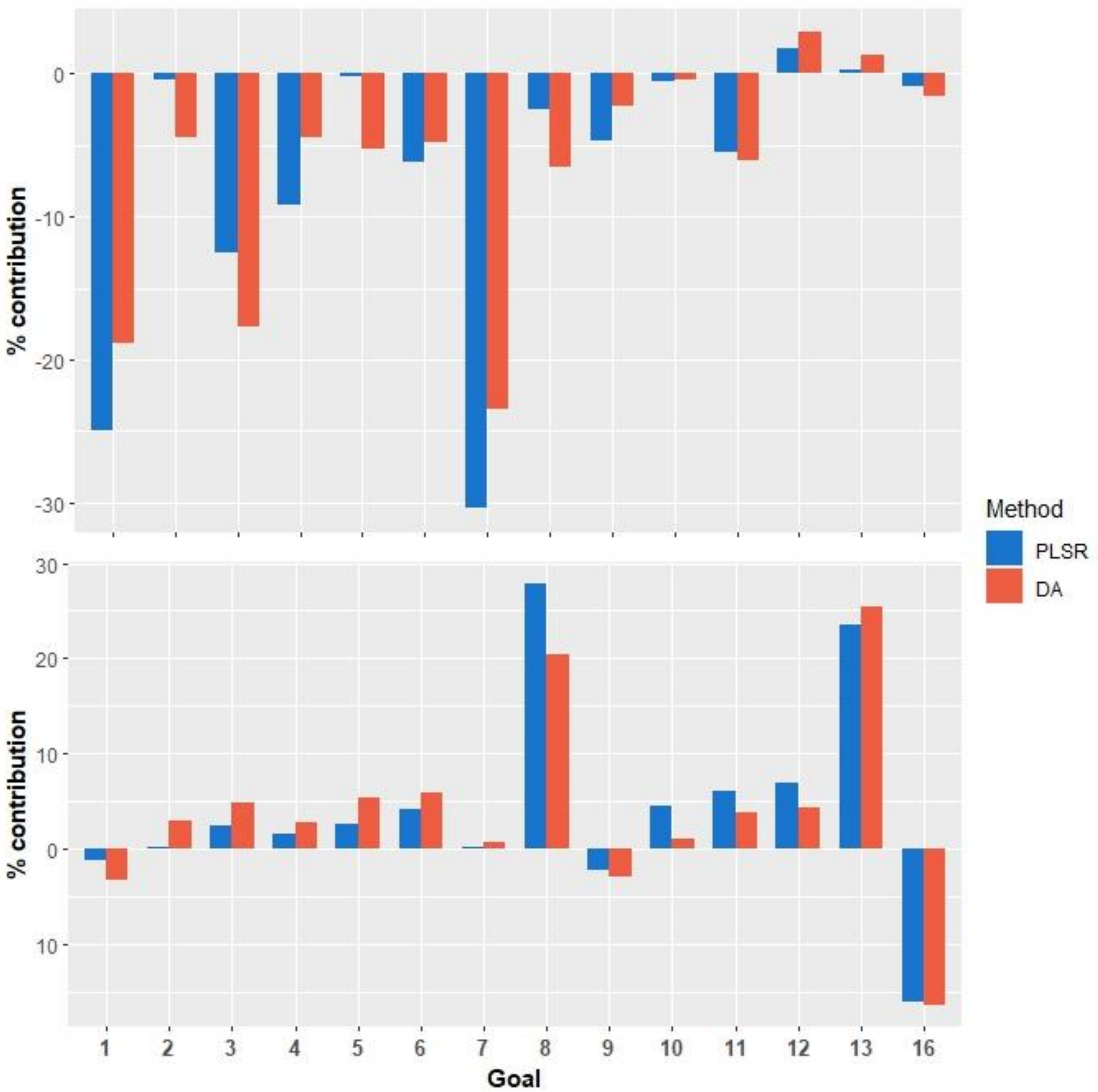

Figure 3.4. Partial least squares regression (PLSR) and dominance analysis (DA) assessments of the relative percentage contributions of the SDGs in explaining percentage tree cover loss between 2017 and 2020 based on GFW data. Upper plot is based on 2017 SDGI scores, and lower plot is based on changes in SDGI scores from 2017 to 2020. Direction of bars indicates sign of coefficients (upward = positive, downward = negative).

3.3.3. Thematic analyses

PLSR to assess the relative importance of the 2017 values of the five themes in explaining net change in forest cover (GFRA data) between 2017 and 2020 found a one-component model to have the lowest RMSEP value (0.547), using 84.9% of variance in the predictors to explain 30.2% of net change in forest cover. This model identified matters of well-being (i.e. poverty, food security and health), economics (i.e. education and economic growth) and infrastructure (i.e. energy, industry and cities) as being the most important predictors, with higher values associated with reduced forest loss/forest gains in all cases (Figure 3.5). DA using this same dataset also identified the same predictors as being most important in explaining 32% of the variation in net forest cover change, but also highlighted social issues (i.e. gender equality, equality, and peace/justice) as making an important contribution, which PLSR did not. The two methods also disagreed on the relative importance of economy and infrastructure, with PLSR identifying infrastructure as having greater relative importance than economy, and vice versa for DA. Nevertheless, both methods agreed that these are the two most important groups.

PLSR to assess the relative importance of the 2017 values of the five themes in explaining percentage tree cover loss (GFW data) between 2017 and 2020 found a one-component model to have the lowest RMSEP value (2.503), using 84.7% of variance in the predictors to explain 18% of tree cover loss. This model identified matters of well-being and infrastructure as being the most important predictors, with higher values associated with reduced tree cover loss in both cases (Figure 3.6). In contrast to our assessment using the GFRA data, this analysis did not highlight matters of economy as having high importance. DA using this same dataset also identified matters of well-being and infrastructure as being the most important predictors in explaining 23% of the variation in percentage tree cover loss. However, the two methods disagreed on the relative importance of the two themes with PLSR assigning greater importance to infrastructure than well-being, and vice versa for DA.

PLSR to assess the relative importance of value changes of the five themes between 2017 and 2020 in explaining net change in forest cover (GFRA data) between 2017 and 2020 found a two-component model to have the lowest RMSEP value (0.586). This model used 81.3% of variation the predictors to explain 22.8% of the variation in the forest change data, identifying matters of economics and sustainability (i.e. water, production/consumption and climate change) as the two most important predictors, with higher values associated with increased forest loss/lower forest gains in both cases. DA also identified these same two predictors as being most important in explaining 23.8%

of the variation in forest cover change; however, the two methods disagreed slightly on the relative importance of each, with PLSR identifying economics as having greater relative importance than sustainability, and vice versa for DA.

PLSR to assess the relative importance of value changes of the five themes between 2017 and 2020 in explaining percentage tree cover loss (GFW data) between 2017 and 2020 found a one-component model to have the lowest RMSEP value (2.563), using 82.6% of variance in the predictors to explain 16.4% of tree cover loss. As with the GFRA data, this model highlighted changes in matters of sustainability and economy as being of greatest relative importance, with higher values associated with higher levels of tree cover loss in both cases. DA using this same dataset also identified matters of sustainability as the most important factor in explaining 19.8% of the variation in percentage tree cover loss. However, in this case matters of economy were not identified as having high relative importance.

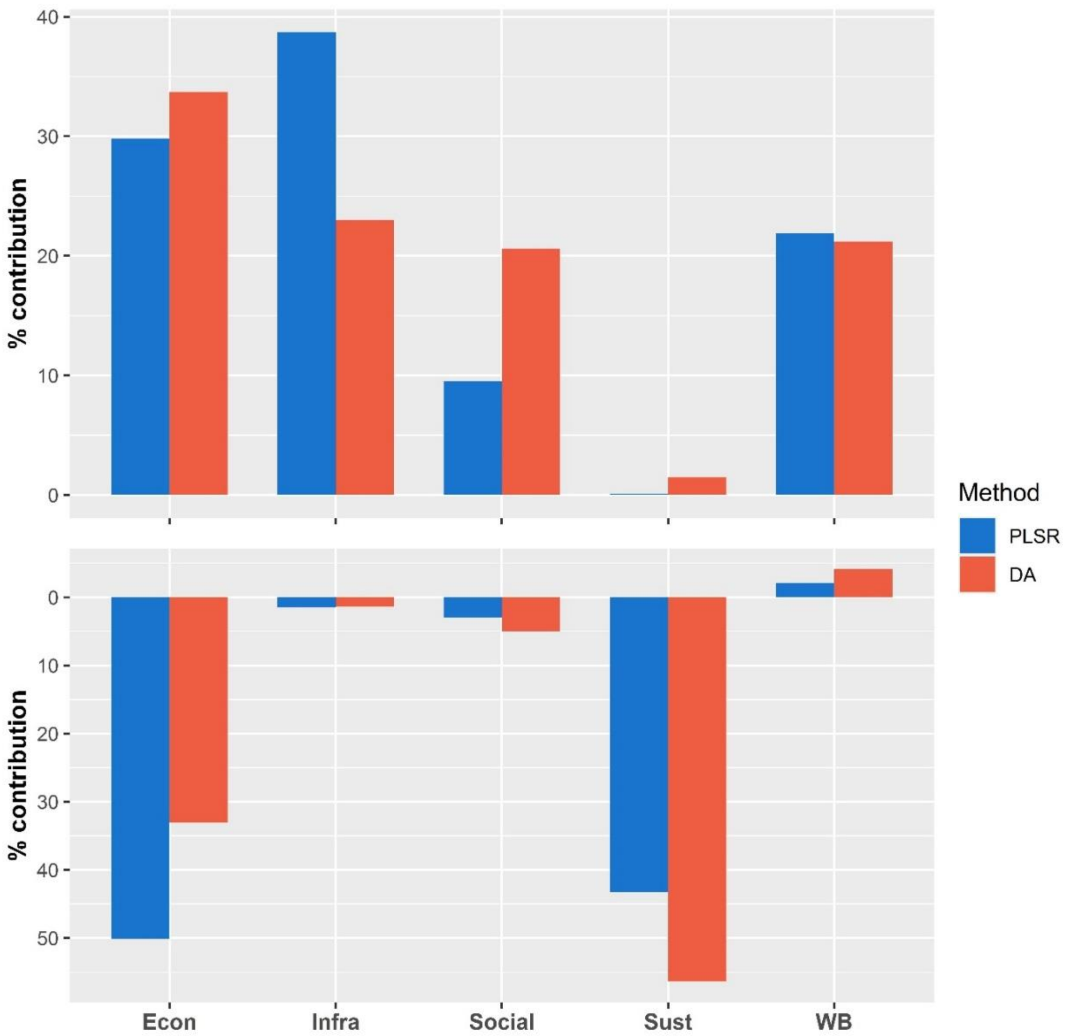

Figure 3.5. Partial least squares regression (PLSR) and dominance analysis (DA) assessments of the relative percentage contributions of five SDG groups (Econ = economic; Infra = infrastructure, Social = social issues, Sust = Sustainability, WB = well-being; see methods for variables included in each) in explaining net change in forest cover (GFRA data) from 2017 to 2020. Upper plot is based on 2017 SDGI scores, and lower plot is based on changes in SDGI scores from 2017 to 2020. Direction of bars indicates sign of coefficients (upward = positive, downward = negative).

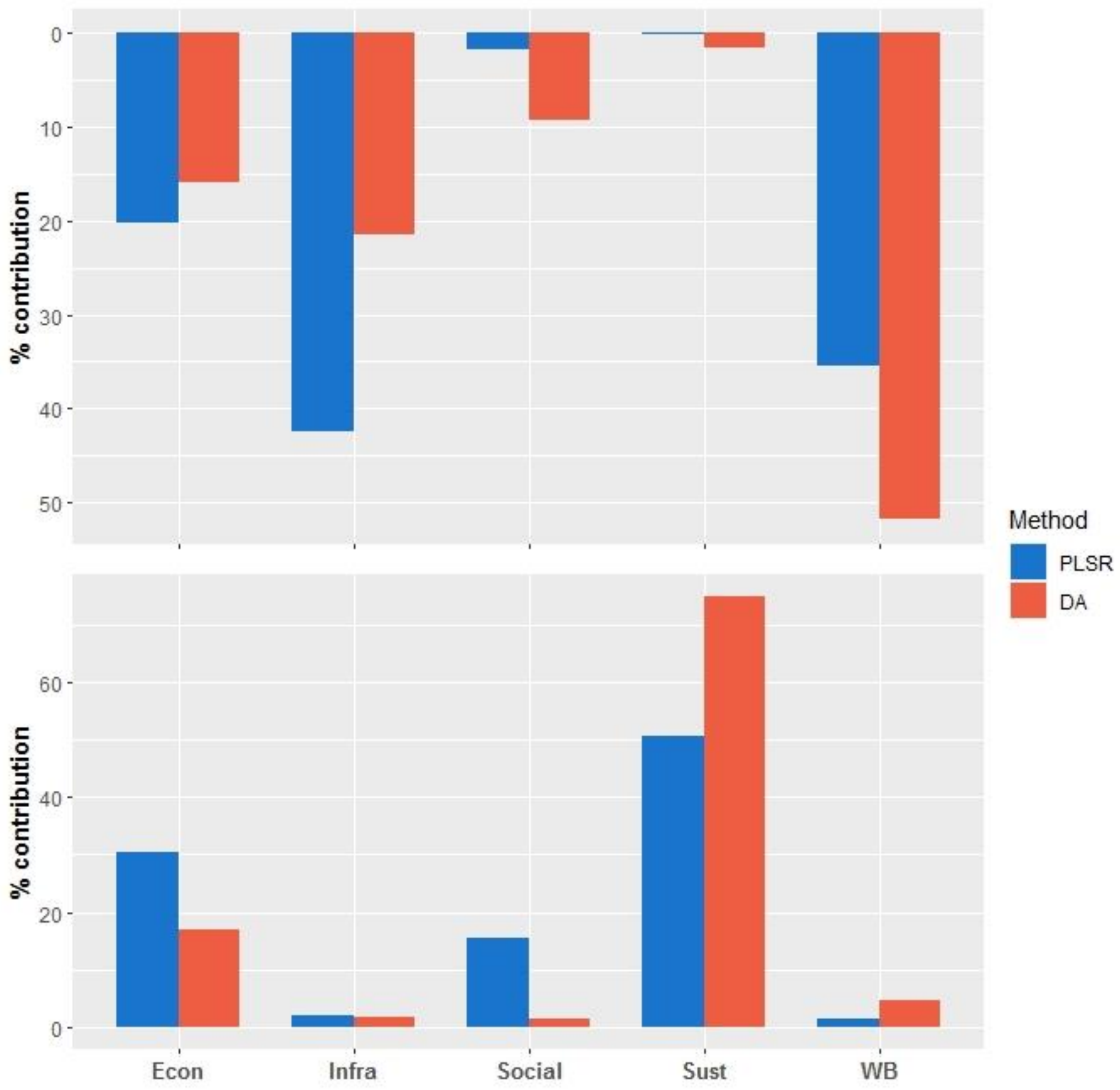

Figure 3.6. Partial least squares regression (PLSR) and dominance analysis (DA) assessments of the relative percentage contributions of five SDG groups (Econ = economic; Infra = infrastructure, Social = social issues, Sust = Sustainability, WB = well-being; see methods for variables included in each) in explaining percentage tree cover loss (GFW data) from 2017 to 2020. Upper plot is based on 2017 SDGI scores, and lower plot is based on changes in SDGI scores from 2017 to 2020. Direction of bars indicates sign of coefficients (upward = positive, downward = negative).

Repeating the above thematic analyses at the regional level suggests that the global analyses mask some heterogeneity. This is shown in Figures 3.7 and 3.8, which show regional results using the GFRA and GFW datasets as outcome variables, respectively. In terms of 2017 values for the grouped goals, we find that results for Africa are most closely aligned with our global results, including a relatively balanced contribution of grouped goals relating to well-being, economics and infrastructure to explaining net change in forest cover (GFRA data), and matters of well-being being most important in explaining percentage tree cover loss (GFW data). Also similar to our global analyses, PLSR and DA disagree on the relative contributions of certain topics (notably social topics in the case of the GFRA data and matters of infrastructure in the case of the GFW data), but both methods agree that matters of sustainability make the lowest contribution in both cases. For other regions, these similarities wane in many cases. For example, in the Americas, results from both our GFRA and GFW analyses suggest that matters of economics have played the most important role, with matters of infrastructure and well-being (GFW analysis only) possibly having played notable roles (based on PLSR analysis, but not DA), and all other groups playing more minor roles.

In Asia and Europe the results are somewhat less clear, with some divergence between results using the two methods. For Asia, results from analyses using both the GFRA and the GFW datasets found that matters of well-being, social issues and economics have played comparatively minor roles, yet while PLSR suggests that improved infrastructure has played the most important role, DA suggests that matters of sustainability is of greater relative importance. In our analysis of GFRA data for European countries, PLSR suggests that economics and infrastructure have played the most important roles, while DA suggests that social issues have been of greatest relative importance and presents the only instance where higher 2017 values appear to be associated with increase forest loss/reduced forest gains. In our analysis of GFW data for European countries, both methods agreed that matters of economics have the greatest relative importance, while PLSR (but not DA) suggests that matters of infrastructure have also played an important role. In both cases, these variables have positive coefficients, suggesting that higher 2017 scores are associated with higher levels of tree cover loss.

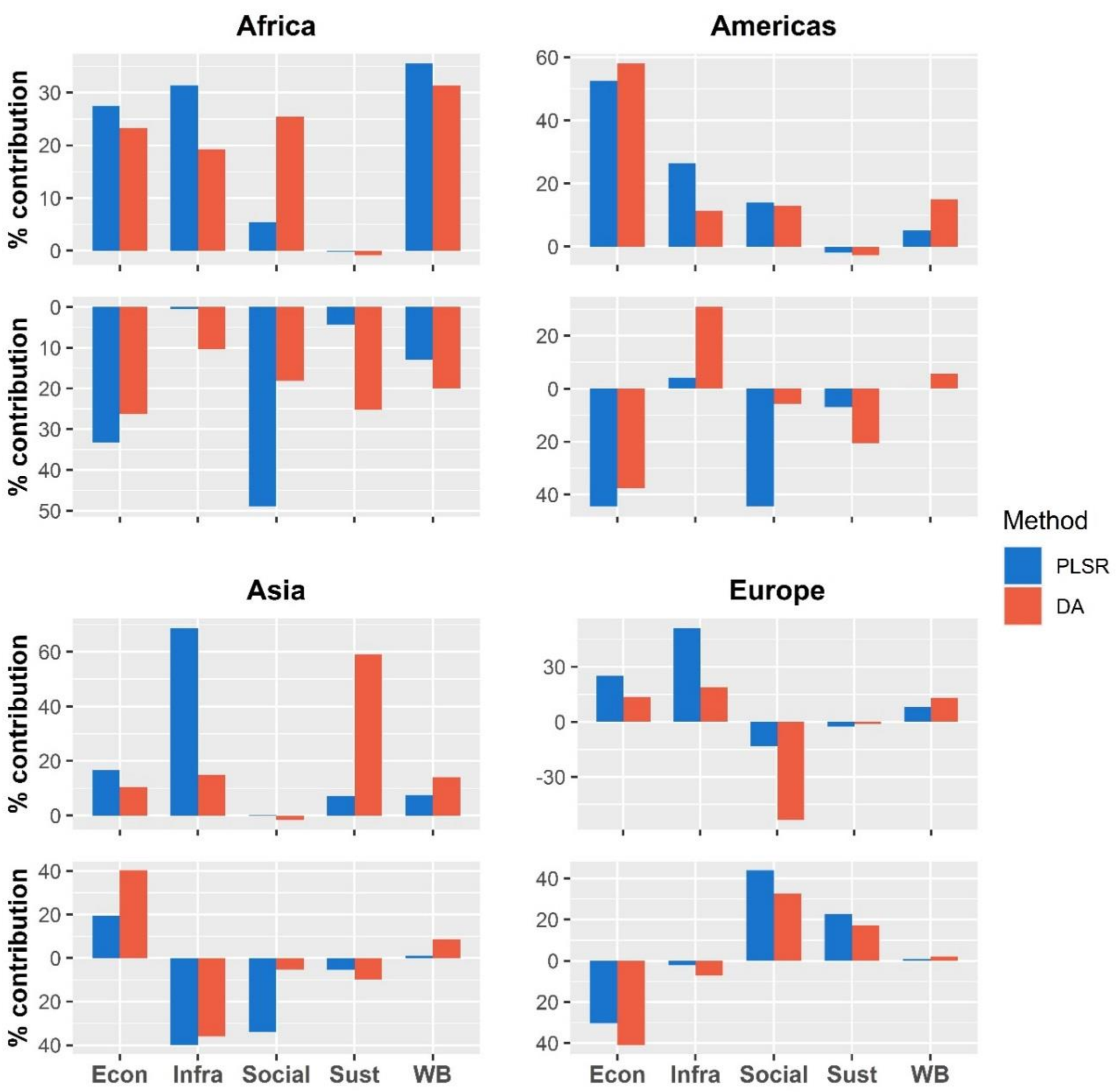

Figure 3.7. Regional comparison of partial least squares regression (PLSR) and dominance analysis (DA) assessments of the relative percentage contributions of five SDG groups (Econ = economic; Infra = infrastructure, Social = social issues, Sust = Sustainability, WB = well-being; see methods for variables included in each) in explaining net changes in forest cover (GFRA data) from 2017 to 2020. For each region, upper plots show groups based on 2017 SDGI scores, and lower plots show groups based on changes in SDGI scores from 2017 to 2020. Direction of bars indicates sign of coefficients (upward = positive, downward = negative).

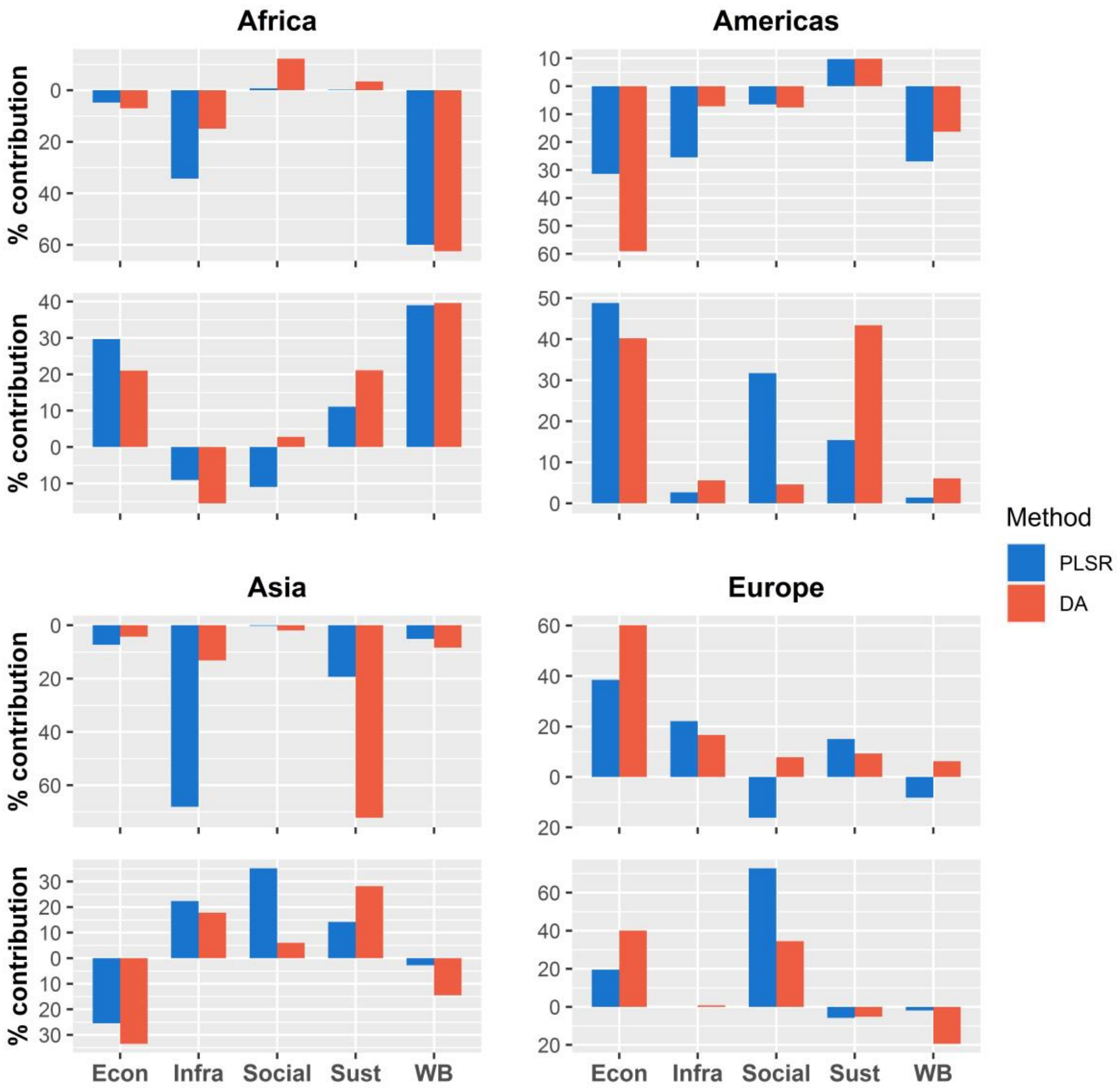

Figure 3.8. Regional comparison of partial least squares regression (PLSR) and dominance analysis (DA) assessments of the relative percentage contributions of five SDG groups (Econ = economic; Infra = infrastructure, Social = social issues, Sust = Sustainability, WB = well-being; see methods for variables included in each) in explaining percentage tree cover loss (GFW data) from 2017 to 2020. For each region, upper plots show groups based on 2017 SDGI scores, and lower plots show groups based on changes in SDGI scores from 2017 to 2020. Direction of bars indicates sign of coefficients (upward = positive, downward = negative).

Regional analyses of 2017 to 2020 score changes using the GFRA data as the outcome variable also differ somewhat from the global analysis. For most regions, findings align with the global assessment in suggesting that progress in matters of economics has been associated with negative forest outcomes. The exception to this is in Asia, where our findings suggest an important positive relationship between economic progress and forest change. In most cases, the exception being for Africa, the regional analyses disagree with the global analysis on the importance of progress in matters of sustainability. While the global analysis attributes relatively low importance to matters other than economics and sustainability, this is not always the case at the regional level, where we find high relative importance of matters such as social progress (all regions), along with well-being in Africa, and infrastructure in the Americas. Curiously, counter to the global results, we also find some cases where progress in a given area is associated with positive forest outcomes, including matters relating to infrastructure in the Americas, economic progress in Asia, and social progress in Europe.

Regional analyses of 2017 to 2020 score changes using the GFW data as the outcome also differ from the global analysis, as well as from analyses using the GFRA data, in many cases. Results for Africa, for example, found matters of well-being to be most important in explaining the outcome, while matters of economy, highlighted as most important in the global analysis of GFW data and the analysis of African countries using the GFRA data, appear to be of secondary importance. For Asia, both methods agreed that greater progress in matters of economy between 2017 and 2020 were associated with lower levels of tree cover loss. This aligns with findings from our analysis of Asian countries using the GFRA data, which also differed from the global analysis in this regard. PLSR and DA analyses using this subset of the data differed in most other cases, however. While PLSR highlighted matters of infrastructure and social issues as having high relative importance, DA did not, and instead highlighted matters of sustainability.

For Europe, and in contrast with our global analysis, both methods highlighted changes in social issues as being most important in explaining percentage tree cover loss. In the case of DA, but not for PLSR, matters of infrastructure were also identified as having high relative importance; a finding that aligns with results based on the GFRA data, but not with the global analysis using the GFW data. In the case of the Americas, results based on the GFW data were relatively well aligned with those based on the GFRA data, including suggested high relative importance of matters of economics (both methods) and social issues (PLSR only) in both cases. Findings from DA differed, however, by highlighting matters of sustainability as being important in the case of the GFW data, which was not the case when using the GFRA data.

When considering these regional analyses, it should be borne in mind that in several cases the models explained notably low proportions of variance in the outcome variable. For example, the PLSR analyses for Asia explained only 15.5% of the variance in the GFRA data and 15% of variance in the GFW data, which is the lowest among all our analyses. The explained variance for all models is given in Appendix B (Table B.7), and the topic is considered further in our discussion.

3.4. Discussion

Our analyses provide important insights with relevance to the global development agenda as it relates to the conservation of forests around the world. At our highest level of analysis – using the SDGI scores for all goals combined as a predictor – we find that countries with pre-existing high levels of development are more likely to show lower levels of forest loss, or forest gains, in the subsequent years. This is coupled with the finding that progress towards attaining higher SDGI scores is associated with higher rates of forest loss, or lower rates of forest gain. The implications of this are positive in the sense that achieving high levels of development should ultimately facilitate forest conservation, but also highlights a need for caution and pre-emptive measures to ensure that development is achieved through processes that do not place unnecessary risks on forests and other natural systems. The significant positive interaction between SDGI scores and subsequent changes in these scores (in the case of the GFRA data, but not the GFW data) suggests that particular attention should be paid to countries at the lower end of the development spectrum, as development progress in these countries could have more significant impacts on forests.

Concerning associations between individual goals and changes in forest cover, our findings indicate that higher achievements in goals relating to health and energy, in particular, are associated with mutual co-benefits in terms of forest conservation. Results also suggest that higher achievements in goals relating to poverty, education, economy/employment, industry/infrastructure and improved peace/justice are associated with positive outcomes, although the evidence is less robust in these cases. We also found that the processes of achieving goals relating to economy/employment and climate change mitigation are associated with negative forest outcomes. There is also some evidence that the process of achieving goals relating to poverty, industry/infrastructure, and peace/justice are associated with positive forest outcomes, but again here the evidence is less robust. The mechanisms underpinning these relationships are in some cases more intuitive than in others, and we discuss each of these in the following paragraphs.

The reasons that higher achievements in goals 3 (health) and 4 (education) are associated with positive forest outcome are arguably less well understood than for other goals (Carr et al., 2021). In the case of SDG 3, past work has made links between improvements in adolescent fertility rate, universal health coverage, and subjective well-being (all indicators employed by the SDGI) and positive forest outcomes (Ali and Jacobs, 2007; Reetz et al., 2012; Starbird et al., 2016). In the case of SDG 4, forest benefits are thought to arise through mechanisms such as increased employment opportunities in the non-agricultural sector, including an associated out-migration from rural (i.e. forested) areas, improved knowledge of more sustainable farming techniques, and general greater awareness of the benefits of conservation (Burns et al., 1994; Ehrhardt-Martinez, 1998; Godoy et al., 1998). In both cases, it is difficult to conceive mechanisms through which the processes involved in their achievement could impact forests negatively in any significant way, and this is evident in our findings. As such, we encourage pursuit of these goals with little need for significant environmental safeguards, and further recommend increased research into the ways that these goals relate to forests, so that conservation initiatives can actively capitalise on the benefits.

The reasons that higher achievement with respect to goal 7 (sustainable energy) should be associated with positive outcomes for forests are perhaps more clear. First, if renewable fuel sources become more common, then a reduction in the mining of terrestrial fossil fuels such as coal should result in a decline in deforestation associated with such extractive processes (Dontala et al., 2015; Ranjan, 2019). Second, an increase in the proportion of the population with access to electricity and/or clean cooking fuels should correspond with a decrease in the use of wood-based fuels for cooking and other energy needs (Agarwala et al., 2017; Brooks et al., 2016; Fall et al., 2008; Tanner and Johnston, 2017, but also see Lee et al., 2015; Trac, 2011). Although wood extraction for fuel purposes is more commonly linked to forest degradation than to deforestation (Hosonuma et al., 2012), numerous studies have recorded this as an important (although often not the leading) contributor to deforestation (Doggart et al., 2020; Geist and Lambin, 2001; Rudel et al., 2009). Although our analysis cannot reveal any specific mechanisms, our findings support past investigations (e.g. Tanner and Johnston, 2017) in suggesting that increased access to sustainable energy can have significant benefits for forests. In some cases, the processes of increasing energy provision can cause demonstrable negative forest impacts, typically through deployment of infrastructure for energy production (Fearnside, 2005; Gibson et al., 2017) and distribution (Gibson et al., 2017; Li and Lin, 2019). However, in our case this was not identified as an important predictor, perhaps because such site-based changes are not sizeable/widespread enough to be discernible in a large-scale assessment such as this. Given the apparently notable benefits for forests that can be gained through achievement of SDG 7, we encourage increased efforts to better understand and capitalise on this interaction. At the same time, however, we urge caution to ensure that any environmental impacts associated with energy infrastructure are minimised.

The topic of economic growth (goal 8) has been well studied in the context of forest impacts, including a suite of studies aiming to (dis)prove the existence of an environmental Kuznets curve (EKC) for forests (e.g. see Choumert et al., 2013). Our findings largely support the existence of an EKC, but we note that other work has shown that although per capita income is a good predictor of declining forest cover at the earlier stages of economic development, the positive impacts in more advanced economies appear much weaker (Crespo Cuaresma et al., 2017). Mechanisms underlying the relationships between economic development and forests are complex and are shaped in large part by the specific means by which such development is achieved (Stoian et al., 2019). Negative impacts may arise where growth is achieved through expanded agriculture, or based upon the extraction/use of resources that can compromise forests (Asicii, 2013; Kaimowitz and Angelsen, 1998). In other cases, however, the improved employment opportunities associated with economic growth may facilitate a reduction in forest-damaging activities, including agriculture (Kaimowitz and Angelsen, 1998; Schmook and Radel, 2008). Improvements in the economic situation of a given country can also increase demand for natural amenities and products from a wealthier population, and, depending on various factors (not least environmental governance), this may either encourage more sustainable management practices or result in unsustainable harvesting (Foster and Rosenzweig, 2003; Kahuthu, 2006). We note again here that our two predictors pertaining to economic growth are highly negatively collinear, indicating that additional progress in this goal typically becomes smaller with increasing pre-existing scores, and that in this case our analysis was unable to assess the relative importance of the two effects. Irrespective of this uncertainty, the implication remains that realisation of SDG 8 appears highly favourable in the context of forest conservation, but that extreme caution should be exercised to ensure that the process of achieving this does not jeopardise natural ecosystems.

Our findings that higher achievements in goal 9 (industry, innovation and infrastructure), as well as the process of making these achievements, may both be associated with positive forest outcomes is somewhat curious. There are reasons to expect that increases in infrastructure, and especially roads (which are a feature of target 9.1) would be associated with forest declines (Doyle and Havlick, 2009; Laurance et al., 2015). Similarly, increased industrialisation, manufacturing and market integration have all been shown to be associated with forest declines, including through deployment of necessary infrastructure and land clearance/resource extraction to support industries (De Castro et al., 2017; Pendleton and Howe, 2002). Although there are some arguments to suggest that industrialisation can promote forest (re)growth (Nagendra and Southworth, 2010; Parés-Ramos et al., 2008), our findings most likely arise from the fact that the indicators employed by the SDGI to characterise goal 9 are focused to a greater extent on the ‘innovation’ aspects than on the ‘industry’ and ‘infrastructure’ components. Specifically, of the 10 indicators included, only one, the Logistics Performance Index, has a direct link to infrastructure, with the remainder focusing on matters of information access, research output and similar topics. Though we are not aware of any research that directly links such topics to forest change, underlying mechanisms may well lie in the associated matters of education (SDG 4) and job creation (SDG 8), both discussed above. We give further consideration to the specifics of the indicators employed by the SDGI, and the importance of considering indicator choices later in this discussion.

The finding that higher achievements in matters of climate change mitigation (goal 13) have no discernible associations with forest change, but that positive progress in this area is associated with negative forest outcomes is somewhat surprising. The indicators used by the SDGI for this goal include CO_2 emissions arising from the consumption of energy and CO_2 emissions embodied in the exports of coal, gas, and oil. In both of these cases, one might expect positive associations, if any at all, given that extraction of both wood- and fossil-based fuels have been linked to deforestation in many cases (Dontala et al., 2015; Geist and Lambin, 2001; Kissinger et al., 2012; Ranjan, 2019). Closer inspection of the first of these two indicators shows that the source data (compiled by Gütschow et al. (2016) and updated annually) does not incorporate emissions from deforestation, despite the authors presenting such data elsewhere in their work. Should this element have been included as a component of the indicator employed by the SDGI, then one would have good reason to expect that our findings would look different. This does not explain, however, the negative associations observed between progress in this goal and forest cover change. We note that progress in this goal is negatively correlated with the 2017 values for a range of other goals (Figure B.1, Appendix B), meaning that countries with better pre-existing achievements in other areas are less likely to make progress towards goal 13. As such, our finding may in fact be a somewhat misleading product of the underlying data, rather than representing a meaningful relationship. Considering the well-acknowledged roles that forests can play in climate change mitigation (Waring et al., 2020), as well as the fact that climate disruption will itself likely impact forests (De Costa, 2011; IPCC, 2022; Khaine and Woo, 2015), we ultimately feel that efforts to realise this goal should be encouraged. In doing so, however, we also recommend (a) increased action to capitalise on the mitigating capacity of forests (e.g. through REDD+ mechanisms or similar); and (b) further research to determine if/how progress in this goal is indeed linked with forest declines, so that appropriate safeguards can be put in place to avoid any inadvertent environmental impacts.

A further notable finding from our goal-level analyses is that goal 2, which calls for improved food security and the eradication of hunger, was not identified as an important predictor of forest change. The topic of agriculture, which is commonly implicated in forest loss around the world (Benhin, 2006; Geist and Lambin, 2002; Laurance et al., 2014) features heavily throughout this goal, including in target 2.3, which calls for agricultural productivity to be doubled, and so one may reasonably expect this goal to have negative implication for forests. A closer inspection of the indicators employed by the SDGI for this goal reveals that no measure of agricultural productivity is included (although the index does include a measure of agricultural yield, which could conceivably provide forest benefits (Ewers et al., 2009)). Similar to goal 9, we postulate that were the SDGI to be more comprehensive in its selected indicators for this goal then our findings may well have looked different. There is also some basis to expect that achievement of targets relating to hunger and nutrition could have beneficial outcomes for forests, at least at a local scale (e.g. Belay et al., 2015), although this is not evident in our global, goal-level analysis.

Our thematic/regional analyses provide interesting insights, highlighting inter-regional variability in the relative importance of the various grouped goals, and underscoring the need to consider contextual matters when considering how matters of development and forest change interact. At a global level, the thematic analyses found that the 2017 scores relating to themes of infrastructure and well-being make notable contributions to explaining both the GFRA and the GFW outcomes (Figures 3.5 and 3.6). The theme relating to economy was also found to be important in explaining the GFRA data, but this was not the case for the GFW data. For the 2017-2020 score changes, the global thematic analyses highlighted matters of sustainability as being important in explaining the both the GFRA and the GFW outcomes. Again here, the theme relating to economy was found to be important in explaining the GFRA data, but not the GFW data.

Findings from our regional analyses indicate some key differences between the world's major regions in terms of the development themes that have been most important in explaining forest cover change. These include higher relative importance of matters of well-being in Africa, economics in the Americas, infrastructure in Asia, and both social and economic issues in Europe. By considering these findings in combination with our individual goal-level regression analyses, and particularly the significant interaction terms shown in Tables 3.3 and 3.4, it is possible in many cases to discern the specific goals that are likely responsible. For example, the significant interactions observed for goals 8 (economic growth), 7 (energy), and 16 (peace and justice) in the Americas, Asia and Europe, respectively, align with the observations noted above, and likely explain these to a large degree. Researchers, policymakers and development agencies working in each region may wish to pay particular attention these observed differences, including investigations into the mechanisms that underpin them, in order to create development strategies that avoid, and ultimately reverse, unnecessary forest loss around the world.

Regional analyses should be interpreted with due caution, keeping in mind that the lower numbers of observations likely affect the associated explanatory power (see below), as well as the fact that some variables display large reductions in variability when subset in this way. In particular, we note that for the Europe subset both of our outcome variables have notably low standard deviations compared with the global data and the other regional subsets (in the case of the GFRA data, this is attributable to a large proportion of zeros). Similarly, we note that some predictors with relatively low underlying variability also correspond with apparently low levels of reported importance. For example, among all predictors based on 2017 score values, we see that the themes of sustainability in Africa and social issues in Asia have the lowest standard deviation, and equally low relative importance in explaining forest change. It is also important to keep in mind the fashion in which we chose to group the goals for these analyses, which will logically bear influence on our findings. As noted earlier, our groupings differ from previous efforts explore grouped SDGI scores using relative importance analysis (De Neve and Sachs, 2020), which was purposeful on our part, and intended to reflect hypothetical, expected relationships with forests. For example, our choice to include a group on ‘infrastructure’ was largely due to the expectation that these goals combined would exhibit negative relationships with forests. However, as we saw from the goal-level analyses, in some cases infrastructure-related goals were associated with positive forest outcomes, which may bring into question our grouping choices, and suggest that, should the goals have been grouped differently, our findings would have looked different. Although we do not explore this topic beyond what has already been presented, this could provide an interesting line of inquiry in future investigations.

When interpreting all of our findings, it is important to keep in mind the associated explanatory power, which is summarised for all models in Appendix B (Table B.7). At its best, PLSR was able to explain 48.5% of the variance in forest cover change, yet at its worst, this value dropped to 15%. Similarly, the baseline models used to perform DA explained a maximum of 56% of the variance in forest cover change, and a minimum of 18%. While these values are comparable with those from other efforts to compare economic and social determinants of forest change internationally (e.g. Choumert et al., 2013; Ehrhardt-Martinez, 1998; Ehrhardt-Martinez et al., 2002; Leblois et al., 2017), it does not change the fact that significant proportions of the variance in the forest change data remain unexplained. This is perhaps unsurprising when one considers that the SDGI summarises matters of sustainable development at a national level. At a subnational scale, past work has shown that neither matters of sustainable development nor forest change typically operate uniformly within a country (Clement et al., 2009; González-González et al., 2021; Herrera, 2019; Wu et al., 2014), and so investigations such as this, which seek to explore interactions between both aspects at a national scale, will inherently miss such nuances. At a supranational level, there are further factors that influence forest change, for example if one country fuels some aspect of its development through depletion of resources sourced from another country (Pendrill et al., 2019). Again, such processes would not be identifiable through an analysis such as this. Lastly, we note that drivers of forest change such as fire or natural processes, which can be significant in some countries (Curtis et al., 2018) will also not be detectable in an analysis such as this. Nevertheless, despite these shortcomings, we feel that, as a cautious exploration of the links between sustainable development and forest cover change, our results remain insightful.

All analyses presented in this work are based on correlational methods, and so a further caution needs to be made concerning the attribution of causality. In the case of analyses examining 2017 values for a given set of SDGI scores there may be some basis to rule out reverse causality, given that the response variable is based on a time period that starts from 2017, but for analyses examining SDGI score changes between 2017 and 2020 this is not the case. We also acknowledge that the sheer complexity underlying matters of forest change around the world means that, even in an investigation such as this, which aims to explore a diverse range of potentially contributing factors, not all factors can be included. Nevertheless, by cautiously exploring large-scale trends, this work has been able to highlight important relationships between sustainable development and forests at the highest levels.

We also note that our analyses do not consider interactions between different aspects of the development agenda. This could represent an important limitation to our work, as a number of studies have established that multiple SDGs can interact to influence a given outcome (Lim et al., 2018; Lusseau and Mancini, 2019), including forests (Carr et al., 2021; Swamy et al., 2018). Moreover, studies have shown that the ways that development-related variables affect forests can be mediated by additional, external factors. For example, the effects of economic growth are thought to be mediated both by a country's initial levels of forest cover (Ewers, 2006) and by rural population density (Cropper and Griffiths, 1994). Although techniques exist to include interaction terms in PLSR (Næs et al., 2011), these methods are not well established, and we are not aware of any efforts to examine interactions between predictors using DA. Although our data do not have sufficient degrees of freedom explore such interactions, the topic would likely provide a useful line of inquiry if the methodological challenges could be overcome.

Two final caveats associated with our analyses relate to the timeframes examined and the indicators used to develop the SDGI. Concerning timeframes, we assess development and forest changes over a three-year period, which was largely a matter of convenience based on the input data available to us, and not necessarily an inference on our part that this is an optimal timeframe to examine. A three-year window is nevertheless likely to be appropriate, given that we do not necessarily expect all impacts to manifest immediately following a given development change, but we acknowledge that some impacts may be even slower to manifest, and so would not be identified in our analysis. Concerning the indicators employed by the SDGI, we have already noted above (for SDGs 2 and 9) that the SDGI does not necessarily reflect the full suite of targets and indicators contained within the SDGs, and that this is likely to have affected the outcomes of our analyses. Other notable gaps in the SDGI's composite indicators include matters of access to economic resources, basic services, and land/property (target 1.4), the economic contributions of tourism (target 8.9), and access to housing (target 11.1), which are all thought to have implications for forests (Brandt and Buckley, 2018; Friesen et al., 1995; Naughton-Treves and Wendland, 2014). There are likely other missing components from the SDGI that will have shaped the outcomes of our analyses, and ultimately their capacity to convey a holistic picture of how achievement of each goal could affect forests. Nevertheless, the SDGI arguably provides the most comprehensive assessment of country-level progress towards the SDGs ("Tracking progress on the SDGs," 2018), and so we remain confident that our findings are insightful and will hopefully encourage, inter-sectoral dialogue, research and action to help maximise the overall sustainability of the SDGs.

3.5. Conclusions

We have assessed the empirical relationships between achievement of the SDGs and changes in forest cover around the world using appropriate methods to overcome multicollinearity in our data and low sample size to predictor ratios. Our findings highlight in particular that matters of health, education, energy, economy, innovation and climate change mitigation are among the most important development-related factors that can have implications for forest change around the world. In most cases, higher achievements are associated with positive outcomes for forests, but for some goals (most notably economic growth and climate change mitigation) the process of progressing towards higher achievement is associated with negative forest outcomes, and so we urge caution. Our regional analyses highlight heterogeneity in the relative importance of different aspects of the SDGs in shaping forest change in different parts of the world, and underscore a need to consider contextual factors when examining topics such as this. Overall, despite challenges surrounding the underlying data, we feel that our analyses provide important insights that will hopefully serve to facilitate greater consideration of forest conservation among sectors not directly concerned with matters of the environment.

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Chapter 4 Assessing risks and opportunities for tropical forests in the face of sustainable development

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The reference style and the figure, table and section numbers have been formatted to be continuous throughout the thesis.

Abstract

Understanding how countries' future development pathways could affect forests can help to avoid negative impacts and instead promote positive ones. Exploring this topic requires knowledge of which areas of the development agenda are likely to show the greatest progress and how these expected changes relate to the drivers of deforestation and forest degradation that are currently affecting forests, or which may emerge as result of development-related changes. We present an assessment framework that draws upon a range of data types to identify specific components of the development agenda that are likely to be of greatest relevance to forest conservation at the national level. We then assess the potential magnitude and likelihood of imminent changes in these areas over the short- to medium-term. We use this framework to assess 48 tropical countries, providing insights into the areas of sustainable development that are most likely to provide risks, opportunities or enabling conditions for forest conservation across much of the tropics. Our findings suggest that in many countries, ongoing risks to forests associated with agriculture, transport infrastructure and urban infrastructure are likely to worsen, and that new risks from energy infrastructure could emerge. Opportunities relating to poverty reduction, tourism and industry, among others, will require care to ensure that associated progress results in positive rather than negative forest impacts. Enabling conditions associated with improved education, inclusive decision-making and effective governance, among others, still have much room for improvement, and the anticipated likelihood of imminent progress in these areas varies between countries and regions. We discuss the implications of our findings for policymakers and development agencies, and consider potential future applications of our assessment protocol to topics other than forests.

4.1. Introduction

The 169 targets that comprise the UN Sustainable Development Goals, and which provide a framework for a universally prosperous and sustainable future, are acknowledged as having numerous synergies and trade-offs, which can respectively help or hinder the achievement of two or more targets (Anderson et al., 2021; Nilsson et al., 2016; Pradhan et al., 2017). Understanding synergies and trade-offs within and among the SDGs, and identifying where (and to what extent) they are (un)likely to emerge, can allow governments and planning agencies to adjust their policies and interventions to help mitigate against anticipated negative outcomes and facilitate positive ones (Nilsson et al., 2018, 2016). In this regard, consideration of human-environment interactions is particularly important, as numerous synergies and trade-offs are known to exist between environmental and non-environmental elements of the SDGs (Scharlemann et al., 2020). Countries must carefully consider the order and manner in which they choose to address different aspects of the development agenda in order to promote, rather than inhibit, effective nature conservation alongside other non-environmental goals and targets (Waage et al., 2015).

In this work, we consider synergies and trade-offs between the wider development agenda and one specific aspect of the environment, forest ecosystems. The work responds to research question 3 of this thesis, which asks "which SDG targets might we expect to result in risks, opportunities or enabling conditions for the conservation of tropical forests in the short- to medium term?". The conservation of forests receives notable attention in the SDGs, particularly under SDG 15 (life on land), where the topic features in three of its twelve targets (Inter-Agency and Expert Group in Sustainable Development Goal Indicators, 2016). Forests are also key to achieving several other SDG targets, including those relating to climate, water, health and economic growth, among others (Sayer et al., 2019). At many locations around the world, and especially in tropical regions (which form the focus of this study), forests are being depleted, often through processes associated with sustainable development (e.g. expansion of transport and energy infrastructure (Gibson et al., 2017; Laurance et al., 2015, 2009) or the production of food (Laurance et al., 2014), among others). Given that a high proportion of tropical countries are considered ‘underdeveloped’ (Permanyer and Smits, 2020), the magnitude of potential damage to forests as they pursue progress towards achieving the SDGs could be significant. Concurrently, however, these countries also have the potential to develop in areas that are associated with reduced damage to forests, including matters of governance (Smith et al., 2003) and education (Godoy and Contreras, 2001), among others.

Past efforts to anticipate how development trajectories could affect forests have generally used what can be collectively referred to as ‘systemic models’, which includes integrated assessment models, agent-based models, and a variety of others (see den Herder et al., 2014 for a review). Essentially, these methods work by linking multiple features from a whole system (or at least part of it) in a quantitative way, based on assumed or previously observed relationships. This can include higher-order interactions between model components (i.e. relationships between three or more variables), as well as causal feedback loops. Models are then used to assess how changes in one part of the system will manifest as changes in another, for example, a change in a forest indicator of interest, typically comparing two or more hypothetical scenarios, and their outputs considered by relevant stakeholders to help inform decisions around policies and possible interventions (den Herder et al., 2014).

Systemic models typically necessitate a trade-off between model complexity and robustness of the results obtained (Castro et al., 2018). Models with reduced complexity may fail to integrate all relevant sectors and variables, which will limit robustness of the outputs (Aggestam and Wolfslehner, 2018). Conversely, with increasing complexity comes reduced reproducibility (as specialised knowledge is usually required to do so), as well as reduced interpretability, which has been noted as a common concern among stakeholders wishing to make decisions based on model outputs (Alcamo and Henrichs, 2008; Castro and Lechthaler, 2022; den Herder et al., 2014). All systemic models, including those pertaining to forests, rest on inherent assumptions of one form or another. Common assumptions include that previously observed relationships will persist in the future and/or in other contexts, and that humans will behave in a particular way at a future time (Trubins et al., 2019). Should these assumptions prove incorrect, which is invariably the case in many instances, it will lead to erroneous model outputs (Aggestam and Wolfslehner, 2018; den Herder et al., 2014). Work comparing systemic models that differ in their assumptions and/or composition has shown that small changes can notably alter the model outputs (Blujdea et al., 2021; Schmitz et al., 2014), which raises questions over the level of faith that should be placed into such models for informing decision-making around important subjects.

Several notable attempts have been made to use systemic models to assess how changes in the wider development agenda could affect the natural environment, including forests (Hughes et al., 2021; Randers et al., 2019). However, these are subject to the same issues of uncertainty and interpretability described above, and we are not aware of any cases where these have directly informed policies relevant to environmental conservation. Given the myriad contextual factors that shape if and how forests will be affected by changes in the development agenda, relationships observed in one location are unlikely to persist elsewhere in many cases, and it is therefore unlikely that a universally accurate predictive model will ever be developed. Nevertheless, an urgent need remains for those engaged in helping to achieve the SDGs to adequately consider the impacts of anticipated changes on forests, and it is our opinion that a lack of certainty around certain complexities (e.g. higher-order impacts and feedback loops) should not prevent due consideration of the potential impacts for which existing knowledge is better established.

By examining development indicators from SDG targets with known potential implications for forests (e.g. from works such as (Carr et al., 2021) and (Katila et al., 2019)), and by linking these to known drivers of forest loss/degradation, we suggest that it is possible to identify aspects of the development agenda that may require attention in order to maximise forest conservation efforts. Our approach does not rest on any assumptions that a change in a given aspect of the development agenda will be guaranteed to result in a specific outcome, but instead highlights areas for which anticipated development progress could potentially result in risks, opportunities or enabling conditions for the conservation of forests, based on knowledge from past research. Based on this, policymakers and development agencies will be better able to consider the possible implications of their proposed development trajectories for forests, and make necessary adjustments in order to minimise trade-offs and maximise synergies.

In the context of forest impacts, SDG targets can be thought of as either ‘benign’, or resulting in possible ‘risks’, ‘enabling’ conditions or ‘opportunities’ (Carr et al., 2021). ‘Benign’ targets are those not expected to affect forests in any way. ‘Risk’ targets are potentially associated with negative forest impacts, which includes agriculture (e.g.

target 2.3, double agricultural productivity) and infrastructure (e.g. for energy (target 7.b), transport (target 9.1), housing (target 11.1)). 'Enabling' targets are associated with conditions that enable forest conservation, which can include education (e.g. target 4.1), inclusive decision-making (e.g. targets 5.5 and 11.3), and sound governance (e.g. targets 16.5 and 16.6). 'Opportunity' targets are those for which forest outcomes can be either positive or negative, depending on context and/or the specifics of how the target is achieved. Examples include target 8.9 (increased tourism), which can both encourage forest conservation to attract visitors, but also deplete forests to make way for necessary infrastructure and to meet increased demand on forest resources (Brandt and Buckley, 2018)), and target 9.2 (increased industry and manufacturing), which can cause damage through associated infrastructure, pollution and influxes of workers, but can also be beneficial if it promotes a shift away from employment in agriculture.

Risk, enabling and opportunity targets manifest as forest impacts via drivers of deforestation and forest degradation (hereafter 'drivers'), which can be thought of as either direct (sometimes referred to as proximate) or underlying (Geist and Lambin, 2002). Direct drivers are activities or occurrences at the local level, such as illegal logging or agricultural expansion, that directly affect forests, while underlying drivers are fundamental social processes, such as political matters or demographic factors that underpin the direct causes. Direct drivers typically operate at the local level, while underlying drivers can operate from local to national levels, and may even involve multiple countries. Disentangling and exploring the ways in which future development trajectories may impact upon forests requires understanding of how a focal country (or some other geographic area) will pursue its development objectives, as well as any direct or underlying drivers that are either playing a role in ongoing forest change (and therefore have the potential to be exacerbated or mitigated) or which may emerge as a result of some development-driven change.

Our framework identifies specific components of the development agenda likely to be of relevance to forest conservation at the national level over the short- to medium-term, and subsequently assesses the possible magnitude and likelihood of imminent changes in these areas. Our framework is based on the understanding that all changes to forests (whether positive or negative) manifest via drivers. It therefore follows that any external forces affecting forests (including those arising from progress towards development objectives) must be operating through the mitigation, exacerbation or creation of one or more drivers. It is important to keep in mind that not all drivers are affected/initiated by the same aspects of the development agenda, and also that multiple different components can bear influence on one or more drivers at any one time. There exists a large body of literature documenting how various aspects of development can affect forests, as well as on drivers and the factors thought to influence them, and it is based upon such information that we draw links between drivers and specific SDG targets in this work (see Materials and methods). A summary of the information on links between drivers and SDG targets is provided in Appendix C (Tables C.1 to C.3).

Where target-driver links exist, progress towards achieving the target in question can result in one of several outcomes (Figure 4.1). Where an enabling target is linked to an ongoing driver, then any progress towards achieving the target could help to mitigate the driver. However, if no ongoing drivers have links with a given enabling target, then progress towards achieving this target will (despite being highly desirable for other reasons) likely have minimal relevance for forest conservation. Where a risk target is linked to an ongoing driver, then any progress towards achieving the target could exacerbate the existing threats associated with the driver. If no ongoing drivers are linked to a given risk target, then progress towards achieving this target may result in emerging risks through one or more novel drivers. In the case of opportunity targets, which can present either risks or enabling conditions depending on contextual factors (including the specifics of how the target is addressed (Carr et al., 2021)), either of the four aforementioned outcomes could result. Where an opportunity target is linked with an ongoing driver, then progress towards its achievement could result in either mitigation or exacerbation of the driver, and where the same target is not associated with any ongoing drivers, any progress made may either result in an emerging risk from a novel driver, or in no forest-related outcome at all.

Having established the key driver-target links for a given focal area, two further questions are of interest: (1) ‘what is the potential extent of impacts on associated drivers of achieving a given target?’ and (2) ‘what is the likelihood that progress in targets deemed to be of importance will occur in the imminent future?’. To investigate the first of these questions, it is appropriate to use data pertaining directly to the SDG targets themselves (e.g. official SDG indicator data, or similar) to quantify the remaining progress required until the target is considered 'achieved'. A greater level of required progress is indicative of greater potential for significant forest impacts. Investigating the second question is challenging, not least because many components of the development agenda are subject to myriad factors that mean that progress is rarely guaranteed. Our framework rests on the expectation that countries that have either exhibited recent progress in, or are clearly prioritising actions to address a target are more likely to achieve imminent progress than countries for which neither applies, and that countries where both aspects are true are more likely still. We apply this logic to selected countries and SDG targets in order to classify their current status as either 'poor', 'medium' or 'good', and the likelihood of imminent change as either 'unlikely', 'possible' or 'likely' (see Materials and methods).

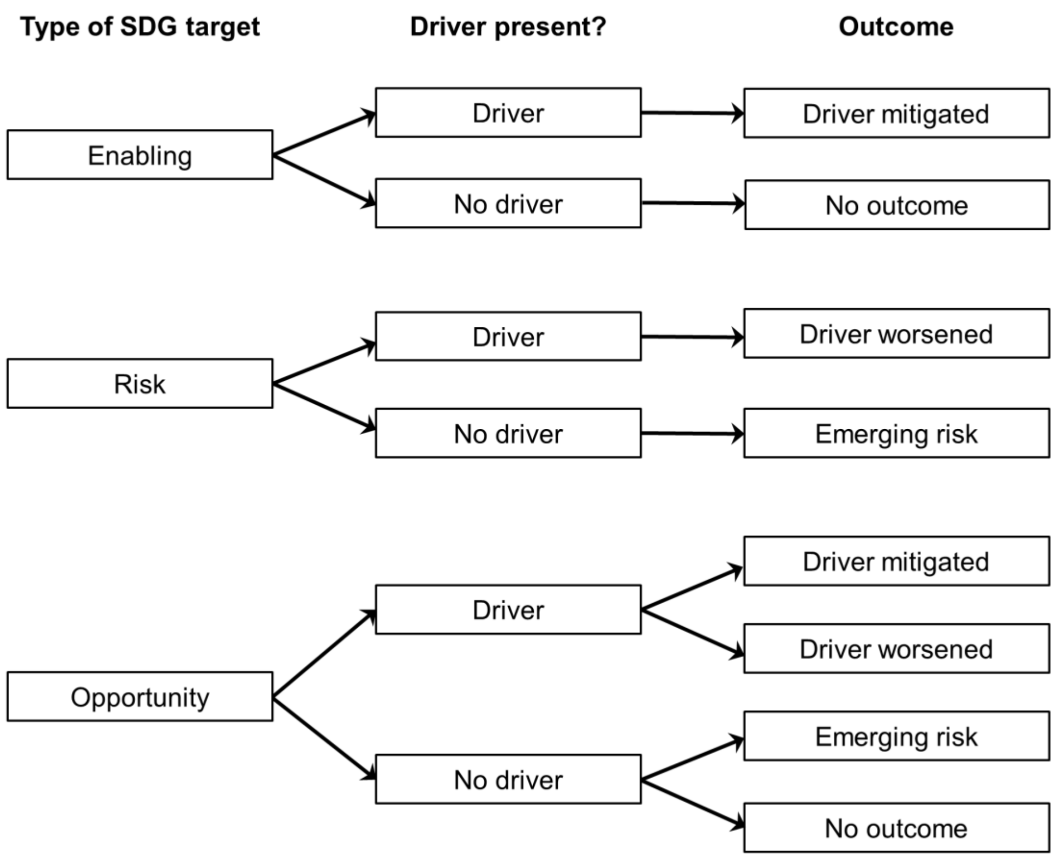


Figure 4.1. Illustration of how enabling, risk and opportunity SDG targets can either mitigate, worsen or create drivers of deforestation and forest degradation.

By combining outcomes from the two questions posed above, we can characterise the key areas of development likely to affect forests in terms of both the potential magnitude of their impacts and the likelihood that any progress will actually occur. The process through which our framework combines these various information types to derive a final assessment is illustrated in Figure 4.2. Our approach yields one of nine possible combinations, which, depending on the nature of the target itself (i.e. risk, opportunity or enabling) can provide target-specific policy recommendations that governments or other agencies could enact in order to minimize risks or facilitate benefits to forests (Figure 4.3).

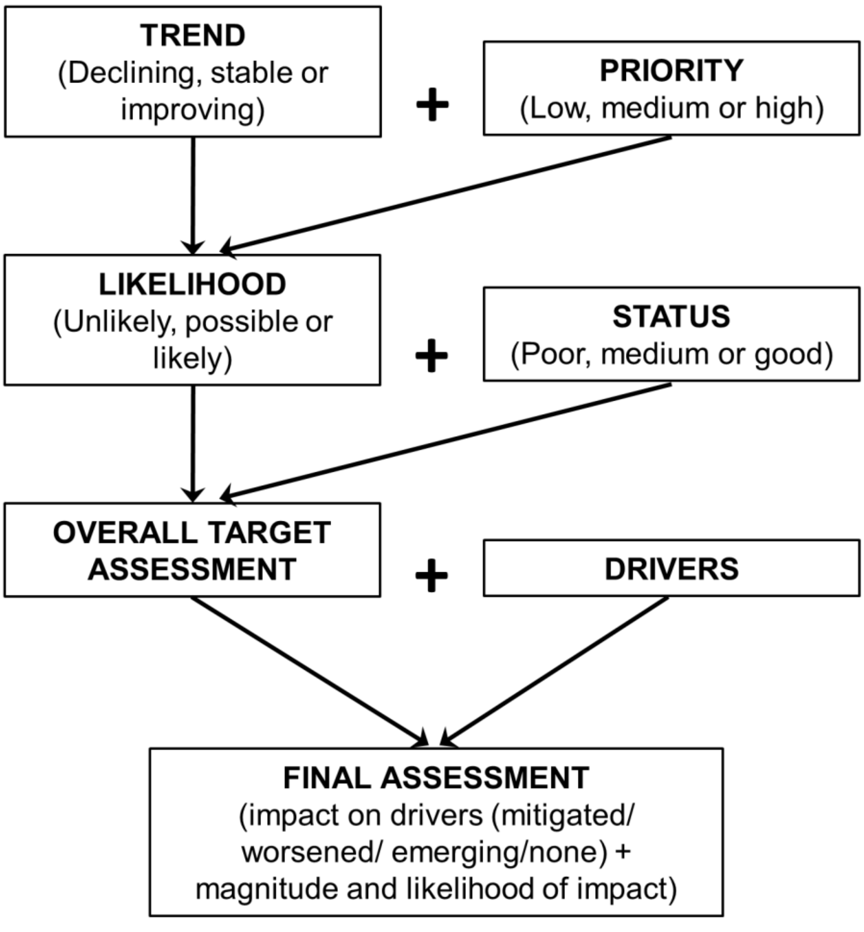


Figure 4.2. Illustration of our assessment framework. For each SDG target, data on recent trend and assigned priority are combined to assess the likelihood of progress. This is combined with an assessment of the current status (indicative of the scale of potential progress) to derive an overall target assessment, which is further cross-referenced with information on national-level drivers to determine whether the anticipated target changes identified are expected to interact with existing (or create novel) drivers of forest change, as shown in Figure 4.1.

Figure 4.3. Policy responses that can promote synergies and avoid trade-offs for forest conservation vary for risk (red), opportunity (blue) and enabling (green) targets, and according to current status and likelihood of imminent change. Following individual target-level assessments, this guide can be used to help identify an appropriate response.

Using this framework, we assessed the potential impacts of 24 selected SDG targets (five ‘risk’, nine ‘opportunity’ and ten ‘enabling’ targets) on existing and possibly emerging drivers for 48 tropical countries spanning three major world regions (Africa, Asia/Pacific and Latin American/Caribbean (LAC)). Data for 25 SDG indicators (or appropriate proxy data) were used to assess the current status and recent trends of each country with respect to 24 forest-relevant SDG targets (one opportunity target was split into one risk target and one enabling target). National development plans were reviewed in order to gauge the level of government priority assigned to each target, and these two elements combined to provide an overall assessment of each target for each country. Target assessments were linked with information on the ongoing drivers in each country, gathered through literature reviews, in order to assess if/how anticipated development progress in each country might be expected to interact with ongoing (or potentially emerging) issues surrounding forest conservation.

This paper targets those engaged in sustainable development and/or forest conservation in the tropics, and hopes to provide them with an early indication of the aspects of national-level sustainable development that may require attention in order to help minimise damage to forests, and instead facilitate their conservation. The work is not intended as a definitive forecast of how the SDGs will affect tropical forests, but rather as a means for stakeholders, policymakers and development agencies to easily identify how anticipated changes may (or may not) potentially affect forests, for better or for worse. Based on this information they should engage in follow-up discussions, with a view to making their development trajectories more environmentally sustainable.

4.2. Results

For 48 tropical countries, we characterised 24 SDG targets in terms of their (i) relevance to ongoing or potentially emerging drivers of deforestation and forest degradation; (ii) magnitude of progress that can feasibly be made (indicative of the potential scale of any associated impacts); and (iii) the likelihood that progress will actually be made. In doing so, we generated 1,167 separate assessments (data were unavailable for 81 cases, or 6.5% of a possible 1,248). A detailed breakdown of all assessment components is provided in Appendix C, Tables C.5 to C.8.

To provide a visual overview of our data we present a bivariate heat map (Figure 4.4) which depicts the current status of each country for each target (ranging from ‘poor’ (blue) to ‘good’ (green)) in combination with the likelihood of progress (ranging from ‘unlikely’ (light shade) to ‘likely’ (dark shade)). Also shown in these figures are cases where targets are not linked to an ongoing driver and either present a potential future risk or opportunity (orange cells) or are not expected to have an imminent impact (beige cells). Our intention is that the assessments presented in this figure can be easily cross-referenced with the policy implications given in Figure 4.3.

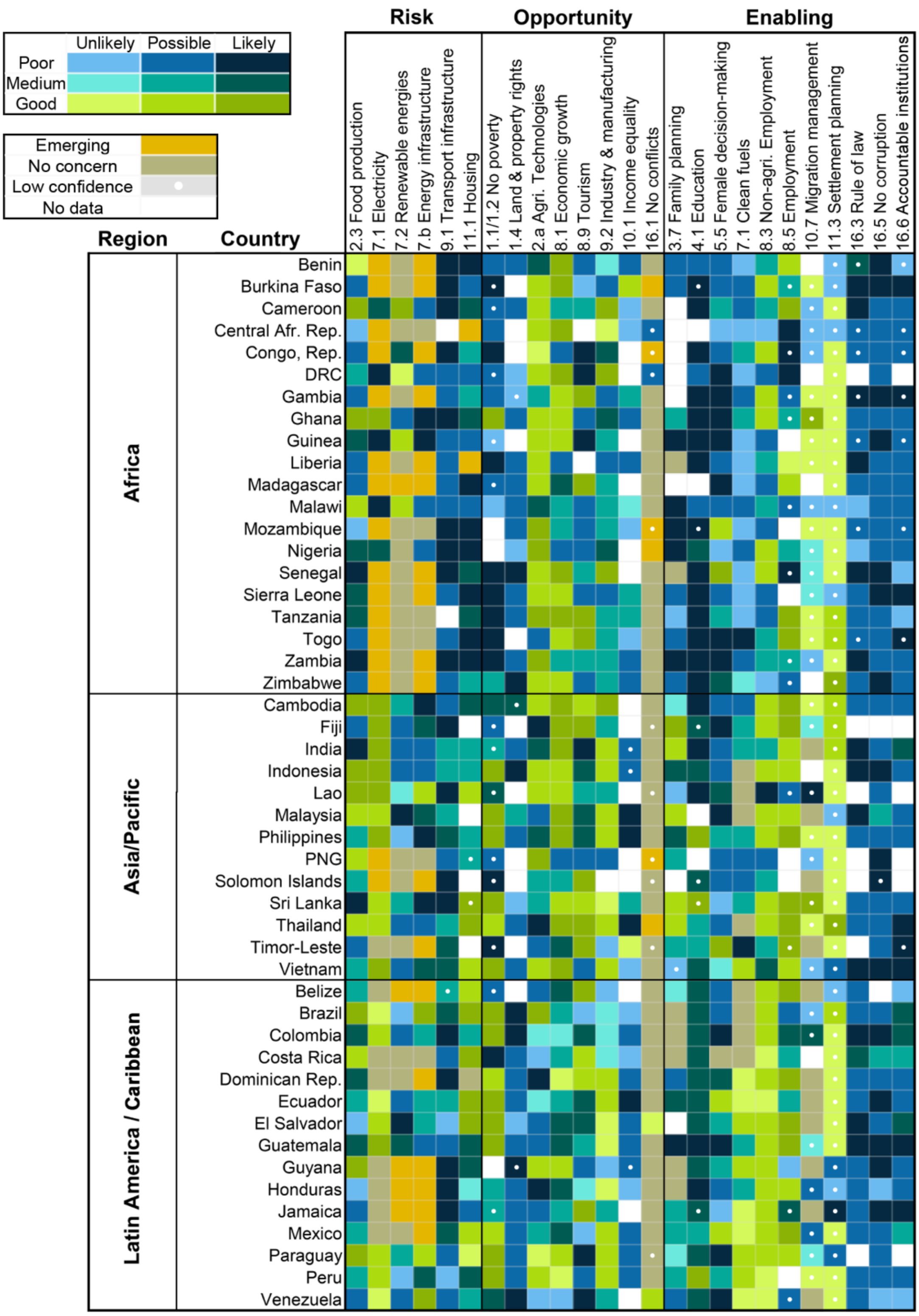


Figure 4.4. Country assessment summaries for all 25 development indicators included in this work. Legend axis showing current target status (ranging from blue to green) is based on indicator data for the most recent years available. Legend axis showing likelihood of imminent change (ranging from light to dark) is based on a combination of recent trend in each indicator over a 10-year period and level of priority assigned to each target by countries in their national development strategies. ***(Legend continues over page)***

Figure 4.4. ***(Legend continued from previous page)*** **Emerging risks/opportunities are cases where targets are not linked to existing drivers, but where a target's status was assessed as 'poor' or 'medium', and likelihood of imminent change was assessed as 'possible' or 'likely'. Cases marked as 'no concern' show enabling targets that are not linked to existing drivers, or risk/opportunity targets not linked to existing drivers and with current status assessed as 'good' and/or imminent change assessed as 'unlikely'. White dots show cases where assessments of either status or trend are based on information gathered from the literature review, rather than from the primary source data used in other cases.**

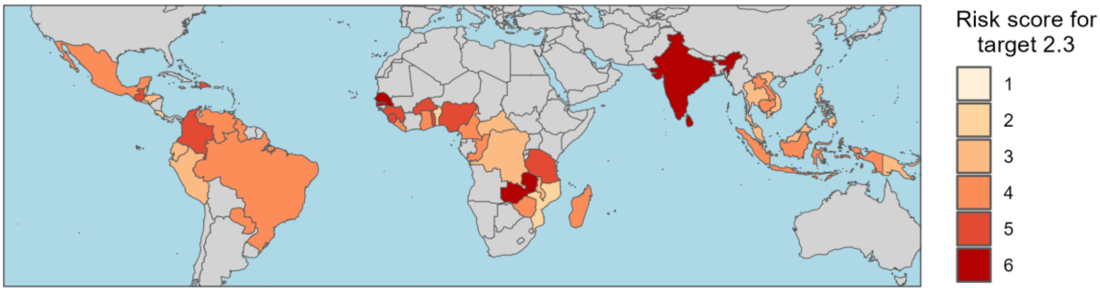
We also present our results in the form of maps that show the indicative scores for each target/country considered. Possible scores range from zero to six (see Materials and methods for full details), with higher scores indicating that a country has significant remaining progress to make in order to achieve the target in question, that notable progress has been achieved in the last decade, and/or that the target is being treated with high priority by governments, and the highest possible scores occurring where all three of these criteria are met. For each target, we test for differences in these scores between regions using one-way ANOVAs.

Lastly, we combine results from all targets of the same type ('risk', 'opportunity' or 'enabling') to derive metrics of 'cumulative impact' and present these as maps. While these maps do not imply that different components of the development agenda act additively in terms of their risks or benefits to forests, they do convey additive complexities from a wider range of socio-economic factors, which should all be considered by conservation and policy-making agencies.

4.2.1. Risk targets

Our findings on increased agricultural productivity (risk target 2.3) convey a complex picture, with few clear patterns emerging within or between regions (Figure 4.5), and no significant differences between continents in terms of target scores ($F(2, 45) = 0.415$, $p = 0.66$). As has been widely noted elsewhere (Benhin, 2006; Franks et al., 2017) risks to forests from agriculture are of high immediate relevance across the tropics. Accordingly, we recorded at least one of the two drivers associated with target 2.3 (small-scale agriculture and commercial agriculture) in all countries in this assessment.

Generally speaking, relatively low proportions of countries were assessed having 'poor' status for this target, although we note that this target is unbounded, having no defined endpoint to indicate 'success', and so high current productivity is, in this case, less indicative of reduced likelihood of further increases. Approximately 50% of countries from each region were recorded as having made notable progress in this target in recent years, and more than 70% of countries from each region were assessed as prioritising increases in agricultural outputs. The four countries with the greatest potential and highest likelihood of progress in this target are India, Senegal, Sri Lanka and Zambia, but our findings suggest that risks to forests from agriculture could continue across much of the tropics.



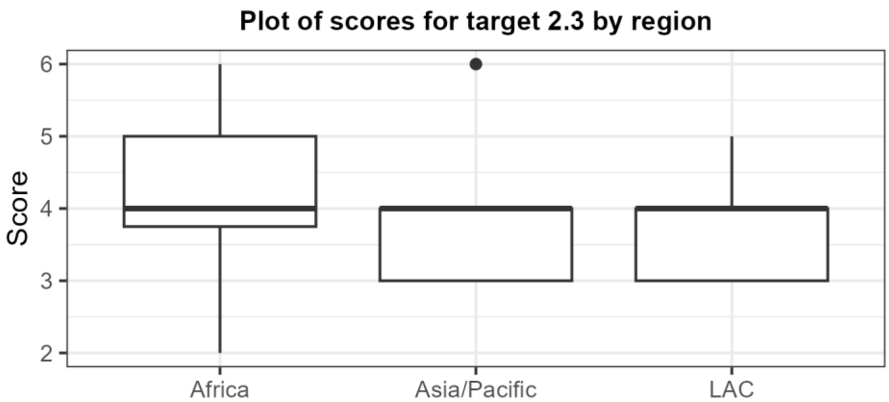


Figure 4.5. Map (above image) showing risk scores for target 2.3 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Our findings show that energy infrastructure across much of Africa, while not recorded as posing a current risk, is expected to undergo significant progress in the coming years. In other regions, energy infrastructure is a more common existing threat, but our data suggest comparatively less significant latent threats from some energy-related SDG targets in these regions compared with Africa. For risk target 7.1 (electricity access, Figure 4.6) we found a statistically significant difference in mean scores between regions ($F(2, 37) = 31.889$, $p < 0.001$). Tukey's test for multiple comparisons found that mean values differed significantly between Asia/Pacific and Africa ($p < 0.001$, 95% C.I. = -2.50, -0.88), LAC and Africa ($p < 0.001$, 95% C.I. = -3.63, -1.86), and Asia/Pacific and LAC ($p < 0.05$, 95% C.I. = -2.02, -0.09). These differences are largely attributable to the fact that 70% of African countries were assessed as having 'poor' status for this target, compared with 0% for the other two regions, and that both recent improvements and levels of assigned priority are much lower for LAC compared with the other two regions.

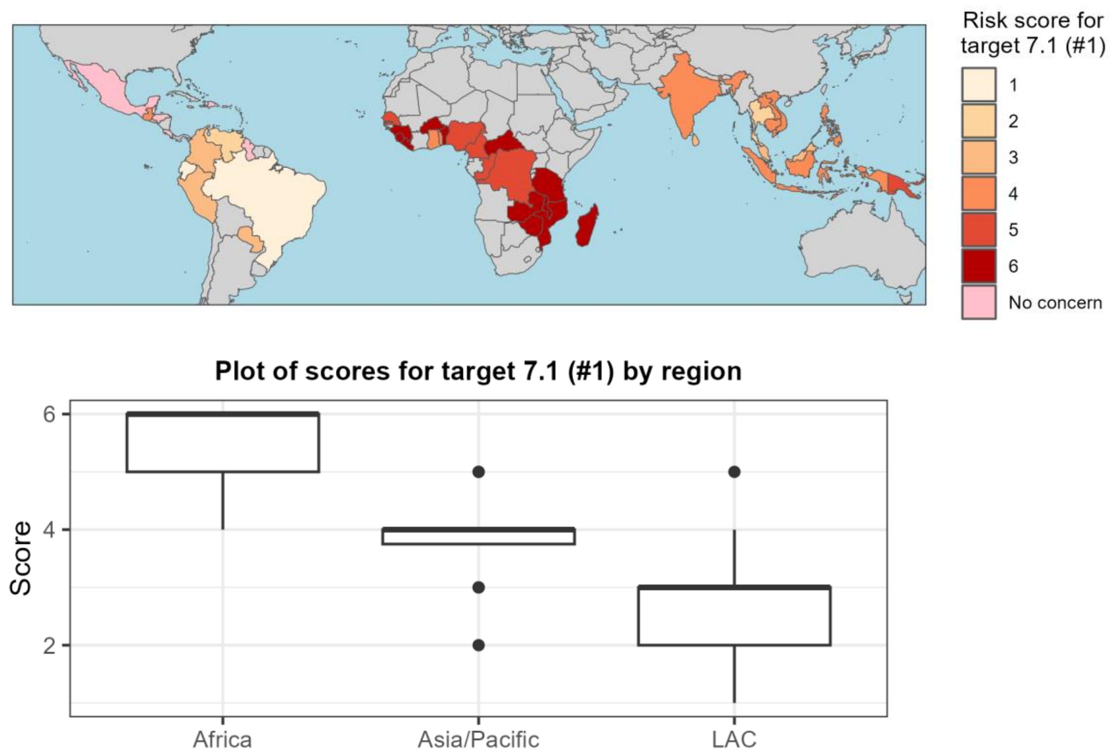


Figure 4.6. Map (above image) showing risk scores for target 7.1 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

For risk target 7.b (energy infrastructure, Figure 4.7) we again found a statistically significant difference in mean scores between regions ($F(2, 38) = 6.363$, $p < 0.01$). In this case, Tukey's test for multiple comparisons found that mean values differed significantly between LAC and Africa ($p < 0.01$, 95% C.I. = -1.99, -0.36), but not between Asia/Pacific and Africa (p = 0.49) or Asia/Pacific and LAC (p = 0.08). This finding is largely attributable to the fact that African countries are more likely to have 'poor' status for this target, less likely to have shown recent improvements, and are typically assigning greater levels of priority, compared with the other regions.

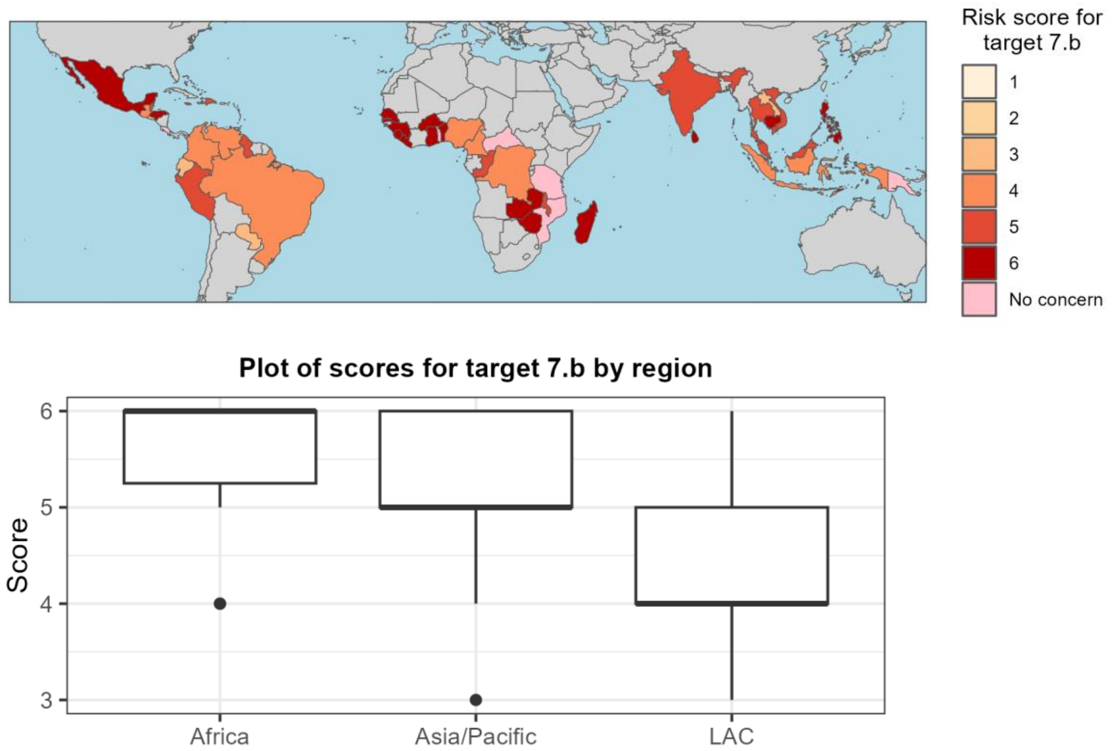


Figure 4.7. Map (above image) showing risk scores for target 7.b by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

This picture differs somewhat for matters of renewable energy (risk target 7.2, Figure 4.8), which is neither a current threat nor expected to show imminent progress across much of Africa, but is already posing risks in the other two regions, and is expected to progress further in many cases. However, mean scores for this target were not found to differ significantly between regions ($F(2, 27) = 1.493$, $p < 0.24$).

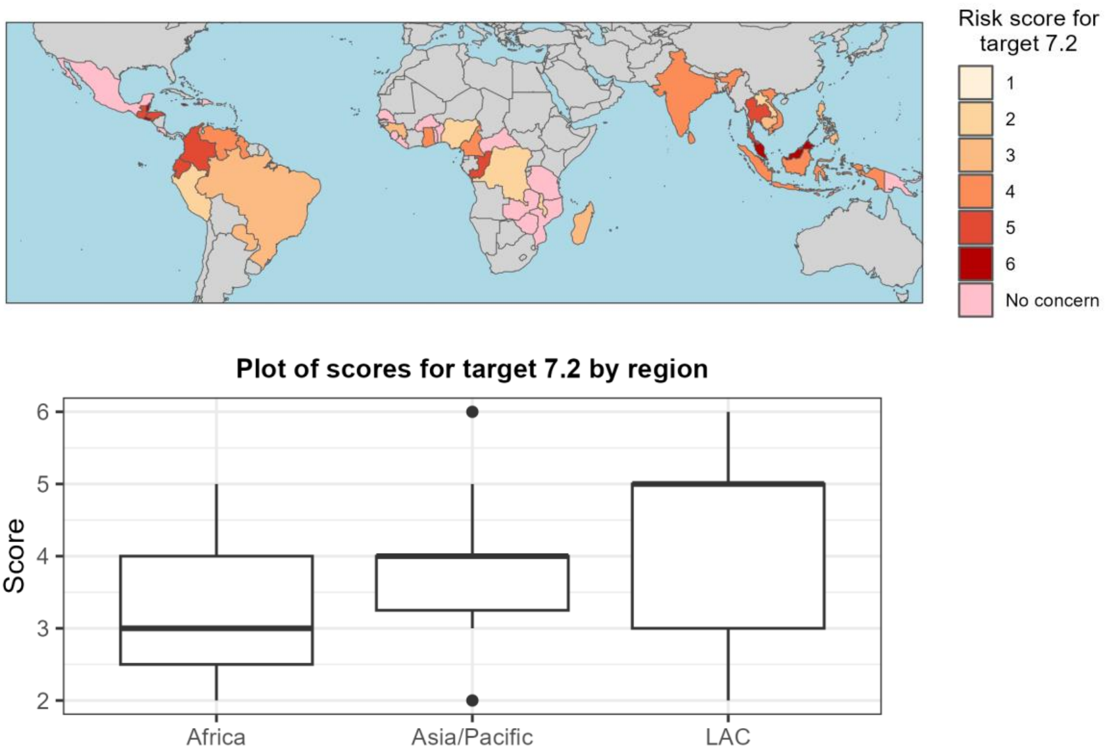


Figure 4.8. Map (above image) showing risk scores for target 7.2 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Risks from infrastructure associated with transport (risk target 9.1, Figure 4.9) appear to be high across all three regions. Recent improvements in this target have been achieved in around 50% of countries in each region, and further improvements are being treated as a priority in almost all countries. Despite scope for potential progress being notably higher in Africa (where 95% of countries have ‘poor’ status) than in Asia/Pacific (46%) and LAC (73%), we found no significant differences between regions in the mean scores for this target ($F(2, 42) = 1.373$, $p = 0.26$).

Risks associated with improving access to housing (risk target 11.1, Figure 4.10) appear more severe in Africa than in the other two regions. Although levels of recent progress in this target have been similar across all regions, proportions of governments prioritising this target are marginally higher in Africa, compared with Asia/Pacific and LAC. Most significantly, however, the extent of potential improvements to be made in this target are significantly higher in Africa, where almost all countries were assessed as having ‘poor’ status, than in Asia/Pacific and LAC, where almost no countries have 'poor' status. Accordingly, we found a significant difference between regions in terms of mean scores for this target ($F(2, 40) = 10.377$, $p < 0.001$), and Tukey's test for multiple comparisons found that mean values differed significantly between LAC and Africa ($p < 0.001$, 95% C.I. = -2.28, -0.54), between Asia/Pacific and Africa ($p < 0.01$, 95% C.I. = -2.52, -0.48), but not between Asia/Pacific and LAC ($p = 0.97$). In two African countries (Central African Republic and Liberia) housing infrastructure was not recorded as a current driver, but in both cases our assessment identified this as a potential emerging risk.

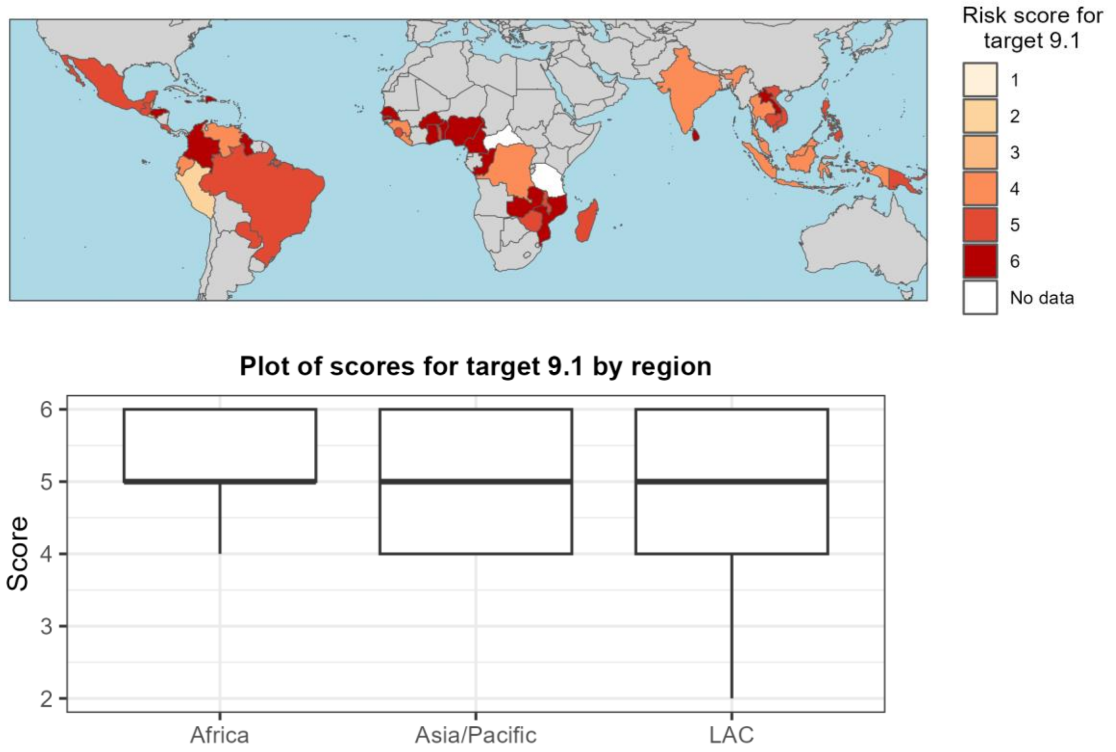


Figure 4.9. Map (above image) showing risk scores for target 9.1 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

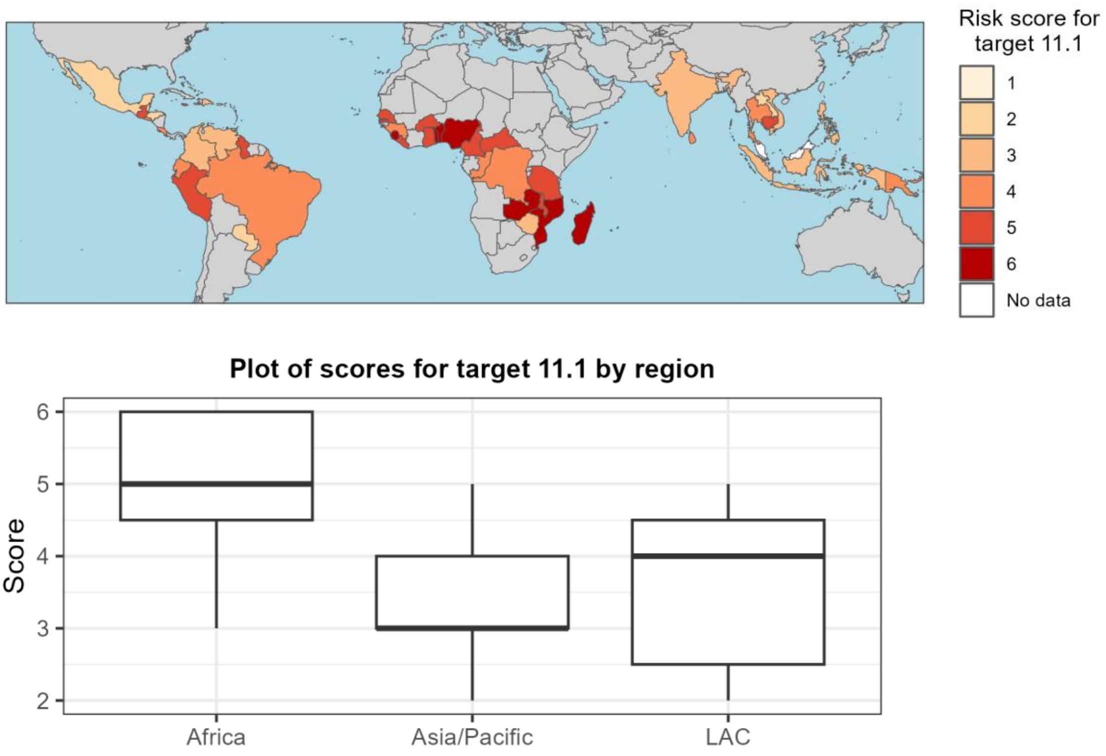


Figure 4.10. Map (above image) showing risk scores for target 11.1 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

In combining all of the risks described above (Figure 4.11), we find that seven of the nine countries with the highest cumulative risk scores are in Africa. These countries (in decreasing order of risk) are Zambia, Senegal, Burkina Faso, Madagascar, Sierra Leone, Congo, Ghana, Sri Lanka and the Solomon Islands. Countries with the lowest cumulative risk scores are predominantly located in mainland Latin America. These countries (in increasing order of risk) are Costa Rica, Ecuador, Paraguay, Peru, Brazil, Lao and Venezuela. We found a significant difference between regions in terms of mean cumulative risk scores ($F(2, 45) = 13.766$, $p < 0.001$), and Tukey's test for multiple comparisons found that mean values differed significantly between LAC and Africa ($p < 0.001$, 95% C.I. = -1.25, -0.46), between Asia/Pacific and Africa ($p < 0.05$, 95% C.I. = -0.87, -0.04), but not between Asia/Pacific and LAC ($p = 0.08$).

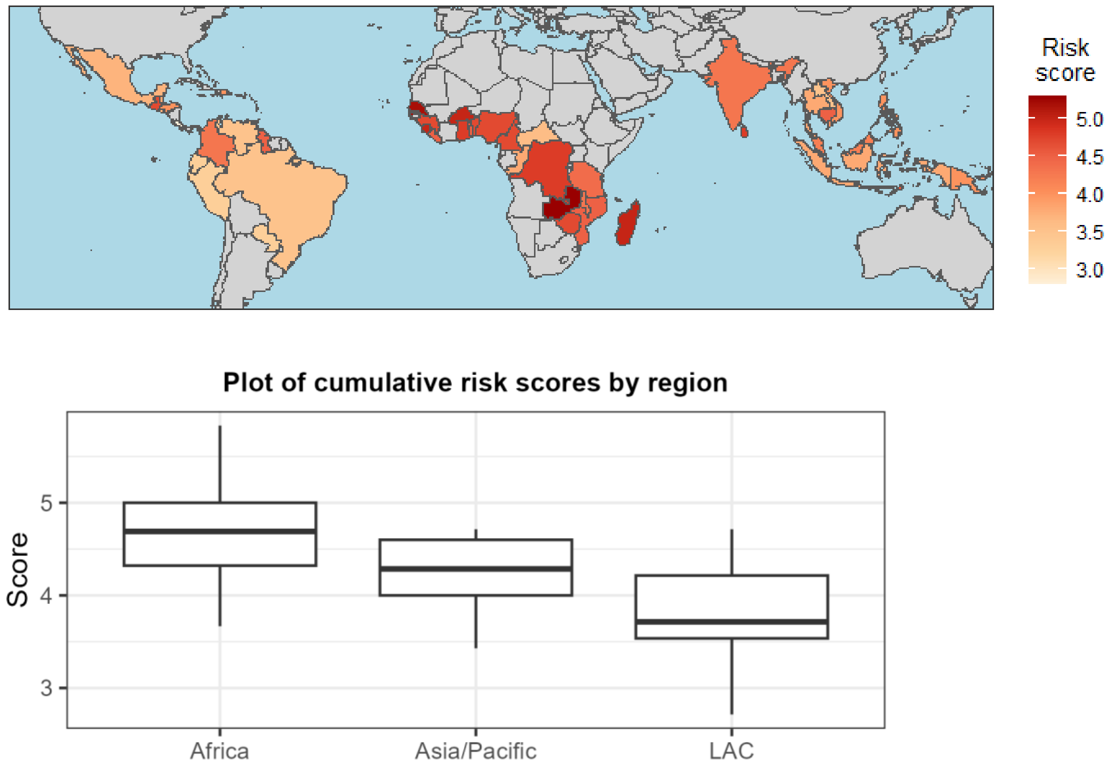


Figure 4.11. Map (above image) showing cumulative risk scores by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

4.2.2. Opportunity targets

Our assessments of eight opportunity targets, which could either help to mitigate or aggravate drivers, showed fewer clear patterns than the two other target types (risk and enabling). One of the few exceptions to this is matters of poverty reduction (targets 1.1 and 1.2, Figure 4.12), which can encourage beneficiaries to reduce forest-damaging activities such as illegal logging, but also to increase consumption of forest products or expand practices such as agriculture (Wunder, 2001). Poverty reduction is being treated with high priority among a large share of the countries assessed in all regions. However, recent progress has been observed more commonly in Asia/Pacific and LAC than in Africa, but still has much greater potential to make significant impacts in Africa compared with Asia/Pacific and LAC. We found a significant difference between regions in terms of mean scores for this target ($F(2, 41) = 4.228$, $p < 0.05$), and Tukey's test for multiple comparisons found that mean values differed significantly between

LAC and Africa ($p < 0.05$, 95% C.I. = -1.83, -0.16), but not between Asia/Pacific and Africa ($p = 0.39$), nor between Asia/Pacific and LAC ($p = 0.31$).

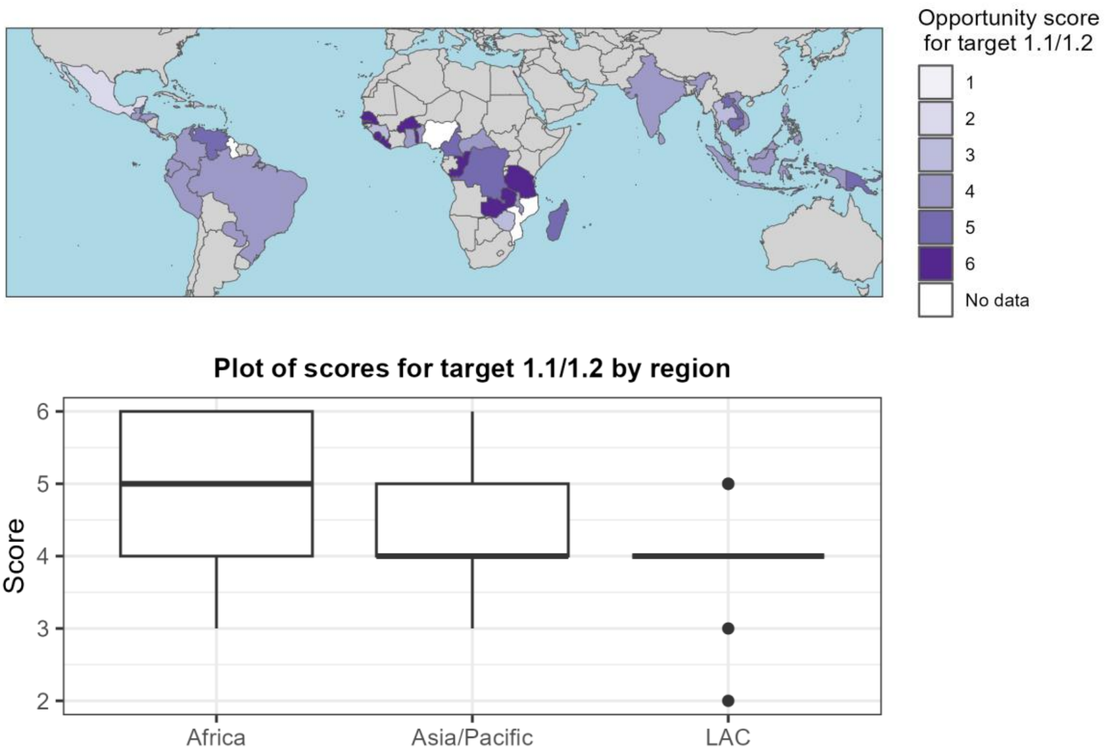


Figure 4.12. Map (above image) showing opportunity scores for target 1.1/1.2 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Improving property and land rights (target 1.4, Figure 4.13) can induce landowners to either clear forests (or sell land to a third party, who may clear them) or to aid their protection (Barkmann et al., 2010; Naughton-Treves and Wendland, 2014; Travers et al., 2015). Proxy data used to assess this target (IPRI, 2020) were incomplete for 11 countries (five each in Africa and Asia/Pacific, and one in LAC). Notwithstanding these data gaps, among countries with sufficient data, we find that all countries in Africa and LAC, and 75% of those in Asia/Pacific were assessed as ‘poor’, indicating significant remaining room for improvement in this area. Although reasonably large proportions of countries have made notable recent progress in this target, assessments concluding that (further) progress is ‘likely’ were relatively less common, owing to the fact that few governments are prioritising this target in their national strategies. We found no significant differences in the mean scores for this target between regions ($F(2, 33) = 0.229$, $p = 0.79$).

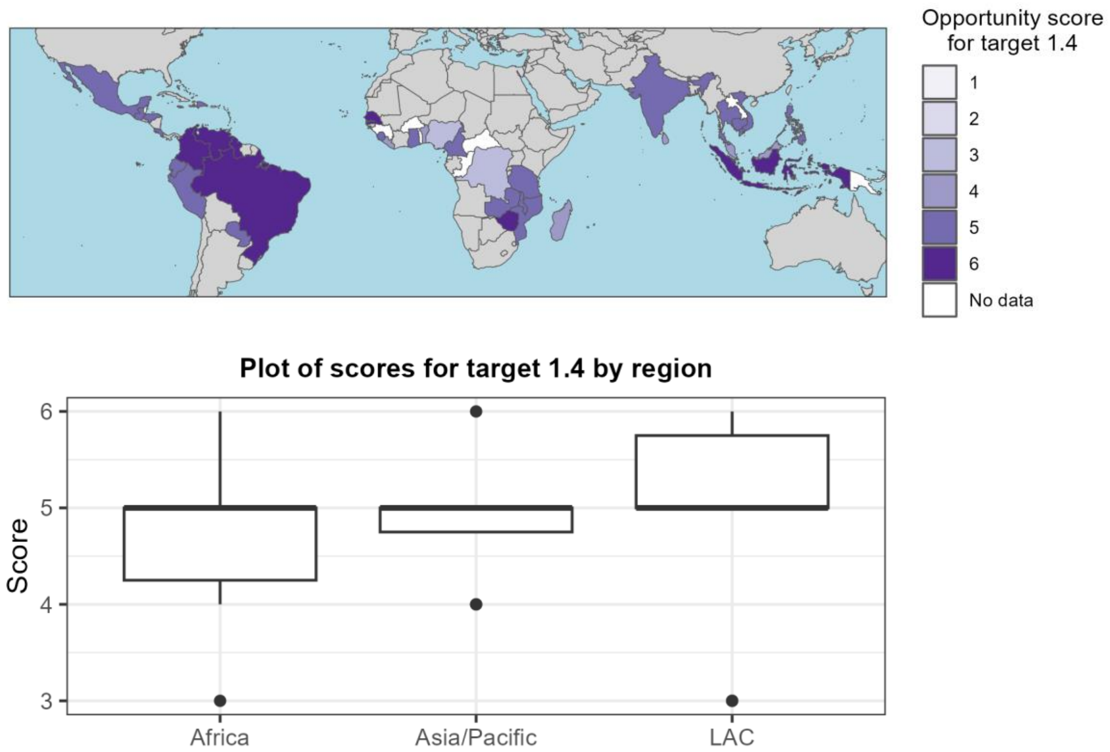


Figure 4.13. Map (above image) showing opportunity scores for target 1.4 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Investments into agricultural technologies and research (target 2.a, Figure 4.14), which we assess based on funds provided by the UN’s International Fund for Agricultural Development, may result in risks to forests due to further agricultural expansion, but can also benefit forests, for example if agricultural intensification means that less land is required to produce the same yields (Ewers et al., 2009). We found that investments into agricultural technologies and research are already high in many countries, and especially so in Africa and Asia/Pacific compared with LAC. Although this target still appears to be a priority among many governments (81% of countries assessed), only 17 countries have seen recent improvements in this area, while 27 have seen declines. This means that our assessments of this target are largely uncertain as to whether investments will increase in the coming years (28 countries were assessed as ‘possible’, compared with 14 countries assessed as ‘likely’). We found no significant differences in the mean scores for this target between regions (F(2, 44) = 2.343, p = 0.11).

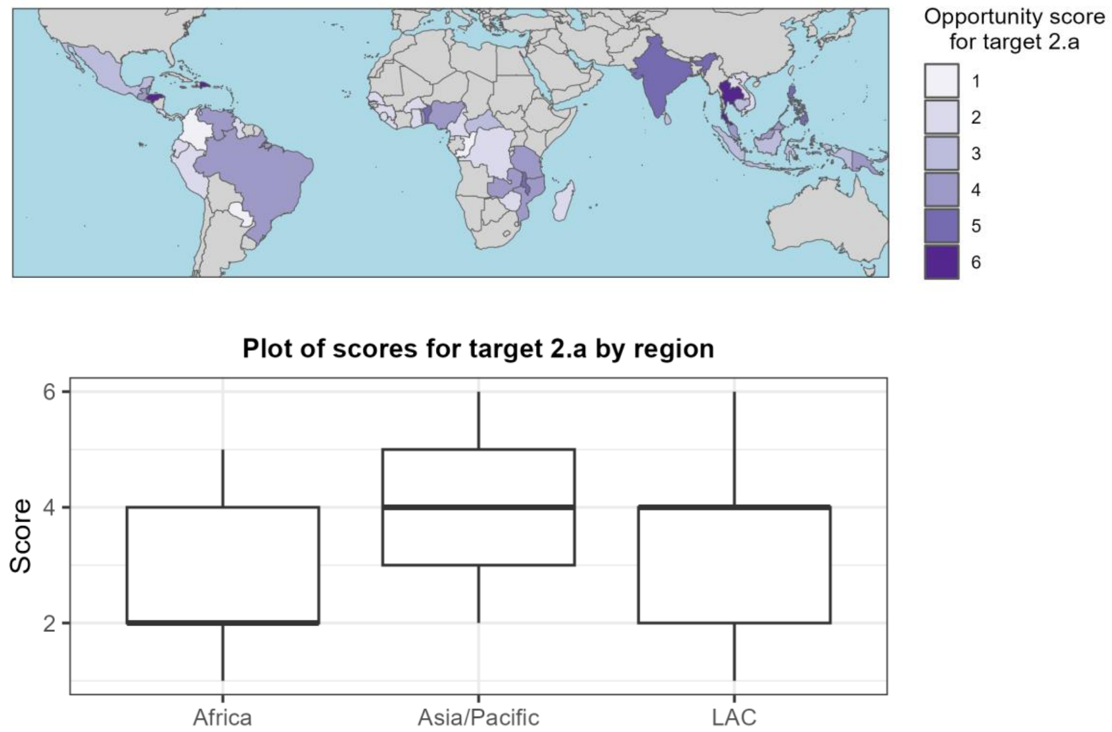


Figure 4.14. Map (above image) showing opportunity scores for target 2.a by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Work on the links between economic growth and forests provides a complex picture, largely suggesting that initial growth in economically weaker countries typically results in loss or degradation of forests, but once higher economic status is achieved, rates of loss/degradation can (but are not guaranteed to) decline (Kaimowitz and Angelsen, 1998). Our assessments of economic growth (target 8.1, Figure 4.15) found that a large proportion of countries are prioritising this target, that approximately half of all countries have improved in recent years, and that existing rates of growth are relatively high across most countries. Altogether, this suggests that further economic growth is ‘possible’ across a large swathe of the tropics, but that existing rates of growth may be approaching their maxima. We found no significant differences in the mean scores for this target between regions (F(2, 44) = 0.812, p = 0.45). However, in this case Levene’s test showed that the assumption of homogeneity of variance between regions was violated ($p < 0.01$), and so this finding should be interpreted with caution.

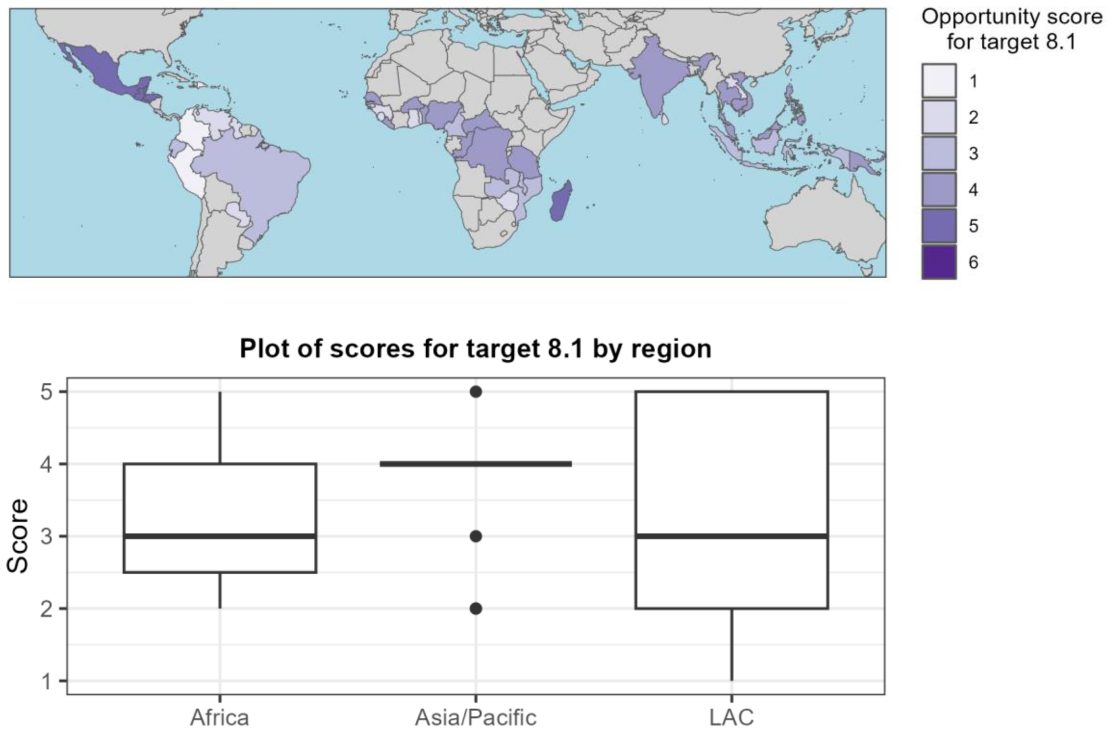


Figure 4.15. Map (above image) showing opportunity scores for target 8.1 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

One of the most important factors influencing how economic growth can affect the environment is the specific way(s) in which a country seeks to achieve growth, and two further opportunity targets are known to play key roles, namely growth of the tourism (target 8.9, Figure 4.16) and industry/manufacturing (target 9.2, Figure 4.17) sectors. Tourism, which can both encourage forest conservation to attract visitors, but also deplete forests to make way for necessary infrastructure and to meet increased demands for forest resources (Brandt and Buckley, 2018)), is being prioritised by around three quarters of countries from each region. Asia/Pacific has shown more notable recent improvements in this target compared with Africa or LAC, but countries with the greatest potential for growth in tourism are more numerous in Africa than in

Asia/Pacific or LAC. Despite these differences, we found no significant differences in the mean scores for this target between regions ($F(2, 42) = 0.163$, $p = 0.85$).

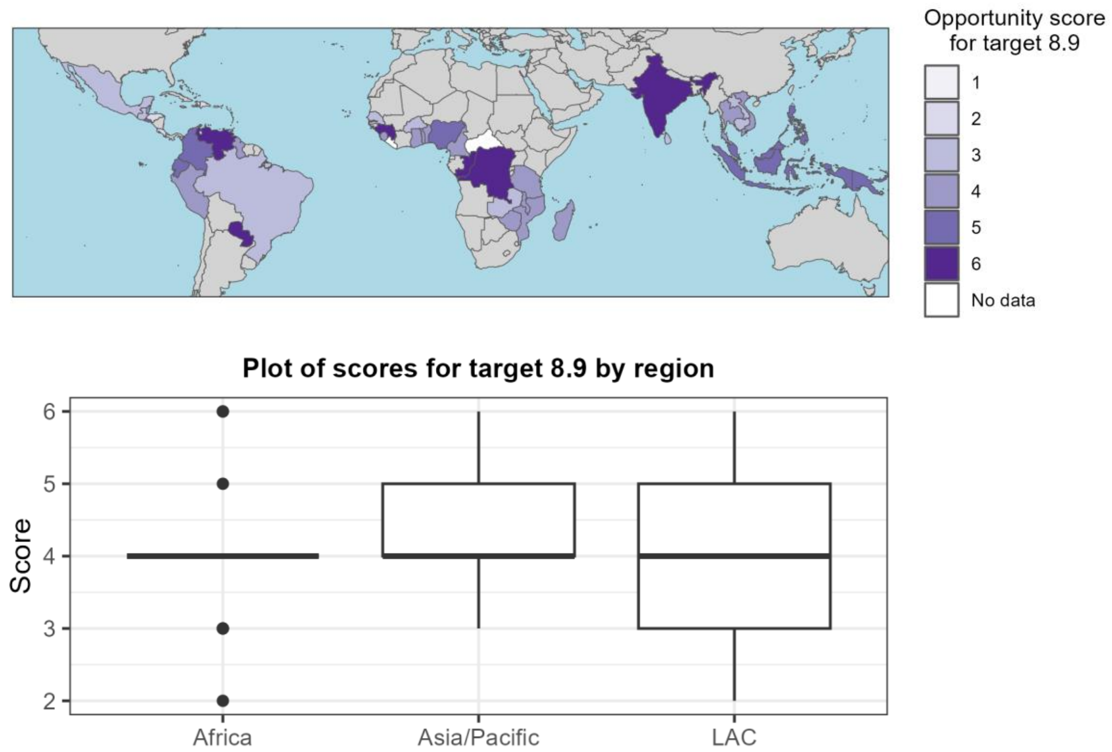


Figure 4.16. Map (above image) showing opportunity scores for target 8.9 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Industry and manufacturing, which can be damaging due to associated infrastructure, pollution and influxes or workers, but can also produce beneficial impacts if it allows a shift away from employment in agriculture or other damaging activities, is a notably higher priority among African and Asia/Pacific countries than among LAC countries. However, across all three regions, the potential for future progress was assessed as 'high' in only 17% of countries. Similarly, recent progress was recorded in only 17% of countries. We found a significant difference in the mean scores for this target between regions ($F(2, 43) = 6.163$, $p < 0.01$), and Tukey's test for multiple comparisons found that mean values differed significantly between LAC and Africa ($p < 0.01$, 95% C.I. = -1.88, -0.01), between Asia/Pacific and Africa ($p < 0.05$, 95% C.I. = -2.07, -0.32), but not between Asia/Pacific and LAC ($p = 0.81$). These findings suggest that although the imminent risks and benefits from this target may be lower than for other aspects of development, they could be slightly higher in Africa compared with elsewhere.

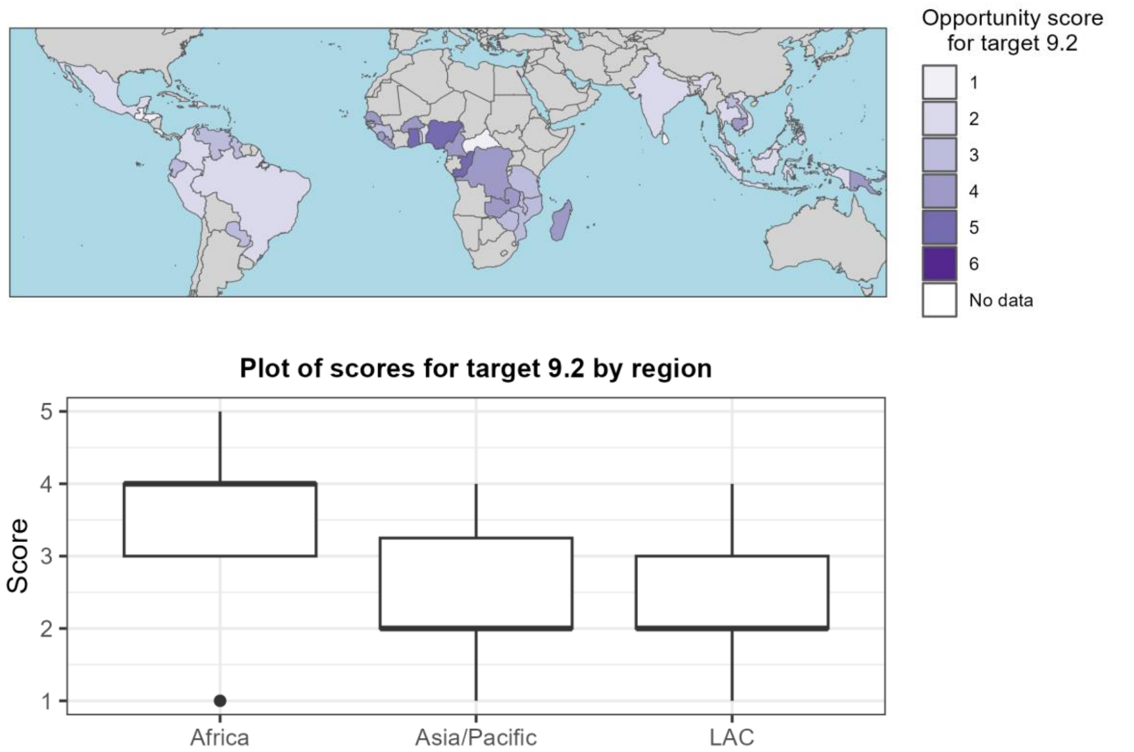


Figure 4.17. Map (above image) showing opportunity scores for target 9.2 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Risks and benefits associated with reducing income inequalities (target 10.1, Figure 4.18) operate largely in the same way as for reducing poverty (see above). This target was the most data deficient of all targets considered, with one or more data elements missing for 14 (29%) countries. Using available data, we found that, despite many countries having high potential for progress in this area, far fewer have made significant progress in recent years, and fewer still are prioritising this target. Overall, despite large potential for progress in this area across the tropics, only four countries (11% of those with available data) were assessed as 'likely' to make imminent progress, suggesting that the associated risks and benefits are less likely to manifest in the near-term than for other areas of development. We found no significant differences in the mean scores for this target between regions ($F(2, 30) = 1.761$, $p = 0.19$).

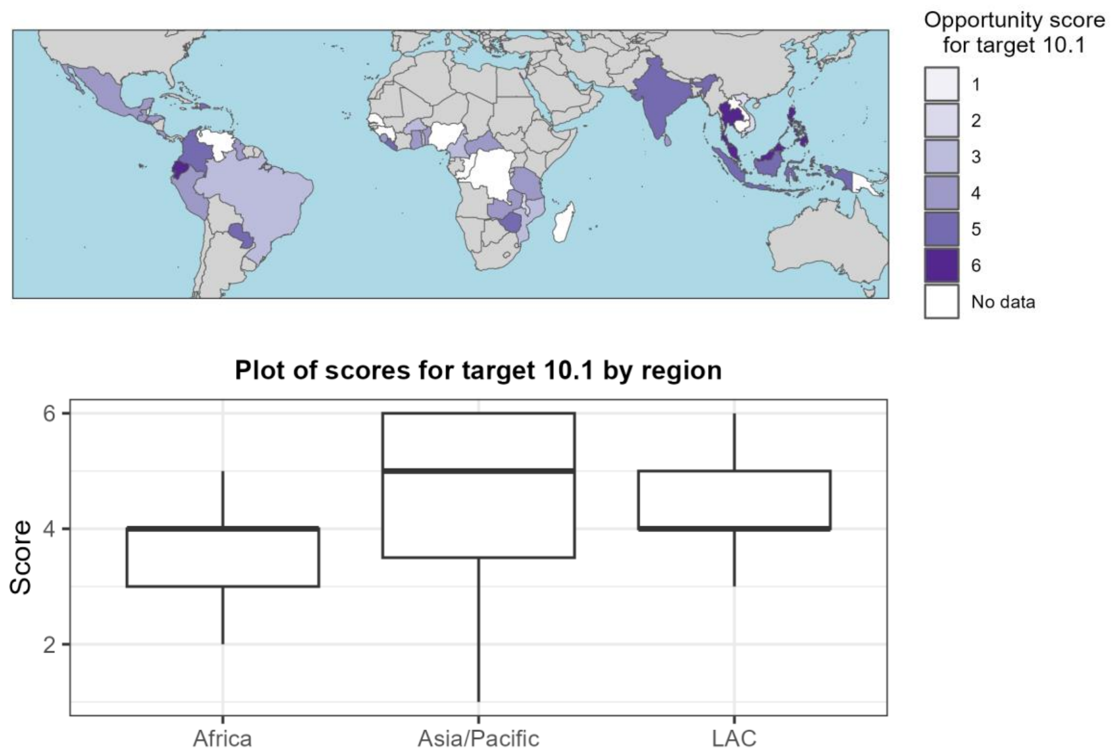
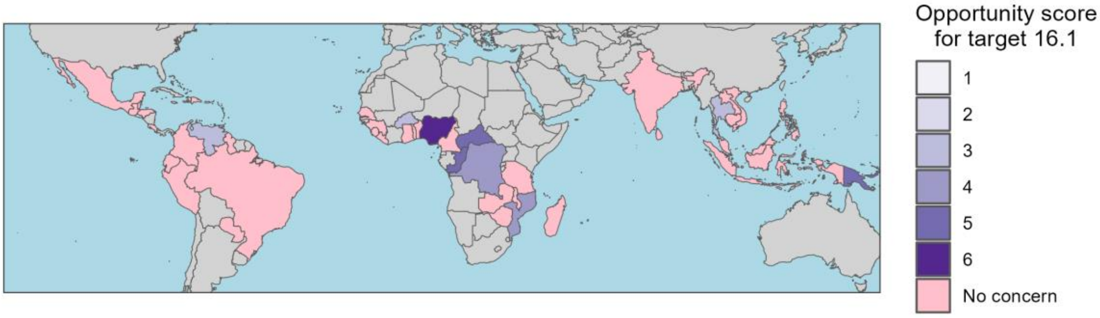


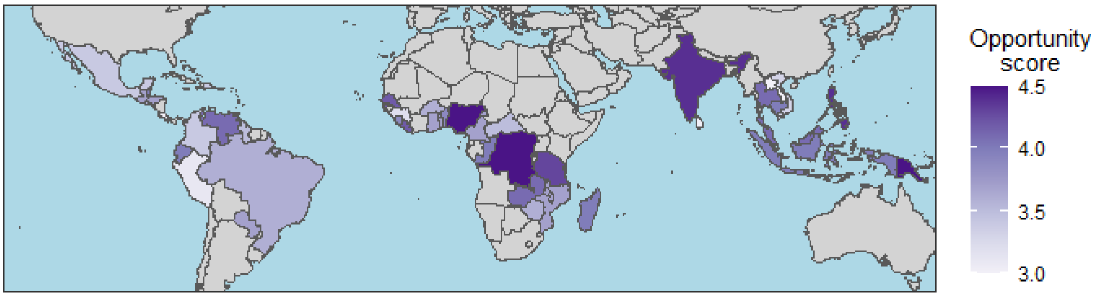
Figure 4.18. Map (above image) showing opportunity scores for target 10.1 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Mechanisms through which reducing violence and conflict (target 16.1, Figure 4.19) can impact forests are complex, often involving a multitude of factors. For example, while ending a conflict may alleviate forest pressures relating to displaced peoples, armed groups residing in forests and/or the breakdown of the rule of law, it may concurrently allow other damaging activities to begin or resume, including agricultural expansion or increased exploitation of forest resources from formerly hostile environments (Álvarez, 2001; Draulans and Van Krunkelsven, 2002; Loucks et al., 2009; McNeely, 2003). This target is only considered relevant in four countries where ongoing violence or conflict was recorded as a current driver (Central African Republic, Democratic Republic of Congo, El Salvador and Venezuela). In both of the African cases, the current status of this target was assessed as 'poor', and in the two South American cases the status was recorded as 'good'. In all four cases, the likelihood of progress in this target was assessed as ‘possible’. Six additional countries were assessed as either ‘poor’ or ‘medium’ with regards to this target, and as either ‘possible’ or ‘likely’ to make imminent progress, and in these cases a final assessment of ‘possible emerging opportunity’ was made. These six countries include four in Africa (Burkina Faso, Republic of Congo, Mozambique and Nigeria) and two in Asia/Pacific (Papua New Guinea and Thailand). Due to the low number of countries for which this target was deemed relevant, we did not test for differences between regions in this case.



4.19. Map showing opportunity scores for target 16.1 by country (see Materials and methods for how these scores were derived).

In combining data for all opportunity targets described above (Figure 4.20), we find that the countries with the highest cumulative opportunity scores (in decreasing order of opportunity) are Congo, Nigeria, PNG, India, the Philippines, Fiji, Jamaica, Tanzania, and the Solomon Islands. Countries with the lowest cumulative opportunity scores (in increasing order) are Costa Rica, Lao, Sri Lanka, Peru, Guinea, Vietnam, Colombia, Dominican Republic, and Mexico. We found no significant difference between regions in terms of mean cumulative opportunity scores ($F(2, 45) = 2.418$, $p = 0.10$).



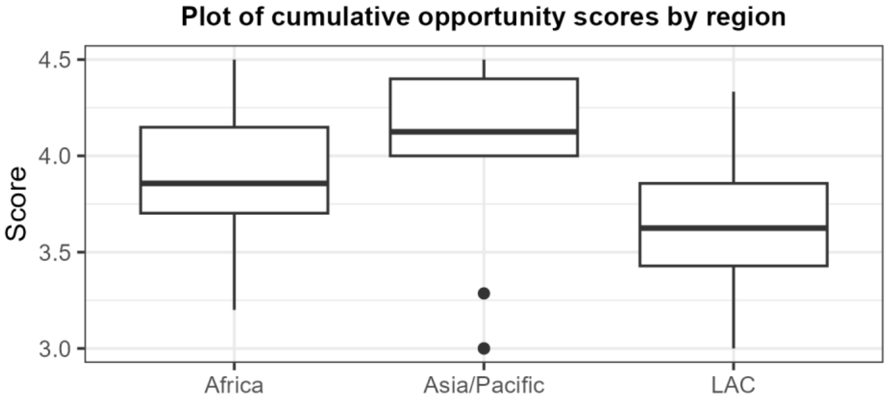


Figure 4.20. Map (above image) showing cumulative opportunity scores by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

4.2.3. Enabling targets

Access to family planning (targets 3.7 and 5.6, Figure 4.21) is beneficial for forests in cases where population growth is an underlying driver of forest change (Mavanza and Grossman, 2007), which we recorded in all but seven countries (Brazil, Colombia, Costa Rica, Guyana, Honduras, Liberia and Senegal). Although one or more data elements for this target were missing for eight countries, based on those with available data, and excluding countries where population growth is not an implicated driver, access to family planning was assessed as currently 'poor' in the majority of countries in Africa, but relatively much fewer in Asia/Pacific and LAC. Recent trends in this target are encouraging (assessed as improving in 67% of countries in both Africa and Asia/Pacific, and 78% in LAC), yet the level of priority awarded to this target varies between region, with 56%, 38% and 20% of countries from Africa, Asia/Pacific and

LAC assigning high priority, respectively. We found a significant difference in the mean scores for this target between regions ($F(2, 29) = 6.325$, $p < 0.01$), and Tukey's test for multiple comparisons found that mean values differed significantly between Asia/Pacific and Africa ($p < 0.01$, 95% C.I. = -3.28, -0.57), but not between LAC and Africa ($p = 0.08$), nor between Asia/Pacific and LAC ($p = 0.55$).

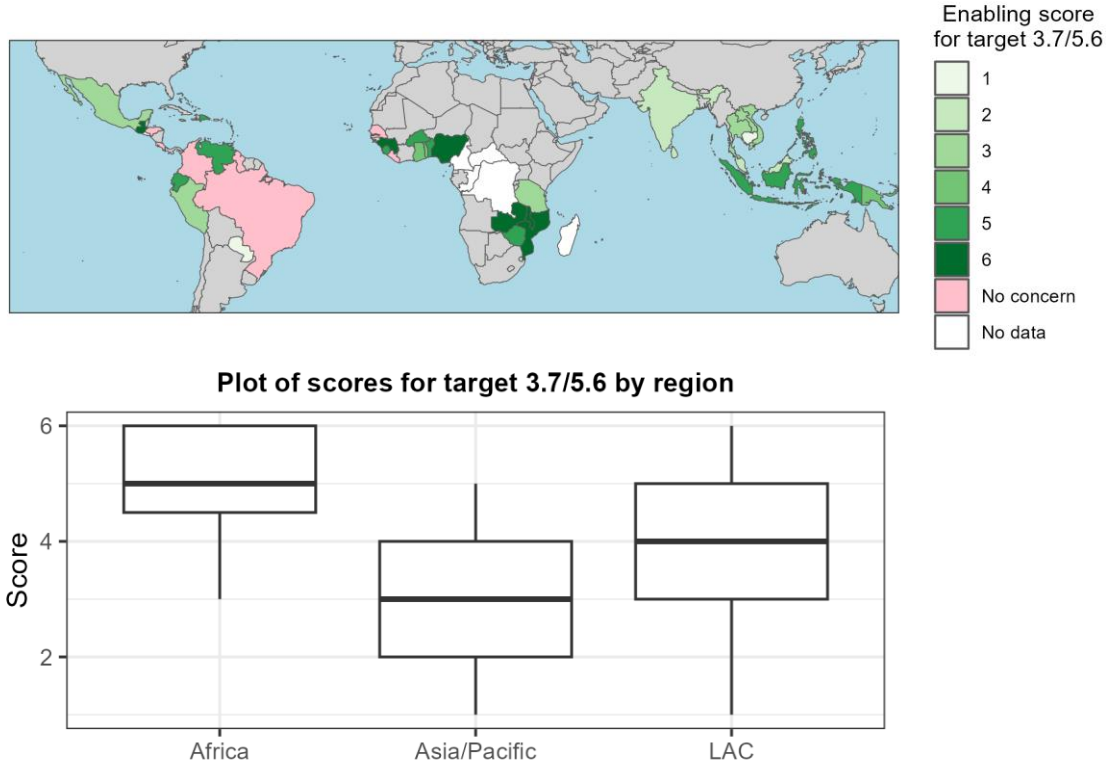


Figure 4.21. Map (above image) showing enabling scores for target 3.7/5.6 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

A well-educated population is increasingly recognised as an enabling condition for successful conservation, particularly as it can facilitate alternative livelihood options that are less damaging to forests, and can promote general awareness of the benefits of conservation (Burns et al., 1994; D'Silva and Pai, 2003; Godoy and Contreras, 2001). Our assessments of target 4.1 (increase access to primary and secondary education, Figure 4.22) found that, irrespective of their current status, 42 countries (91% of those with available data) were assessed as 'likely' to make additional progress. Scope for potential progress is much greater in Africa (17 of the 18 countries with available data were assessed as ‘poor’) compared with Asia/Pacific and LAC where, barring a few exceptions, countries’ statuses were more typically assessed as ‘medium’. We found a significant difference in the mean scores for this target between regions ($F(2, 40) = 8.620$, $p < 0.001$), and Tukey’s test for multiple comparisons found that mean values differed significantly between Asia/Pacific and Africa ($p < 0.01$, 95% C.I. = -1.47, -0.24), and between LAC and Africa ($p < 0.01$, 95% C.I. = -1.39, -0.27), but not between Asia/Pacific and LAC ($p = 0.99$).

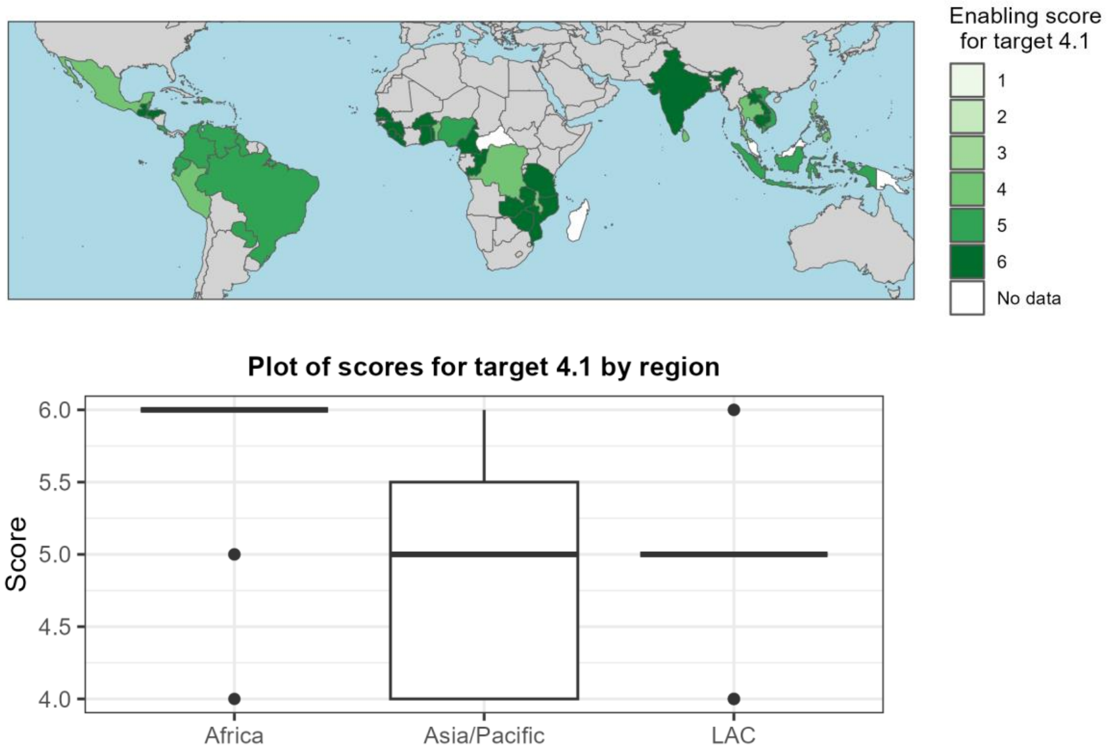
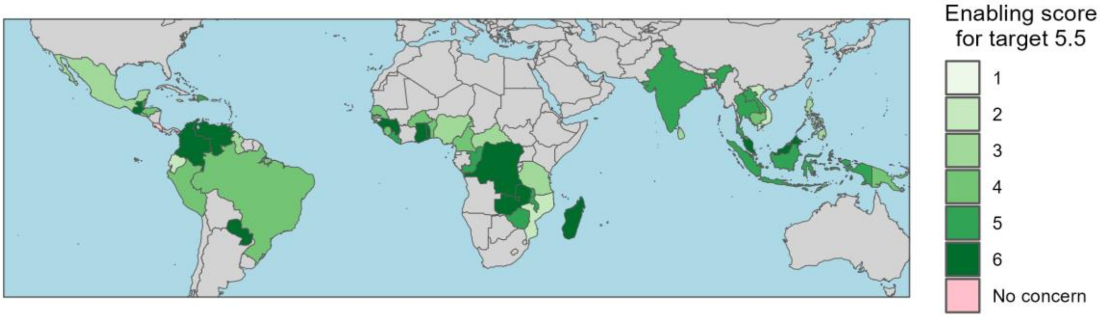


Figure 4.22. Map (above image) showing enabling scores for target 4.1 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Increasing women’s representation in decision-making positions (target 5.5, Figure 4.23) has been shown to have positive implications for forests in its own right (Leisher et al., 2016), and is also likely indicative of a socio-political setting with inclusive and participatory decision-making processes, which is generally thought to be beneficial for forests (Bonatti et al., 2021; Di Gregorio et al., 2012). Our findings identified relatively high numbers of countries with currently ‘poor’ performances in this target, especially in Africa compared with Asia/Pacific and LAC. Although recent progress in this target has been encouraging, with 77% of all countries assessed making recent improvements, only 50% are prioritising this target, and only 38% were assessed as ‘likely’ to make further progress. We found no significant differences in the mean scores for this target between regions ($F(2, 43) = 0.150$, $p = 0.86$).



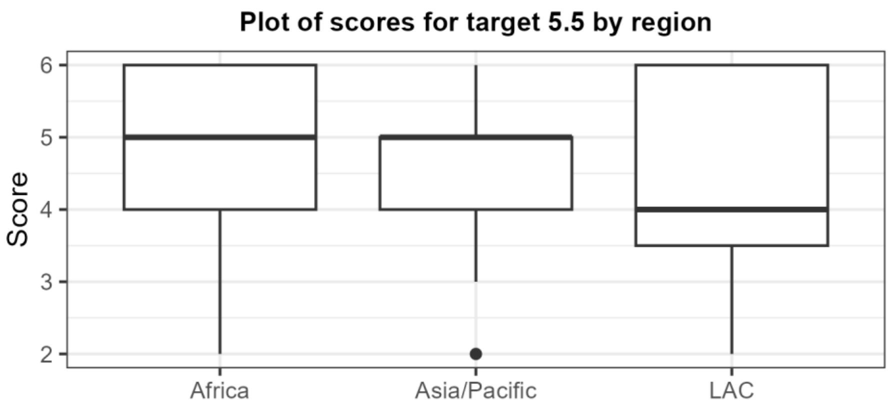


Figure 4.23. Map (above image) showing enabling scores for target 5.5 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Target 7.1 calls, in part, for better access to clean fuels (but also see our consideration of this target under risk targets), which we link to countries where domestic fuel production (typically wood and charcoal) is an acknowledged driver of forest change. This driver was recorded in all but nine countries (five in Asia/Pacific: Indonesia, Lao, Malaysia, Sri Lanka and Thailand, and four in LAC: Belize, Brazil, Colombia and Costa Rica). Among the 39 countries where this target is relevant to forests, we find conspicuous differences between regions in terms of current status (Figure 4.24). In Africa, 17 countries were assessed as ‘poor’, compared with four in Asia/Pacific and zero in LAC. Across all three regions, imminent progress was assessed as ‘likely’ in only two countries (Togo and Timor-Leste), compared with assessments of ‘possible’ in 21 countries and of ‘unlikely’ in 16 countries (41%). Accordingly, we found a significant difference in the mean scores for this target between regions ($F(2, 35) = 8.893$, $p < 0.001$), and Tukey’s test for multiple comparisons found that mean values differed significantly between LAC and Africa ($p < 0.01$, 95% C.I. = -2.74, -0.59) and between LAC and Asia/Pacific and ($p < 0.01$, 95% C.I. = -3.19, -0.55), but not between Asia/Pacific and Africa ($p = 0.91$).

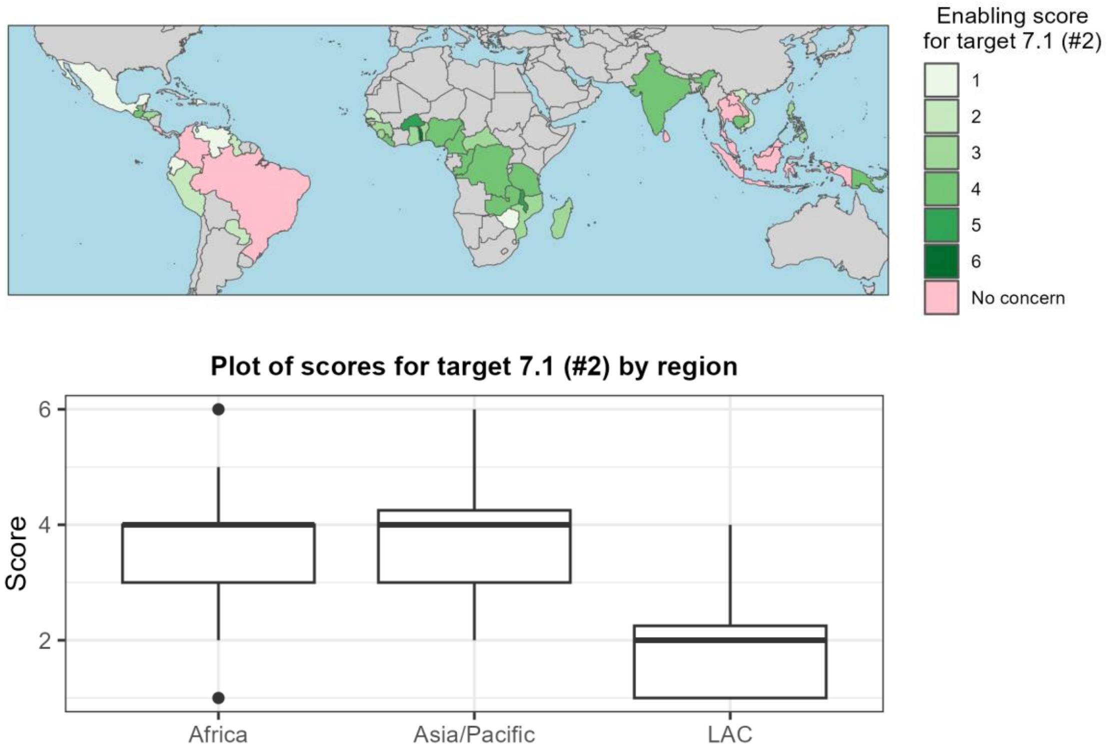


Figure 4.24. Map (above image) showing enabling scores for target 7.1 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Higher levels of employment (target 8.5), especially in non-agricultural sectors (target 8.3) (see Figures 4.25 and 4.26) can, through the provision of alternative livelihoods, reduce forest impacts from agriculture (Rudel et al., 2005; Shively and Martinez, 2001), as well as pressures from illegal logging and overharvesting of NTFPs (Alemagi and Kozak, 2010; Bouriaud, 2005). Assessments of the current status of these targets show similar patterns across regions, with 10, 10 and 28 countries assessed as ‘poor’, ‘medium’ and ‘good’, respectively, for target 8.3, and equivalent values of 11, 9, and 25 (plus three unknown) for target 8.5. Differences emerge, however, when considering the likelihood of future progress in these two targets. For example, while future progress in target 8.5 was assessed as 'likely' for 20 countries, for target 8.3 this was only the case for two countries (Lao and Vietnam). This is largely because almost all assessed countries are prioritising employment in their development strategies, but only the two mentioned above are explicitly aiming to reduce the share of agriculture's contribution to their economies. We found a significant difference in the mean scores between regions for target 8.3 ($F(2, 44) = 6.997$, $p < 0.01$), but not for target 8.5 ($F(2, 38) = 2.057$, $p = 0.14$). Closer examination of findings for target 8.3 using Tukey's test for multiple comparisons showed that mean values differed significantly between LAC and Africa ($p < 0.05$, 95% C.I. = -2.07, -0.16) and between LAC and Asia/Pacific and ($p < 0.01$, 95% C.I. = -2.57, -0.48), but not between Asia/Pacific and Africa ($p = 0.58$). We note, however, that in this case Levene's test showed that the assumption of homogeneity of variance between regions was violated ($p < 0.05$), and so this finding should be interpreted with caution.

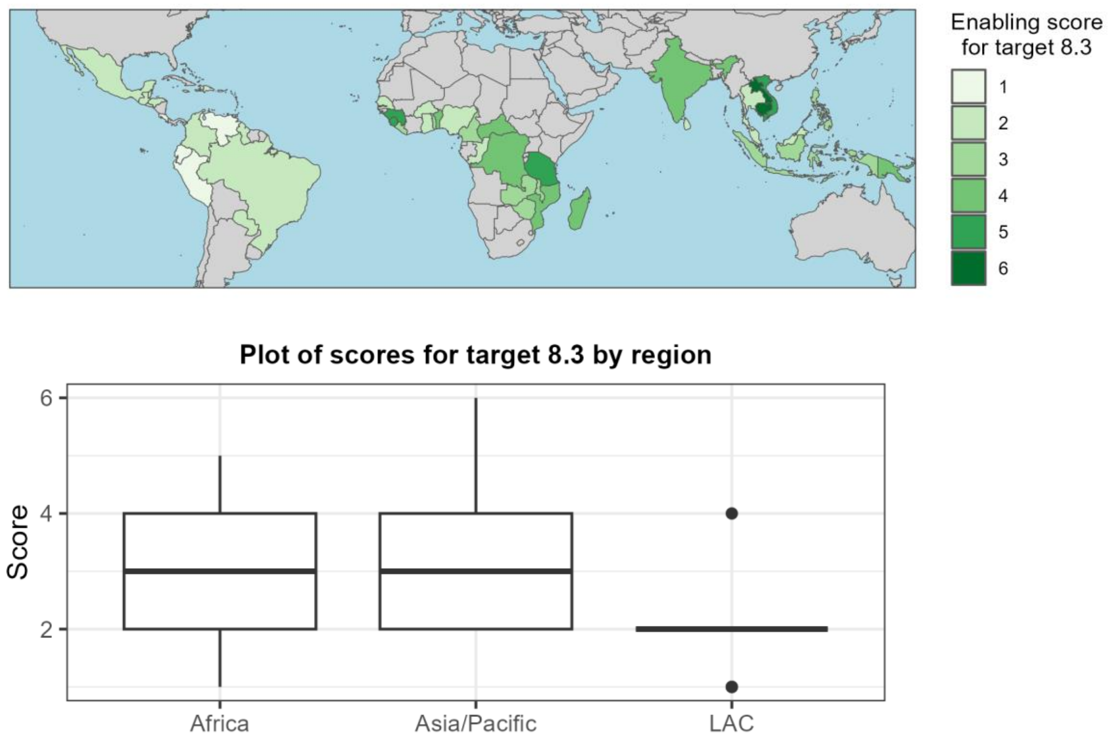


Figure 4.25. Map (above image) showing enabling scores for target 8.3 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

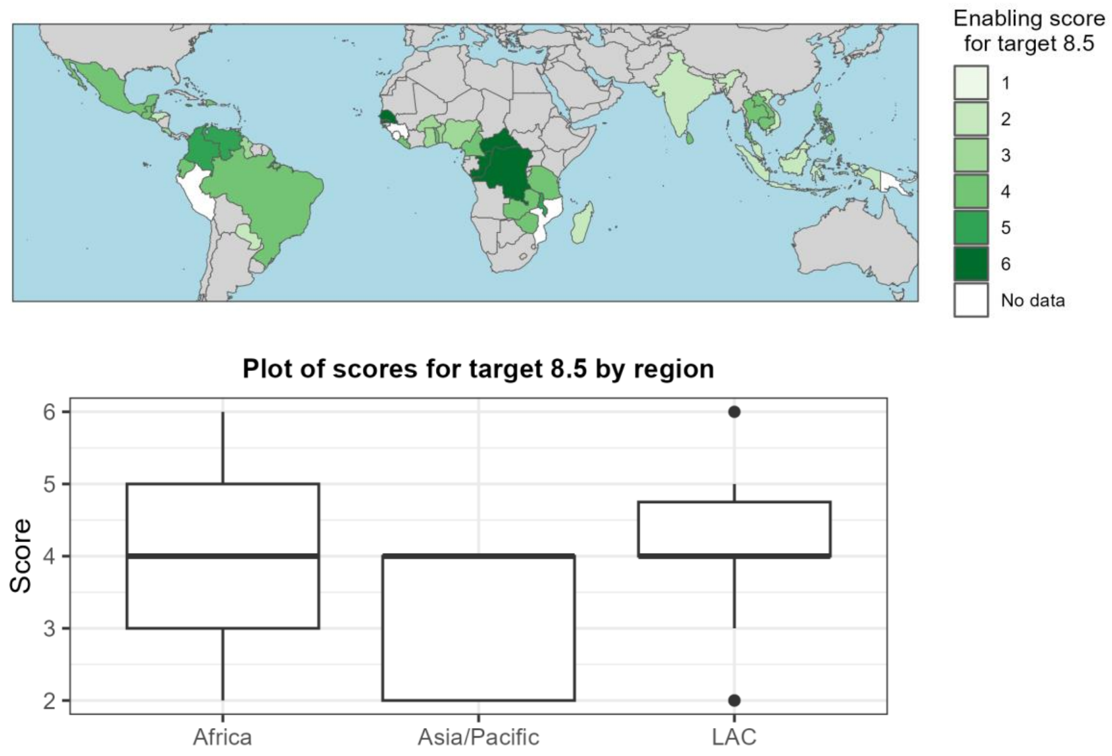


Figure 4.26. Map (above image) showing enabling scores for target 8.5 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

In countries where human migration (whether internal or from abroad) is considered a driver of forest change, well-planned and managed migration policies (target 10.7, Figure 4.27) can help to alleviate the associated impacts (Carr, 2009; Maystadt et al., 2020). One or more drivers associated with this target were recorded in all African countries considered, nine Asia/Pacific countries, and eight LAC countries. Among the 31 countries with complete data and for which this target is relevant, the status of this target was assessed as 'poor', 'medium' and 'good' for 11, 7 and 13 countries, respectively. Imminent progress in this target was assessed as 'likely' for only four countries (Colombia, Ghana, Lao and Sri Lanka) and as 'unlikely' in 25 countries (81% of those with migration-related driver(s) and complete data). We found no significant differences in the mean scores for this target between regions ($F(2, 28) = 1.812$, $p = 0.18$).

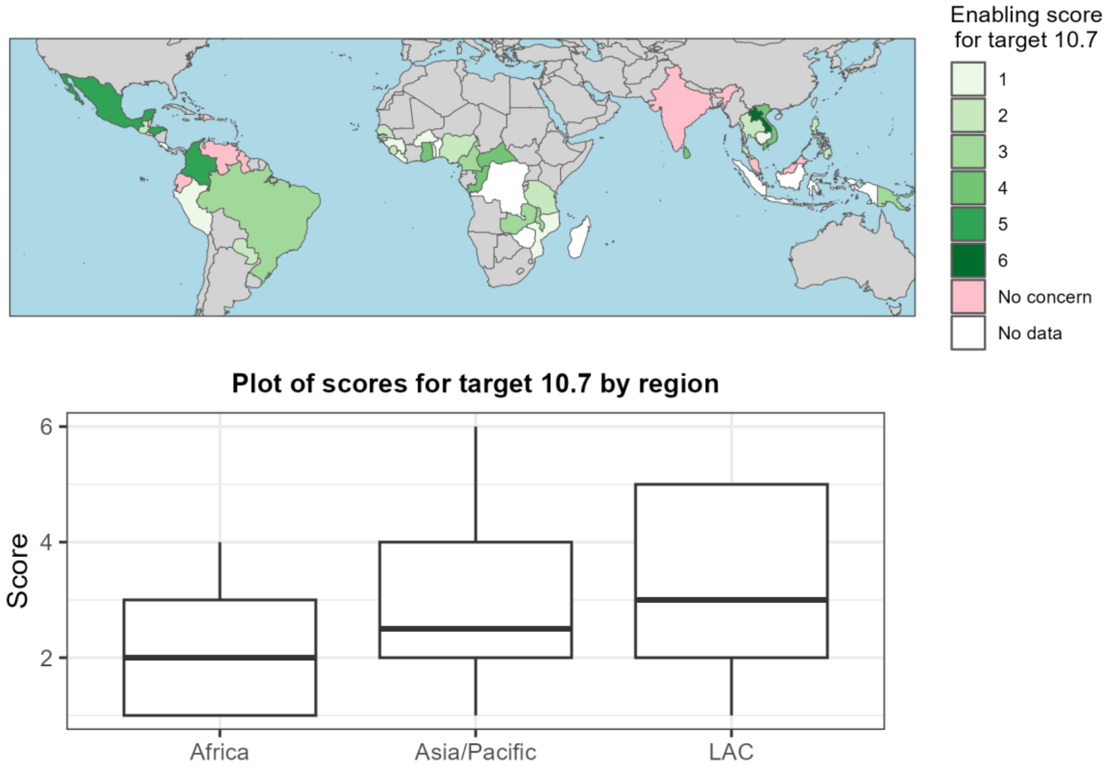


Figure 4.27. Map (above image) showing enabling scores for target 10.7 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

Despite limited empirical evidence, it is widely asserted that more participatory and integrated approaches to human settlement planning (target 11.3, Figure 4.28) can reduce forest loss/degradation from urbanization and other associated infrastructure (Erazo, 2011; Valencia-Sandoval et al., 2010). Assessments of this target suggest that many countries are already performing well in this target, with 36 and 12 countries assessed as having ‘good’ and ‘poor’ statuses, respectively (note that data limitations for this target meant that assessments of ‘medium’ status were not possible; see Table C.2 in Appendix C). Only three countries (Jamaica, Thailand and Zimbabwe) were assessed as ‘likely’ to make additional imminent progress in this target, and a much larger share (36 countries) were assessed as ‘unlikely to make progress. We found no significant differences in the mean scores for this target between regions ($F(2, 44) = 0.099$, $p = 0.91$).

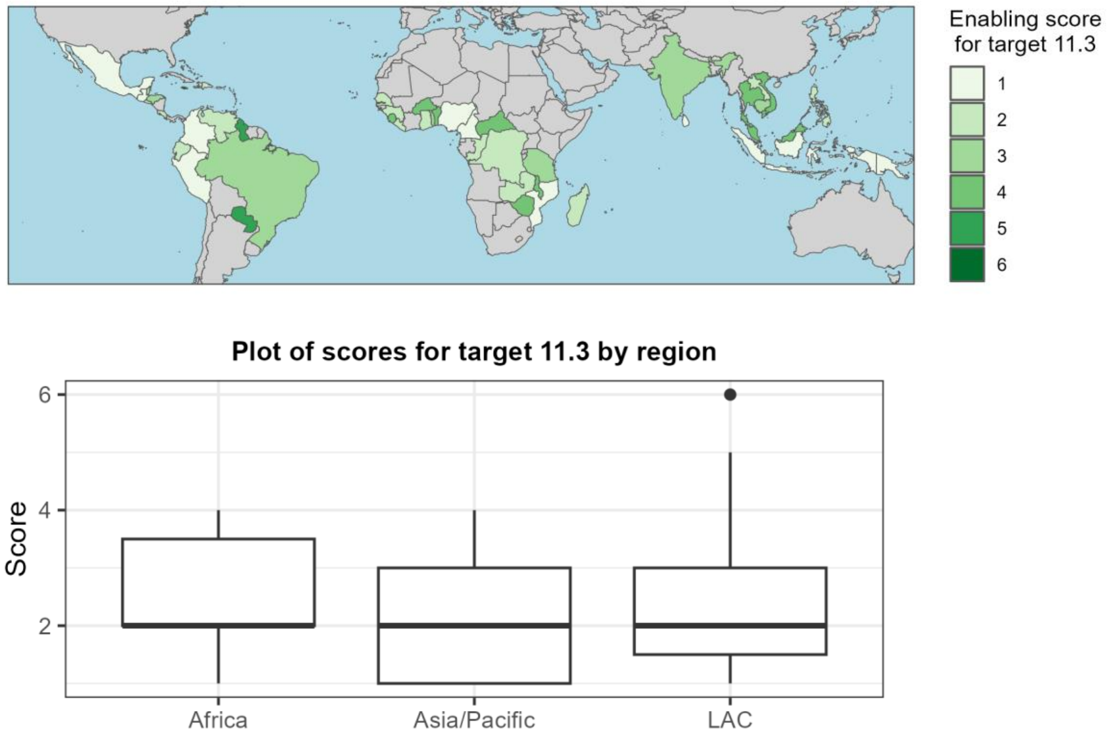


Figure 4.28. Map (above image) showing enabling scores for target 11.3 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

We considered three targets from SDG 16 relating to matters of high-level governance, including improved law enforcement (target 16.3, Figure 4.29), reduced corruption (target 16.5, Figure 4.30) and increased institutional transparency and accountability (target 16.6, Figure 4.31). These targets are increasingly recognised as providing the enabling conditions necessary to reduce forest loss/degradation, including from illegal activities or where environmental regulations or safeguards are circumvented (Brunner et al., 1999; Downs, 2013; Galinato and Galinato, 2013; Klaver, 2009; Sommer, 2018). Among all countries considered, current statuses were assessed as ‘poor’ for large proportions of all three of these targets, including 40 countries for target 16.3, 44 countries for target 16.5, and 36 for target 16.6. In terms of likelihood of imminent progress in these targets, assessments of ‘possible’ were most common for all three, followed by assessments of ‘likely’, and assessments of ‘unlikely’ comparatively few. For target 16.3, 17 countries were assessed as ‘likely’ to make improvements, 24 as ‘possible’, and two as ‘unlikely’, and we found no significant differences in the mean scores for this target between regions (F(2, 37) = 0.133, p = 0.88). For target 16.5, 16 countries were assessed as ‘likely’ to make improvements, 29 as ‘possible’, and two as ‘unlikely’, and we found no significant differences in the mean scores for this target between regions (F(2, 42) = 0.560, p = 0.57). For target 16.6, 13 countries were assessed as ‘likely’ to make improvements, 25 as ‘possible’, and five as ‘unlikely’, and, once again. we found no significant differences in the mean scores for this target between regions (F(2, 38) = 0.373, p = 0.69).

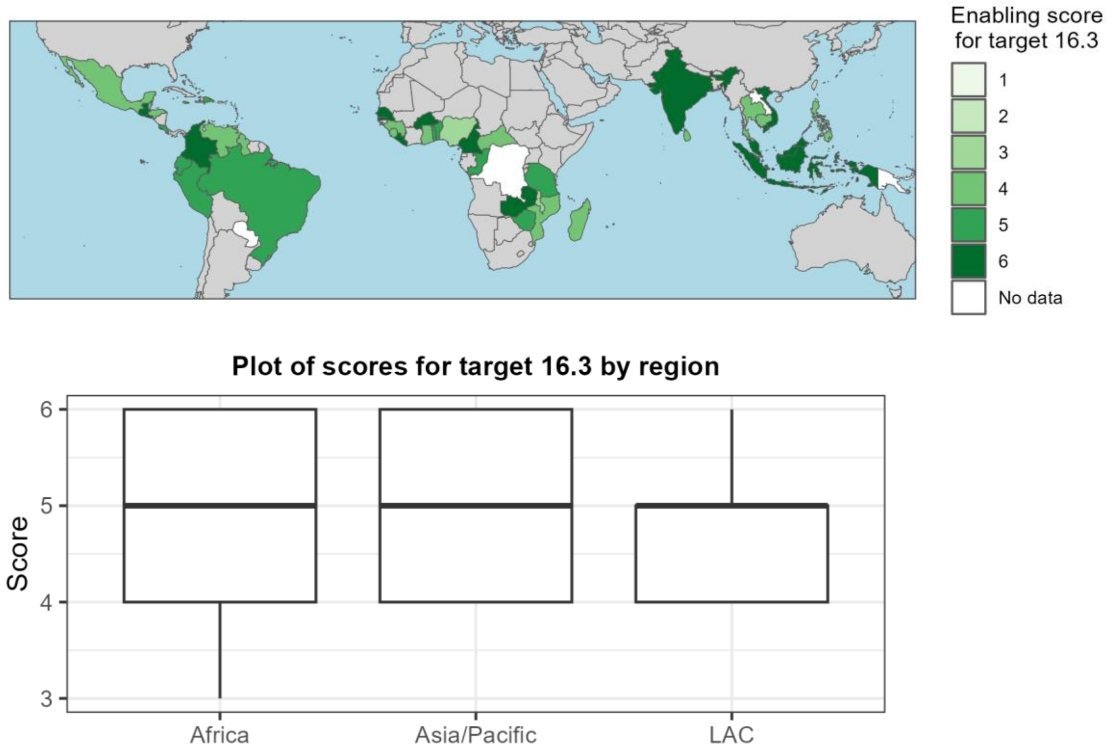


Figure 4.29. Map (above image) showing enabling scores for target 16.3 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

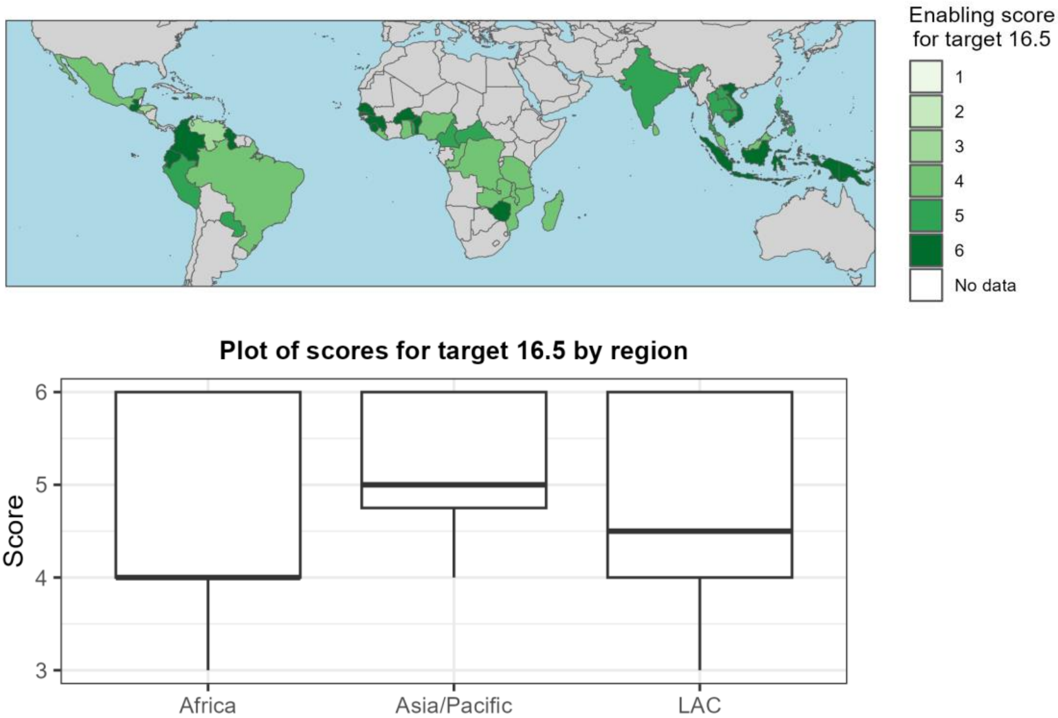


Figure 4.30. Map (above image) showing enabling scores for target 16.5 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

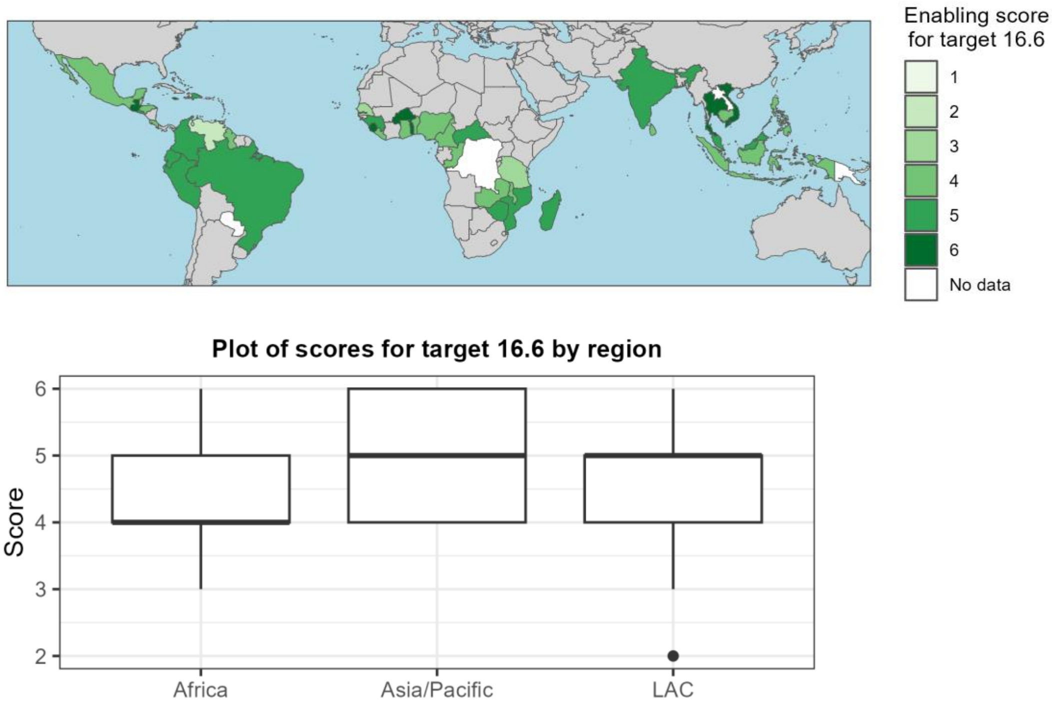


Figure 4.31. Map (above image) showing enabling scores for target 16.6 by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

In combining data for all enabling targets described above (Figure 4.32), we find that the countries with the highest cumulative enabling scores are predominantly in Africa. These are (in decreasing order): the Gambia, Sierra Leone, Guatemala, Togo, Guinea, Zimbabwe, Burkina Faso, Zambia, DRC and Central African Republic. Countries with the lowest cumulative enabling scores are predominantly in mainland Latin America. These are (in increasing order): Costa Rica, Belize, Sri Lanka, Venezuela, Malaysia, Peru, Brazil, Mexico, Ecuador and Honduras. We found a significant difference between regions in terms of mean cumulative enabling scores ($F(2, 45) = 5.238$, $p < 0.01$), and Tukey's test for multiple comparisons found that mean values differed significantly between LAC and Africa ($p < 0.01$, 95% C.I. = -0.72, -0.10), but not between Asia/Pacific and Africa ($p = 0.36$) or between Asia/Pacific and LAC ($p = 0.25$).

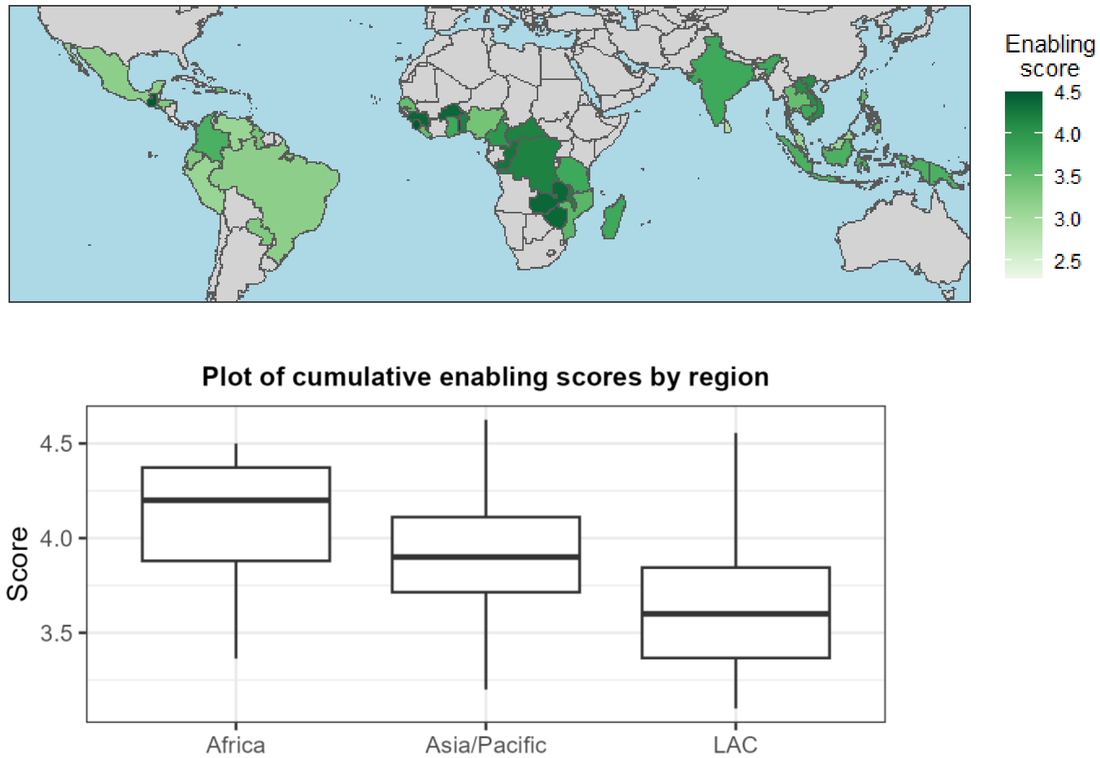


Figure 4.32. Map (above image) showing cumulative enabling scores by country (see Materials and methods for how these scores were derived), and box-whisker plot (below image) showing the distribution of these scores for each region considered.

4.3. Discussion

For 48 tropical countries, our assessments highlight the key risks, opportunities and enabling conditions for forests that we might expect to observe in the short- to medium-term, based on their anticipated development trajectories. Individual country assessments show variation in the make-up of their component target-level assessments, yet some broad patterns are evident. Of particular note is the observation that for the majority of targets, assessments of 'unlikely' imminent progress were less frequent than assessments of 'possible' or 'likely'. Exceptions to this include targets 10.7 (migration management), 11.3 (participatory settlement planning) and, for Africa only, the clean fuels aspect of target 7.1. Given that these are all enabling targets, we urge governments to make greater efforts to address these, both for the forest-specific and the wider benefits they provide. Assessments of the likelihood of progress for each target assessed are more similar between regions (at least in terms of the proportions of countries in each category) than assessments of the magnitude of potential progress. Specifically, we see that, with few exceptions, African countries currently require greater progress in order to achieve many of the targets assessed in this work, suggesting that the latent impacts associated with the different target types (risk, opportunity or enabling) are greater in magnitude there than elsewhere.

Specific risks to forests that could warrant attention over the coming years include ongoing threats from agricultural production, transport infrastructure and urban infrastructure, which all look likely to make further progress in many countries across all regions (including countries that are already performing well in these areas). Energy infrastructure could also pose risks to forests across many tropical countries, though in many cases such threats are yet to emerge. We note that in Africa, possible emerging risks are more typically associated with providing access to electricity and other energy types, while in LAC, possible emerging risks from renewable energies were identified more frequently. While it would be improper to suggest that countries should not strive to achieve progress in these areas, appropriate safeguards, which are often facilitated by sound planning, management and governance frameworks (as per many of the enabling targets considered herein), will be essential in order to minimize any environmental damage caused.

Across all countries, assessments of opportunity targets show greater heterogeneity than those for risk and enabling targets, yet some broad patterns are still evident. For example, poverty reduction and economic growth are clearly high priorities among many countries, and much progress has been made in both areas in recent times. Conversely, assessments of property/land rights and income inequalities showed that much progress remains to be made in these areas, but that in many countries this is less likely to occur than for other targets. As with risk targets, the achievement of opportunity targets is unquestionably desirable, but we encourage those responsible for delivering progress to pursue pathways that support, rather than inhibit, environmental conservation. Ways to achieve such outcomes are innumerable, but examples might include the pursuit of target 8.9 (sustainable tourism) through well-managed ecotourism that facilitates poverty reduction and economic growth (Wunder, 1999), strengthening of land and property rights (target 1.4) for individuals and communities in combination with appropriate environmental regulations and/or conservation incentive programmes (Holland et al., 2014), or the promotion of agricultural technologies (target 2.a) that allow sustainable intensification of otherwise low-yielding, extensive farming practices (Kaimowitz and Angelsen, 2001). Achieving opportunity targets in ways that benefit, rather than damage the environment will, in many cases, require appropriate enabling conditions to be created first, so that resulting planning, management and governance frameworks can help to ensure the most sustainable progress possible.

Assessments of enabling targets show that the majority of countries still have much progress to make on matters of rule of law, corruption and institutional transparency, but that some progress can be expected in these areas in many cases. For a number of other enabling targets, we found that Africa is lagging behind the other two regions considered in many cases. Despite this, across all regions we expect to see progress in many areas, and especially in matters of education, female decision-making, and increased employment. Exceptions include matters of clean fuels (Africa only), reduced agricultural employment, migration management and participatory settlement planning, which were all assessed as less likely to make imminent progress. As the benefits associated with a number of enabling targets typically manifest through the mediation of impacts from other target types (e.g. reducing corruption can help prevent infrastructure projects from bypassing safeguards) we recommend that these targets be treated with the greatest priority. It is also worth noting here that SDG targets pertaining directly to matters of the environment are also all enabling in nature, but were not included in this work as our intention was to focus on matters that can affect forests indirectly. Progress in environment-related targets will be essential to stem the loss and degradation of forests and other natural systems, but achieving these additional, less conspicuously relevant targets will also be highly important to ensure that direct conservation measures are as effective as possible.

Although the results presented in this paper have largely been summarised either by region or by all countries combined, important insights can be gained by considering assessments on a country-by-country basis. Not only is this likely to be the most relevant scale for policymakers and development agencies to act upon, but the fact that no two countries are identical in their constituent assessments highlights the importance of considering matters of national context. To illustrate this we might compare interpretations between two arbitrary countries, say Zambia and Malaysia. In Zambia, risks to forests are expected from ongoing improvements in agricultural production, transport infrastructure and housing, and possibly from energy infrastructure, while in Malaysia these are mostly less of an issue, and deployment of renewable energies was identified as the greatest risk. In Zambia, opportunities will arise from poverty reduction and improved agricultural technologies, both areas with significant scope and high likelihood of progress. In Malaysia, these targets are expected to show progress, but with much less scope for potential gains, and instead, matters of tourism and income equality, both expected to show significant progress, are more relevant. In terms of enabling targets, both countries are set to make significant progress in matters of female decision-making, and rule of law, and neither country looks likely to make the desired progress in matters of institutional transparency. However, few other similarities are evident, mainly as Zambia is lagging behind in many areas (most notably clean fuels and reducing corruption), while Malaysia is already performing relatively well in most other enabling targets. Such differences will necessitate different responses on the part of national-level policymakers and development/conservation agencies to guide national development in a forest-friendly direction. We therefore encourage interpretation of our findings at this more in-depth level, including engagement with local stakeholders and experts to verify whether the potential for forest-relevant outcomes is relevant in their specific context.

Forests have provided a good case study upon which to demonstrate our assessment framework, and we encourage applications of a similar approach to other development-related topics. A key starting point for such assessments is knowledge of the direct and underlying factors that can facilitate or limit success in achieving a given development outcome. Fortunately, such knowledge exists for a wide range of topics featured among the SDG's targets, including both environmental (e.g. wetland conversion (Van Asselen et al., 2013), illegal fishing (Aghilinejhad et al., 2018; Collins et al., 2021)) and non-environmental (e.g. poverty reduction (Anyanwu and Anyanwu, 2017; Warr, 2014), maternal mortality (Cameron et al., 2019; Hussein et al., 2011), sustainable tourism (Dwyer, 2015; Maxim, 2015)) issues. In many cases, this knowledge could be readily used to select key SDG targets to assess how ongoing national development trajectories could affect the development outcome in question, and identify appropriate policy responses, as was demonstrated in this work. For development outcomes where the factors that facilitate or limit success are currently unknown, we encourage efforts address these knowledge gaps (e.g. through literature reviews and meta-analyses). By combining the growing understanding of interactions among development targets with data indicating anticipated progress (or lack of) in key areas, we can develop a more holistic understanding of likely outcomes across a range of development themes, and act accordingly to ensure that different areas of development operate in harmony rather than in discord.

Our assessments highlight key areas of the sustainable development agenda that warrant attention in the context of forest conservation, yet several caveats should be borne in mind when interpreting our results. The list of drivers used in this work is limited to human-driven, national-level factors (see Materials and methods), yet we should not underestimate the importance of other factors that play roles in the loss and degradation of forests, including human-driven factors (e.g. global commodity prices, and foreign investments, policies and resource demands) and natural factors (e.g. climate change). Although we acknowledge the importance of such factors (Assa, 2018; Dale et al., 2000; Pendrill et al., 2019; Verburg et al., 2014; Zhao et al., 2021), their inclusion would be challenging, not least because they are typically stochastic and/or beyond the control of any single government. Similarly, we focused on a subset of SDG targets with the best documented links with drivers of forest change (and with sufficient data availability). Notable omissions from our assessments include matters of access to vocational and tertiary education (target 4.3), and access to finance and markets by small-scale enterprises (target 9.3), for which good evidence exists to suggest beneficial and damaging impacts on forests, respectively (Ehrhardt-Martinez, 1998; Pendleton and Howe, 2002). Our omission of certain drivers and development targets means that our assessments are not wholly representative of the myriad ways in which sustainable development may affect tropical forests. Nevertheless, we cover many of the major issues surrounding the forest impacts of sustainable development, and hence provide an informative and comprehensive overview of the outlook over the coming years. Moreover, given the simplicity of our approach, the inclusion of additional indicators (e.g. once useable data become available) in future applications of this framework would present few challenges.

Though our assessments do, to some extent, intrinsically cover interactions between more than two targets, for example our inclusion of target 4.1 (access to education) assumes that benefits to forests from this target will manifest, at least in part, through changes in employment status (targets 8.3 and 8.5), these were not explicitly investigated in this work. To do so would require a much deeper understanding of how two or more targets can interact to result in environmental impacts, which is currently lacking, at least compared with the more simple interactions involving only two targets considered in this work. At the current time, these more complex interactions are typically only considered through use of systemic models, which, as was described at the outset of this paper, are subject to range of uncertainties and assumptions. As knowledge of multi-target interactions continues to grow, the inclusion of such factors in assessments aiming to identify emerging risks and opportunities, could well represent a valuable area of inquiry. In the meantime, however, a limited understanding of these more complex interactions should not prevent appropriate action to address possible interactions that are better understood, which was the underlying motivation for this this paper.

4.4. Materials and methods

4.4.1. Selecting focal countries

From an initial list of 96 countries (excluding dependent territories) falling within or largely within the tropical zone, we excluded those considered ‘high income’ by the World Bank (World Bank, 2021), as such countries are expected to have less scope for imminent development progress and are therefore of less interest in this regard. We excluded countries with less than 20% total natural forest cover in 2018, based on data compiled by the United Nations FAO and made available as part of the World Bank’s Development Indicators (World Bank, 2022) (development progress in these countries is less likely to impact upon forests compared to those with higher forest cover). Lastly, we excluded countries that had not published an official Voluntary National Review (VNR) of recent progress towards achieving the SDGs (as detailed in the following sections, these documents were a key source for data for this work). This resulted in a list of 50 remaining countries for investigation, though we subsequently excluded two further countries (Saint Lucia and Vanuatu) due to a lack of useable indicator data. The total estimated forest cover of the initial 96 countries and for our subset of 48 is 18,067,728 km^2 and 15,224,221 km^2, respectively, meaning that, notwithstanding dependent territories, our assessments are relevant to countries containing around 84.3% of all tropical forests. Our subset of 48 countries comprised 20 countries from Sub-Saharan Africa, 13 countries from the Asia/Pacific region, and 15 countries from the LAC region.

4.4.2. Assessing national-level drivers of deforestation and forest degradation

As there is currently no repository for storing or providing data on national-level drivers, our approach drew upon available literature, including peer-reviewed articles and other high-level reports. We used a series of four searches (country name, plus each of the terms "deforestation", "forest change", "forest degradation" and "forest drivers") in both Google and Google Scholar, excluding publications prior to 2015 and, in each case, inspecting the first 50 results for relevant information. For each country, we also specifically sought the following documents, which all typically present summaries of national-level drivers: (i) World Bank ‘Country Forest Notes’ (e.g. World Bank, 2020); (ii) CIFOR working papers from their ‘Context of REDD+’ series (e.g. Pham et al., 2019); and (iii) REDD+ preparation documentation (predominantly, but not exclusively national ‘Readiness Preparation Proposals’), made available by the Forest Carbon Partnership Facility (FCPF, 2021).

We reviewed each document for relevant information, recording each direct and underlying driver reported, including those reported as likely to emerge in the near future. We did not include drivers related to fire events or climate change, nor those that are typically beyond the control of a given country of interest (e.g. timber market prices or levels foreign direct investment), which are all beyond the scope of this work. We also did not include drivers relating to formal government policies, as, given that government policies form a key source of information for this work, we would risk making circular arguments. At this initial review stage, all drivers were recorded in their raw form, as specified in the source documents. Subsequently, all recorded drivers were grouped into logical categories (33 in total, see Table C.1 in Appendix C) to provide consistency and comparability between countries. With few exceptions, all of the literature reviewed used similar terminology and classification schemes to describe drivers, and so this process presented few challenges.

We did not attempt to assign relative weights or levels of importance to drivers, as in the majority of cases, the complexities surrounding causes of forest change, even at national levels, makes this unfeasible. While our approach was not exhaustive, it can be considered comprehensive, and in the majority of cases, individual drivers were reported across multiple documents, suggesting that our searches captured the most important contributing factors.

4.4.3. Selecting SDG targets

Initial selection of SDG targets was based on Carr et al. (2021), who identified 63 targets as having potentially damaging, beneficial or mixed implications for forests (corresponding with our categories of ‘risk’, ‘opportunity’ and ‘enabling’ targets, respectively). From these, we excluded targets for which linkages were deemed uncertain (i.e. reported as 'low confidence' by the authors) or where the original findings were based on highly specific contexts, not applicable to a multi-country assessment such as this (e.g. the authors' findings on target 16.4 related specifically to efforts to reduce organised crime in Colombia). To validate these target-forest relationships, we also consulted Katila et al. (2019), who provide a qualitative, expert-driven assessment of the impacts of achieving the SDGs on forests. Where, for a given target, one source suggested beneficial or damaging impacts and the other suggested mixed impacts (as was the case for target 8.9, on tourism), the target was placed in the opportunity category. In one case (target 6.1, access to water) the two sources disagreed entirely, with one suggesting negligible impacts and the other damaging, and so this target was not included due to this uncertainty. Because Katila et al.'s assessment was not systematic in nature, not all targets were necessarily considered in their work, and so in cases where the Carr et al. study cited impacts for a target that was not mentioned by Katila et al., the former was taken as the default option.

As targets 4.1 (access to primary and secondary education) and 4.2 (access to pre-primary education) are expected to be closely related, we only included the former, which had better data availability. Two targets (4.3 on technical and vocational education and 9.3 on access to credit and markets) were not included due to a lack of available indicator data to inform assessments. Assessments of targets 1.1 and 1.2 (poverty measured using international and national scales, respectively) were combined, and two separate assessments were made for target 7.1 (access to modern energy services); one on access to electricity and another on clean fuels (see details in Table C.2). Despite being assessed by Carr et al. (2021) as having impacts with low associated confidence, we included assessments of access to family planning (targets 3.7/5.6), responsible migration policies (target 10.7), inclusive and participatory settlement planning (target 11.3), and accountability/transparency of institutions (target 16.6), which can all be linked with commonly cited underlying drivers of forest change (Bizzo and Michener, 2017; Busch and Ferretti-Gallon, 2017; Erazo, 2011; Hugo, 2008), and so were deemed informative in our context. Overall, we considered 25 indicators, relevant to 24 SDG targets, which are listed in Appendix C (Table C.2).

4.4.4. Establishing linkages between drivers and SDG targets

In many cases, the links between SDG targets and drivers of forest loss/degradation are straightforward. For example, plans to increase agricultural output (target 2.3) could result in the emergence or worsening of drivers relating to agricultural expansion, while efforts to address corruption (target 16.5) will likely help to address cases where corruption is a known underlying driver. In many other cases, however, these links are less clear, and so to establish linkages for the purpose of this assessment, we again drew upon the published literature. When assessing the national-level drivers for each of the 48 countries considered in this work, many of the documents reviewed described ways that specific drivers could be mitigated or aggravated by suggested interventions or anticipated changes. This was especially the case for documentation associated with REDD+ (e.g. Readiness Preparation Proposals and synthesis reports), which commonly give detailed breakdowns of identified national-level drivers, including suggested solutions and/or anticipated changes that could cause them to worsen. This information was compared with the official SDG targets and indicators (Inter-Agency and Expert Group in Sustainable Development Goal Indicators, 2016) to determine which of the SDG targets best aligned with the solutions/changes that were identified as having implications for a given driver.

The documents used to select SDG targets for inclusion in this work also contained useful information in this regard. The review by Carr et al. (2021), which was conducted by several authors involved in this work, provided a large body of literature containing much information on the specific mechanisms through which individual targets could affect forests, which could be readily linked to specific drivers. The book by Katila et al. (2019) also provides detailed descriptions of how each SDG is expected to interact with forests, often making or (inferring) explicit links with drivers. Information gathered from these sources was cross-referenced with our list of drivers, and all linkages recorded.

Having compiled information on the possible ways that selected SDG targets can interact with drivers, the resulting information was condensed into two tables; one organised by drivers (showing SDG targets with recorded linkages), and the other organised by SDG targets (showing drivers that could be affected) (see Appendix C, Tables C.1 and C.2), and subsequently used to develop a matrix showing all links used to conduct this assessment (Appendix C, Table C.3). We acknowledge that our assessment of the links between SDG targets and drivers in this way may not have captured the full range of complexities, but we feel that our approach was thorough, and should have captured the most important relationships. We also acknowledge that some of our recorded linkages may not apply in all countries and contexts. However, as our intention is to indicate *possible* ways that anticipated development progress could affect forests, which we hope will be further discussed among experts with more detailed contextual knowledge, we prefer to be inclusive, allowing exclusion of a particular relationship deemed irrelevant at a later point, rather than to exclude potentially relevant relationships, which could be later overlooked.

4.4.5. Assessing SDG target indicators

For each target, and for each country, we aimed to assess three features: (i) the current status, designated into categories of either 'poor', 'medium' or 'good', (ii) the recent trend, using categories of either 'declining', 'stable' or improving' and (iii) the level of priority assigned by national governments, using categories of either 'low', 'medium' or 'high'.

For elements (i) and (ii) we first sought data directly pertaining to the official SDG indicators, made available on the UN's Global SDG Indicators Database (United Nations Statistics Division, 2022) and by the World Bank (World Bank, 2022) (the latter often being more data rich, and so used preferentially where data for the same indicator were available from both sources). In cases where targets or indicators are multi-faceted in nature, we purposefully chose indicators most closely related to the forest impacts identified by Carr et al. (2021). For example, for target 1.4 ("*By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance*") we were specifically interested in matters relating to "control over land and other forms of property", which was identified by the authors as playing a key role in matters of deforestation and forest degradation. In cases where data from our preferred source were unavailable or insufficient, we identified alternative data sources thought to adequately reflect the target in question. Additional sources included: the Physical Property Rights component of the International Property Rights Index (IPRI, 2020) for target 1.4 (control over land and other forms of property); FAO data on national levels of agricultural production (FAO, 2021) for target 2.3 (increase food production); data from the World Justice Project (World Justice Project, 2021), which includes a range of indices relating to matters of national-level governance, for targets 16.1 (no conflicts), 16.3 (rule of law) and 16.7 (institutional transparency); and Transparency International's Corruption Perceptions Index (Transparency International, 2021) for target 16.5 (reduce corruption).

For all targets/countries, we collated information for the most recent years available (excluding cases with no data available for 2015 or after) as well as for 10 years (or as close as possible) prior to the most recently available value. Information on all targets/indicators considered in this work, including data sources, is provided in Appendix C (Table C.2).

For indicators with defined endpoints (i.e. those based on bound indices or where a 0% or 100% outcome is desired) we calculated the global (using all countries with available data) standard deviation (SD) from this endpoint. We then considered national-level distances from the defined endpoint, and assessed values less than the global SD as 'good', those greater than one SD but less than two SDs as 'medium', and those greater than two SDs as 'poor'. Where indicator endpoints are less well defined (e.g. proportion of total GDP derived from tourism for indicator 8.9.1), we assigned our own success thresholds based on reasonable assumptions of desirable target values (see Table C.2), and applied this same approach. While this approach may attract criticism for use of somewhat arbitrary values, other approaches (e.g. comparing country-level values to global averages (Zeng et al., 2020)) are limited by the fact that reference values may not be indicative of the levels that countries wish to achieve (i.e. if global performance for a given target is currently poor), and so our approach is preferred. Assigning categories that characterise recent change (i.e. 'declining', 'stable' or improving') in a given indicator faces similar challenges, again because there are no pre-established thresholds with which to distinguish between stable and either declining or improving (given that some level of change, even if very small, can be expected in the majority of cases). We calculated the percentage change between the latest available data value and the corresponding value from 10 years previous (extrapolating from intermediate values as required), and with few exceptions (see Table C.2) considered absolute changes of less than five percent as 'stable'. Although our use of ordinal categories may mask some of the between-country variation present in the raw data, it does allow straightforward comparison between countries and indicators. Future applications of this framework could potentially capture a wider extent of the variability by using more than three categories, but for the sake of interpretability, we opted for this simpler approach.

Assessments of the priority assigned to each target by governments used official national development plans as well as the most recent Voluntary National Reviews of the SDGs (Sustainable Development Knowledge Platform, 2021). Targets explicitly stated in these documents as being a priority and/or with detailed information on how the target will be achieved were considered 'high' priority. Targets receiving mention, but lacking details on how they will be achieved, were considered 'medium' priority. Targets not mentioned at all were considered 'low' priority. Because an improving trend in a given indicator does not guarantee that improvements will continue, and because governments simply stating that a particular target is a high priority does not necessarily mean that they will honour this, we combined these two elements to derive a measure of likelihood of imminent change using the following logic: for targets exhibiting recent progress and considered high government priority, imminent change was assessed as 'likely'; for targets where only one of the above was true, imminent change was assessed as 'possible'; and for targets where neither of the above was true, imminent change was assessed as 'unlikely'.

In cases where a given target was not linked to an acknowledged country driver, two assessment outcomes were possible: for opportunity and risk targets with current statuses assessed as either poor or medium and with imminent progress assessed as either possible or likely, the category or 'possible imminent opportunity/risk' was assigned. For enabling targets, and for opportunity and risk targets not meeting the above criteria, we assigned the category of 'not currently relevant'.

4.4.6. Deriving and comparing indicative, target-level scores

To derive indicative values that can be compared between countries, individual targets for each country were scored as follows: for current status, good = 0, medium = 1, poor = 2; for trend, declining = 0, stable = 1, improving = 2; and for priority, low = 0, medium = 1, high = 2. Each of these component scores was then summed so that minimum and maximum possible scores were zero and six, respectively. The nature of this scoring process means that higher scores can result where countries have significant progress to make in order to achieve targets, where observed progress has been achieved in the last decade, or where targets are being treated with high priority by governments, and combinations of all three of these criteria result in the highest possible scores. These scores are presented as maps for each target in our results section. To compare these scores between our three regions of interest, we used one-way ANOVAs to assess differences in the means for each region, as well as box-whisker plots (accompanying the respective maps) to present these comparisons visually. ANOVAs were supported by Levene's tests to assess the equality of variance between the three groups, and we report only on cases where this assumption was not met. ANOVA tests indicating significant differences ($\alpha = .05$) between regions were followed up with Tukey's range tests in order to examine which regions differ specifically.

To derive cumulative scores for each target type (risk, opportunity or enabling), values for all targets in each category were summed (with scores of zero given to enabling targets without recorded target-driver links), and final country values for each category derived by taking the mean of all values for each target with complete available data. These are presented as maps in the respective sections of our results. As noted earlier, high cumulative scores are not necessarily indicative of a higher intensity of expected forest outcomes (whether positive or negative), but rather a greater complexity of factors that governments, conservationists and development agencies will need to consider in order to achieve development trajectories that are conducive to forest conservation.

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Chapter 5 Conclusions

In section 1.7 of this thesis I set out the overarching aim of this research, as follows: to provide a comprehensive assessment of the roles that the SDGs and their constituent targets play in shaping the dynamics of deforestation and forest degradation, and to provide an assessment of where these interactions are likely to be most impactful across the tropics. The first publication included in this thesis (Chapter 2) comprised a comprehensive systematic review of the ways that non-environmental SDG targets have been recorded, or may be expected to affect the health and quality of natural forests, whether for better or for worse. The second publication (Chapter 3) drew upon open access, global data to examine whether progress towards achievement of the SDGs has positive or negative impacts in terms of its effects on forest cover, and to identify the specific goals that are most important in shaping the outcome. The third publication (Chapter 4) used a novel framework to identify imminent risks, opportunities and enabling conditions that progress towards achieving the SDGs could present for forest conservation in 48 tropical countries.

Although investigating the ways human development can/may impact forests is not a novel line of enquiry, this work is the first to quantitatively examine the topic in the context of the SDGs. Given the importance of the SDGs in shaping the development objectives and trajectories of much of the world (all 193 UN member states), this work has significant global relevance, which I hope will help to facilitate better consideration of forest conservation by all parties engaged in matters of sustainable development around the world. This work responds to the call for the academic community to investigate and map the interactions between the SDGs and their targets (Nilsson et al., 2016), and should therefore be seen as a contribution to a wider body of research that seeks to help achieve a broad suite of desirable outcomes in the most harmonious possible way.

In this concluding chapter, I highlight the key findings from all three publications (both individually and as a whole), including the wider implications of the work for the sustainable development community at large. I discuss the major limitations of the work, the novel contributions that the work has made, and provide suggestions for future research that would help to progress this line of enquiry even further. The chapter closes with a concluding statement that encapsulates the most important take-home messages from the thesis.

5.1. Summary of key findings and their implications

In this section I summarise what I feel are the most important findings from the work presented in this thesis, and discuss the implications of these for governments and agencies working on matters of sustainable development. However, given the wide-ranging subject matter of this thesis, it is not possible to describe all findings and their implications here, and readers are encouraged to refer back to earlier chapters for more comprehensive summaries.

1. **Impacts on forests arising from achievement of the SDGs are not uniform between or within the individual goals, nor necessarily within individual targets.**

   The review presented in Chapter 2 of this thesis identified 63 non-environmental SDG targets that have known or suspected impacts on forests, and made a distinction between those that have damaging or beneficial impacts, or in some cases, both. This included 29, 15 and 19 targets with potentially beneficial, damaging and mixed impacts, respectively.

   Variation between each of the goals in terms of the relative proportions of damaging, beneficial or mixed impacts is evident. SDG 4 (education) was the only goal assessed as having impacts that do not appear to vary in nature between its composite targets, as all six (from a possible 10) targets from this goal with recorded impacts on forests are expected to be beneficial. Several authors (e.g. Godoy and Contreras, 2001; Kanowski et al., 2020) have noted that SDG 4 can have positive implications for environmental conservation, and this thesis provides further support for the idea that the relationships between the two topics should be better explored and capitalised upon in order to achieve win-

wins wherever possible. For all other goals, the types of impacts recorded showed variation between their composite targets. In some cases, these were either predominantly beneficial (e.g. SDG 16, peace, justice and strong institutions), damaging (e.g. SDG 11, sustainable cities and communities), or mixed (e.g. SDG 7, energy), while in other cases, targets showed varying combinations of the three categories (see Figure 2.2 in Chapter 2).

To generalise the implications of these findings is difficult, as these are typically goal-specific in most cases. However, it is clear that across all sectors (with the possible exception of education), parties involved in enacting or facilitating some form of change should be aware that development targets within their field of interest can have the potential to cause or enable both damage and benefits for the environment. This should be minimised and promoted, respectively, through careful pre-planning, ideally in partnership with relevant stakeholders, who are likely to best understand the complexities of the areas or communities being targeted.

The 19 targets recorded as having mixed impacts show that the ways that the SDGs may affect forests can vary at the target level. A further 19 targets also had two or more records indicating variation in the direction of their impacts, but were not recorded as ‘mixed’ overall due to differences in confidence assigned to each record. For a given target, mixed impacts can occur due to contextual factors, different ways of addressing the target in question, or if the target is multi-faceted or open to interpretation in some way. Here, the implications are more straightforward: parties responsible for helping to achieve a given SDG target should, consider, to the greatest extent possible, the potential implications of any changes that they hope to make or see, including from all possible options available. This should again be in partnership with relevant stakeholders, who can help to highlight important contextual matters. Once again, wherever possible, damaging impacts should be avoided or mitigated, and beneficial ones promoted.

2. **Confidence surrounding the potential impacts of each SDG target on forests is varied, and findings suggest a research bias toward damaging over beneficial outcomes.**

The 963 target-level forest impacts recorded through Chapter 2's systematic review were highly concentrated around certain topics, with more than 50% focusing on matters of energy, land tenure, agriculture, corruption, economic growth, infrastructure and law. Furthermore, in Figure 2.3, which provides a summary of the levels of confidence surrounding each of the 63 targets identified as having known or suspected impacts, we saw that targets associated with damaging impacts (coloured red in the chart) have much higher levels of associated confidence than those with beneficial impacts (coloured blue). One possible reason for this apparent research bias is that damage caused to forests (e.g. through land conversion) can be a lot more conspicuous than the often subtle changes that occur from beneficial impacts; for example, a reduction in the rate of forest loss could go unnoticed if it occurs in a localised area surrounded by ongoing deforestation. Irrespective of the reasons, the implication here is that many (currently theoretical) positive impacts, and lessons that might be learned from these, are poorly understood, and the research community should seek to redress the balance by focusing on the impacts of lesser-studied targets. This topic is discussed further later in this chapter.

3. **At the goal-level (or higher), higher levels of achievement are mostly associated with reduced forest loss, but progress towards achieving higher levels of development can have negative impacts.**

The analyses presented in Chapter 3 showed that countries with a higher overall level of development (i.e. when all SDGs are considered in combination) tend to have lower rates of forest loss (and in some cases are experiencing forest gains), compared with countries with a lower level of development. Conversely, progress towards achieving higher levels of development can be associated with forest losses, especially in countries with lower pre-existing levels of development. This finding makes logical sense, as once higher levels of development have been achieved, fewer additional major changes will likely be required. The implications here are positive in the sense that achieving high levels of development should ultimately help promote forest conservation, but the finding also highlights a need for caution and pre-emptive measures to ensure that development is achieved through processes that do not place unnecessary risks on forests and other natural systems.

Relative importance analysis to examine the contributions of individual SDGs to the above relationships showed that goals on health, education, energy, economy and industry/infrastructure are most important in shaping forest change once achieved, and that goals on economy, industry/infrastructure and climate change are most important in terms of the processes of actually attaining higher achievements. These findings indicate the areas of the development agenda where attention may be best directed by international policymakers and development agencies in order to help achieve harmony between sustainable development and forest conservation. They also highlight that target-level impacts do not necessarily scale up to the level of goal, and vice versa, an observation made previously by Lusseau and Mancini (2019). While goal-level analyses remain useful for informing broad governance matters (i.e. those pertaining to whole thematic areas), they are less appropriate for informing specific interventions, and the same applies in reverse.

4. **Global analyses mask regional heterogeneity in the relative importance of different aspects of the SDGs in shaping forest change.**

Chapter 3 also compared how various ‘themes’ encompassed by the SDGs vary between regions of the world in terms of their relative importance in shaping forest change. Notwithstanding the caveats associated with this analysis (see sections 3.4 and 5.3), the results indicate a high degree of variation between regions. In Africa (and similar to the global analysis) we see a relatively balanced contribution from all themes, whereas in Asia matters of well-being and social issues play comparatively lesser roles, and in Europe and the Americas, themes surrounding economics and social issues appear comparatively more influential. Furthermore, in some cases, the overall effect of a given theme can vary regionally; for example, in Asia, progress toward achieving goals related to matters of economics has a seemingly positive effect on forest cover, whereas in all other regions (and globally) the effect is negative.

Inter-regional heterogeneity in impacts associated with achieving the SDGs has been shown previously, including in other goal-level analyses (e.g. De Neve and Sachs, 2020), as well as in target-level assessments (e.g. Bali Swain and Ranganathan, 2021). The implication here is that efforts to achieve forest conservation through interventions targeted at other aspects of the development agenda need to keep in mind that no ‘one-size-fits-all’ policy exists, and that consideration of contextual factors specific to the target area is crucial.

5. **In many tropical countries, existing threats to forests from transport infrastructure and agriculture could become worse, while new threats from energy infrastructure could emerge.**

Chapter 4 considered six SDG targets whose progress has been previously observed to cause damage to forests. For 48 countries, each of these was assessed in terms of the progress still remaining to be achieved (a proxy for the potential damage that could be caused) and the likelihood that progress will occur imminently. Among these targets, improvements to transport infrastructure (target 9.1) stood out in particular as being an existing driver of forest change in all 48 countries, as well as still having notable improvements required, and this being possible or likely to occur in for 44 countries. Suggested solutions/mitigating measures to the impacts of roads on forests have included increased protected area coverage/effectiveness; improved planning processes and decision-making tools; improved environmental impact assessment processes, including widened stakeholder consultations; and the explicit consideration of the impacts of roads in forest carbon-trading initiatives such as REDD+ (Laurance et al., 2017, 2015, 2009).

This same process also found that agriculture (of varying scales) is a known driver of forests change in all 48 countries, and that in 30 of these countries significant increases in agricultural productivity (target 2.3) are still required and are either possible or likely to occur in the near future. Agriculture has been acknowledged elsewhere as being the leading driver of deforestation globally (Curtis et al., 2018; FAO and UNEP, 2020; Hosonuma et al., 2012), and this analysis reemphasises the urgent need for effective mitigating measures. Suggested measures to help reduce the threats to forests from agriculture have included the following: improved planning and land allocation/zoning processes; intensification of agriculture, including through improved technologies and high-yielding crop varieties; provision of off-farm employment opportunities; education of farmers on more sustainable practices and techniques; and improving the living standards of farming households to reduce the need for over-production (Cerri et al., 2018; Laurance et al., 2014; Law et al., 2021; Pham and Smith, 2014). Where increased agriculture is intended for export, then further suggested measures include policies to increase the transparency, accountability and environmental codes of conduct of producers and all involved in the supply chain, especially large corporations (Lambin et al., 2018).

Across much of the tropics, expanding energy infrastructure (including renewable technologies) could pose a threat to forests. Of the 48 countries assessed in Chapter 4, energy infrastructure was recorded as an existing driver of forest change in 24. Of these, 23 were assessed as both requiring improvements and likely to make improvements in the near future. In a further 15 countries, energy infrastructure was recorded as a possible emerging risk. While improvements in matters of energy (SDG 7) can facilitate some beneficial outcomes for forests (see elsewhere in this chapter/thesis), deployment of energy infrastructure has been recorded in many instances as causing significant forest damage (Fearnside, 2005; Gibson et al., 2017; Li and Lin, 2019). As such, this finding highlights a need for pre-emptive measures to ensure that this is not repeated as countries strive to meet energy targets. For the most part, avoiding environmental damage from energy infrastructure will require similar measures as for other types of infrastructure, such as those suggested above for roads (e.g. site protection, improved planning and decision-making processes etc.). In the case of energy, however, there are further considerations to be made, most relating to the choice of technologies employed. Wherever possible countries should avoid use of large-scale energy generation technologies that necessitate land-use change (large hydropower systems are particularly notorious in this regard (Fearnside, 2005; Jolli, 2012; Magintan et al., 2017)), in favour of less-damaging, smaller scale systems. Similarly, promotion of small-scale grid systems that reduce the need for extensive transmission networks, which can cause significant forest damage (Hyde et al., 2018; Wassie and Adaramola, 2019), will also be favourable wherever possible.

6. **The development trajectories of many tropical countries will present opportunities to help conserve forests, but bad choices could make things worse.**

The analyses presented in Chapter 4 considered eight SDG targets that have previously been recorded as having mixed impacts on forests, meaning that their achievement can lead to positive and/or negative impacts, depending on a range of factors (see above for details). Using the same process as described above to assess the progress still remaining to be achieved and the likelihood that progress will occur imminently, three targets stood out in particular, namely targets 1.1/1.2[5] (no poverty), 1.4. (ownership and control over land and natural resources), and 8.9 (increased tourism).

Poverty was identified as a driver of deforestation or forest degradation in 41 of the 48 countries considered, and is also linked to several other drivers (e.g. illegal logging (Alemagi and Kozak, 2010) or overexploitation of NTFPs (Soe and Yeo-Chang, 2019)). As such, the eradication of poverty would logically seem the most straightforward way to address these issues (see also: Miyamoto, 2020; Sreedharan and Matta, 2010). The situation is more complex, however, and work has shown that in some cases poorer households clear less forests than their wealthier counterparts (Babigumira et al., 2014). A review by Wunder

[5] Recall that targets 1.1 and 1.2 were merged into an individual assessment. Here they are treated as a single target.

(2001) suggested that increased monetary wealth increases access to technologies such as chainsaws, and can also increase the tendency for beneficiaries to acquire (and clear) forestlands in order to further avoid poverty (Wunder, 2001 and references therein). Empirical work in Mexico by Alix-Garcia et al. (2013) found that additional income led to increased demands for land-intensive goods, which increased deforestation. The complex relationships between poverty and forests makes suggesting recommendations difficult. Sound policies and regulations to ensure that those escaping poverty are not inclined to use newly acquired resources to exploit forests seem imperative, as does choosing a route towards poverty reduction that is not founded on the exploitation of forests or the land on which they occur.

Insecure or unclear property/land tenure arrangements was recorded as an underlying driver of forest loss or degradation in 44 of the 48 countries included in our analyses. Land tenure security has links with a range of deforestation and forest degradation drivers (e.g. illegal logging, infrastructure expansion), and so its improvement is largely associated with reduced forest loss/degradation (Robinson et al., 2011). However, there are cases where it has resulted in mixed or even damaging impacts on forests. Travers et al. (2015) noted how land titling reforms in a Cambodian protected area, designed to give greater security of tenure to indigenous minorities, resulted, in some cases, in the sale of these lands to commercial farming companies, who subsequently cleared much forest. Similarly, Barkmann et al. (2010) found that increased land tenure security in Indonesia attracted buyers wishing to convert forestlands for cocoa production. Yang et al. (2018) found that forest tenure reforms in China, designed to increase the rights of local households, significantly increased fuelwood extraction. Progress in target 1.4, which calls for improved ownership and control over land and natural resources, was assessed as possible or likely in 32 countries, which is 86% of those with available data. The implication here seems to be that, when embarking on the laudable (and often beneficial, from a forest conservations standpoint) task of improving security of land tenure, governments should include regulations that restrict unnecessary forest clearance by the owners or sale for commercial purposes.

Increasing tourism (target 8.9) is a priority among many tropical countries. The sector still has high potential for growth across much of the tropics, and notable recent improvements in more than half of the countries assessed in Chapter 4 suggest that further progress can be expected. Tourism can be associated with increased disturbance of forests systems due to increased footfall, increased extraction of forest resources to meet the needs of tourists (e.g. wood to produce souvenirs) and/or expansion of infrastructure into forested areas to support the growing industry (Brandt and Buckley, 2018; Gaughan et al., 2009; Wang and Buckley, 2010). Conversely, however, it has been suggested that well managed tourism can help to mitigate forest loss/degradation if it provides local employment that replaces more damaging activities and/or highlights to local people that forests are an asset that can attract tourists, and hence encourages their conservation (Munanura et al., 2019; Stoian et al., 2019). Government regulation will be key to promoting sustainability and good practices in the tourism sector, including effective enforcement, as tourism operators are often known to be non-compliant where rules are poorly enforced (Williams and Ponsford, 2009). Economic incentives for sustainable tourism, for example tax breaks, awards, certification, or grants that recognise and reward environmentally friendly practices, will also be helpful to minimize any damage from tourism (Pan et al., 2018; Williams and Ponsford, 2009; Wunder, 2000). The onus must also be placed, at least in part, on tourists themselves to choose their destinations and activities in a responsible manner. This could potentially be promoted through awareness-raising campaigns by organisations such as the Global Sustainable Tourism Council (GSTC, 2022). Ultimately, a more widespread demand for sustainable tourism will be most important in ensuring that those leading and working in the sector act responsibly (Williams and Ponsford, 2009).

7. **In many tropical countries, expected progress in some SDG targets will enable forest conservation, but some other targets still require greater attention.**

The analyses presented in Chapter 4 considered 11 SDG targets thought to provide conditions that can help to enable forest conservation. In most cases, much progress remains to be achieved in these targets, yet they vary in terms of the likelihood that this progress will occur in the near future. Targets on education (4.1), female decision-making (5.5), rule of law (16.3), corruption (16.5) and institutional transparency (16.6) are all acknowledged as providing co-benefits for forests (Arora-jonsson et al., 2020; Kanowski et al., 2020; McDermott et al., 2020), and were all linked to one or more drivers in all 48 countries assessed. This suggests that improvements in these areas could facilitate forest conservation in all cases. For all of the above, recently observed progress, combined with high levels of assigned priority by national governments, suggests that further progress in these areas is likely. The implications of this are positive, and recommendations for further actions are few, other than to urge governments to honour their plans to address these areas, as set out in their national development strategies, in order to help facilitate environmental co-benefits.

For some other enabling targets, however, findings were less positive. For example, target 11.3 (participatory, integrated and sustainable human settlement planning and management) was deemed relevant to one or more drivers in all countries assessed, yet only four countries were assessed as either possible or likely to make significant improvements in this target over the coming years. Although empirical evidence is lacking, there are many reasons to believe that a more participatory approach to settlement planning can help avoid damage to surrounding landscapes (Erazo, 2011; Valencia-Sandoval et al., 2010), and so governments should consider awarding greater priority to this target in order to help simultaneously achieve their environmental objectives.

Ensuring universal reliance on clean fuels (target 7.1[6]) is another area that appears to require greater attention on the part of governments. This target, if pursued correctly, could help to reduce overharvesting of forests to provide domestic wood fuel and charcoal (Jagger et al., 2020), and will also help with

[6] Recall that target 7.1 was split into two components for this assessment: Increasing access to electricity (risk) and use of clean fuels (enabling).

achievement of target 3.9, which aims, in part, to reduce deaths and illnesses from hazardous household air pollution. Although increasing use of clean fuels is not necessarily relevant to forest conservation in all countries included in the assessment (in eight countries domestic fuel production was not recorded as a driver of forest loss/degradation), for many it is, including all African countries considered. This work identified 16 countries where progress in this area would likely benefit forests, but is unlikely to occur, based on recent trends and government priorities. This includes 11 countries in Africa, which is more than half of those assessed. These governments should award greater priority to this area of the development agenda, perhaps by pursuing strategies such as increasing electricity access (while accounting for the possible risks from infrastructure, described above), as well as promoting the use of new technologies, such as fuel-efficient/clean-burning stoves and household biodigesters, which could all help achievement of target 7.1 while simultaneously relieving pressure on forests (Dresen et al., 2014; Meeks et al., 2019; Tanner and Johnston, 2017).

5.2. Novel contributions made by this thesis

This thesis contributes to a wider body of work looking at how different aspects of the sustainable development agenda interact; an important line of enquiry that can assist those striving for mutual progress on a wide range of social, economic and environmental issues to ensure that their diverse aims complement rather than counteract each other. Specifically, this work considers how three specific SDG targets relating to forests (targets 6.6, 15.1 and 15.2) can be affected by components of the SDGs not typically associated with matters of environment, including at the level of target and goal. Past work on this topic (e.g. Katila et al., 2019; Swamy et al., 2018) has provided useful qualitative assessments, and in this thesis I have built on this by providing more systematic and quantitative assessments, and by considering how imminent progress towards achieving the SDGs could potentially affect forests in a number of countries.

Systematic reviews have been used previously to synthesise information on forest conservation and related policy matters, including on topics such as the drivers of tropical forest cover increase (Borda-Niño et al., 2020), polices that improve forest cover (Min-Venditti et al., 2017), and the effects of food supply chain policies on forest conservation (Garrett et al., 2021). However, until now, the approach had not been used to assess forest change within the context of such a diverse and globally relevant development framework. By consolidating a significant body of past research on the topic in a systematic way, I have been able to provide insights into the varied ways that other SDG targets affect forests, including the extent to which each target is thought to have damaging, beneficial or mixed impacts. Importantly, the review has provided insights into apparent research biases (and consequent knowledge gaps) surrounding how certain elements of the SDGs interact with forests. In doing so, I have hopefully provided guidance for other researchers that wish to further the understanding of how forest conservation can best be achieved amid a wide range of other laudable objectives.

Various past studies have sought to statistically assess how levels of development relate to losses and/or gains in forest at a cross-national level. In some cases, these have used a predictor designed to reflect levels of development as a single metric, for example the UN's Human Development Index (HDI), which combines measures of life expectancy, education and gross national income per capita (Jha and Bawa, 2006; Kauppi et al., 2018). More commonly, research on this topic has employed selected development-related indicators considered *a priori* as being most relevant expected predictors of forest change. Commonly employed predictors in such studies include measures of population growth/density and other demographic factors; economic growth; agricultural productivity or trade; and measures of governance quality; among various others (Capistrano and Kiker, 1995; Crespo Cuaresma et al., 2017; Damette and Delacote, 2012; DeFries et al., 2010; Imai et al., 2018; Koop and Tole, 2001; Leblois et al., 2017; Mahapatra and Kant, 2005). However, none of the above have specifically aimed to relate matters of forest change to a globally-relevant development framework that encompasses such a diversity of topical issues, such as the SDGs, and this thesis has helped to fill this gap.

Moreover, many past investigations on this topic have chosen to overcome multicollinearity among predictors by excluding one or more variables (e.g. Capistrano and Kiker, 1995; Imai et al., 2018), potentially losing some valuable information. By employing relative importance analysis, I was able to overcome problems of multicollinearity without the need to exclude any predictors, providing a more holistic assessment of the links between the SDGs and forest change. To my knowledge, this is the first time that these methods have been used in this context. By assessing the relative importance of each of the SDGs in shaping global forest change, I have been able to provide insights that are relevant to development planning and policymaking around the world. The inclusion of such a wide range of goals as predictors has revealed some perhaps surprising relationships; for example, the apparently beneficial links between SDG 3 (health) and forests is not well acknowledged or understood, as was revealed in Chapter 2. The findings of the analyses in Chapter 3 will hopefully stimulate thought, discussion and further research on the topic, and ultimately contribute to better integration of environmental conservation into the most relevant areas of the development agenda.

With growing understanding around how progress in matters of sustainable development can interact with forests, the logical next step is to use this knowledge to assess where the most important synergies and trade-offs will occur, and to develop policies and interventions accordingly. To date, the most work in this regard has employed systemic models, which have a range of limitations, often arising from their complexity (which can limit their interpretability by end users) and their frequent reliance on assumptions about how two more or more components interact (which can cast doubts over their overall validity) (Alcamo and Henrichs, 2008; Niet et al., 2022; Price and Keppo, 2017; van der Zwaan and Seebregts, 2004). Although understanding of complexities such as higher-order interactions and causal feedbacks remains notably poor (see following section), my view is that sufficient knowledge and data exists to inform appropriate actions without the use of complex models, and the assessment framework presented in Chapter 4 demonstrates this. By combining information from national development plans, national-level indicator data, and existing knowledge derived from the literature, I highlight specific SDG targets that could present risks, opportunities or enabling conditions for forest conservation. Such an approach is, to my understanding, completely novel, and its strength lies in its simplicity. Importantly, it does not rely on any assumptions, but instead raises a flag to any concerned parties about changes that are (or are not) expected to occur, and may require actions to help promote and avoid synergies and trade-offs, respectively. My hope is that my demonstration of this simple approach will motivate further similar applications, including in the context of forests (e.g. for specific locations, where stakeholders can refine the elements considered), as well as to other ecosystems, and other aspects of the development agenda.

5.3. Limitations and uncertainties

The topics investigated in this thesis are inherently highly complex, and so, almost by necessity, they are subject to a number of limitations and uncertainties. In the following paragraphs, I describe the most important of these. In many cases, these provide a basis for the topics presented in the following section, where I discuss how future work could build upon the work presented in this thesis.

The interactions considered in this thesis are conceptually simple in nature, looking at unidirectional relationships between a maximum of two variables at any one time (essentially asking ‘how does a particular SDG component affect forests?’). However, this conveys a somewhat over simplistic picture, as in practice, the ways that the wider development agenda can affect forests will typically involve multiple factors at any one time (which may themselves interact). The ways that multiple targets (or some other combination of SDG components) can interact to influence forests (or indeed some other outcome) can be either facilitating (achievement of one target permits achievement of a second, which has subsequent impacts), mediating (achievement of one target mediates the expected impacts of a second) or synergistic (achievement of two or more targets results in impacts that are greater than those expected from a single target), and examples of each of these were provided in Table 2.1.

SDG-forest interactions may also be subject to feedback loops, where, for example, a change in a target affects forests, which in turn affects the original target, and so on. Feedback loops involving forests are commonly considered in the context of climate change (e.g. Staal et al., 2020), but arguably less so in the context of sustainable development. Nevertheless, the existence of such mechanisms has been suggested, for example where roads promote deforestation, which in turn provides political justification for building more roads (Fearnside, 1987). The non-inclusion of mechanisms such as multi-target interactions and feedback loops in this work does not detract from its validity, but moving forward it will nevertheless be valuable to gain a better understanding of how they work, and I discuss this in the next section.

For the most part, this thesis has only concerned itself with SDG-forest interactions occurring within individual countries. However, in some cases the effects of development progress in one country can have impacts on forests that extend beyond that country's borders. For example, Kissinger et al. (2012) note that increased wealth in one nation may increase the demand for certain food types, such as meat, which can place pressures on land in other countries in order to meet export demands. A more recent study by Pendrill et al. (2019) studied post-forest transitions countries (countries experiencing net forest gains), and concluded that around a third of the forest gains in these countries were achieved through importing commodities rather than producing them in-country, in effect exporting their own deforestation abroad. Similar to the absence of multi-target interactions, this fact does not detract from the validity of the results presented in this thesis, but means that they may paint a somewhat incomplete picture. This is particularly the case for Chapters 3 and 4, which were based solely on national-level data, and, as was noted in Chapter 3, this is likely to be part of the reason for some of the unexplained variance in the models presented.

Further caveats to the analyses presented in Chapter 3 include shortcomings in the indicators employed by the SDGI, and an inability to attribute causality or to consider contextual matters. Although the SDGI arguably provides the most comprehensive assessment of country-level progress towards the SDGs ("Tracking progress on the SDGs," 2018), it does not necessarily reflect the full suite of targets and indicators contained within the SDGs, and this is likely to have affected the outcomes of our analyses. This is possibly responsible for the somewhat surprising finding that progress towards achieving SDG 9 (industry, innovation and infrastructure) is associated with reduced, rather than increased, forest cover loss. As was noted earlier, the indicators used to represent this goal are more indicative of the 'innovation' aspects of SDG 9, rather than those relating to 'industry' or 'infrastructure'. The absence of an indicator on agricultural productivity (target 2.3) is also unfortunate, as one might expect this to have increased the relative importance of SDG 2 in the models presented. Several other potentially influential indicators are absent from the SDGI, as was discussed in section 3.4.

The correlational methods used in Chapter 3 have limited ability to attribute causality to the relationships identified. While this does not mean that the findings cannot provide useful insights for further consideration, it does mean that the underlying mechanisms can only remain speculative, and future work to address this is suggested in the next section. Arguably the most important caveat to the analyses in Chapter 3 relates to the global scale of the investigation, and the associated loss of contextual factors that may shape the outcomes when considering relationships at this scale. Several authors have noted the importance of local contextual matters when considering SDG interactions (ICSU, 2017; Langou et al., 2019; Nilsson et al., 2016), and this is no less relevant for the focal topic of this thesis. Past work has shown that neither matters of sustainable development nor forest change typically operate uniformly within a country (Clement et al., 2009; González-González et al., 2021; Herrera, 2019; Wu et al., 2014), and these nuances will inevitably be ‘smoothed over’ when scaling up to the national level, and even more so when looking at an international level (Moyer and Bohl, 2019).

This issue of context is also relevant to the assessment framework presented in Chapter 4. The presented demonstration of this framework was based solely on national level data, and so again fails to capture the complexities that are inevitably present at smaller scales. Even more importantly, the underlying basis for this approach rests on the assumption that the relationships between SDG targets and drivers of deforestation and forest degradation persist across all countries, and indeed within individual countries at different locations, which is unlikely the case. When introducing this framework in Chapter 4, I made efforts to communicate that the results presented should not be seen as a definitive forecast of how sustainable development will impact forests in each country, but rather as an indication of *possible* interactions that may or may not emerge, and which could be of interest to those engaged in forest conservation and/or development policymaking. To increase the utility of this framework at national or sub-national scales will require refinement by experts and stakeholders with in-depth knowledge of the location(s) under assessment, and this idea is considered further in the following section.

5.4. Future work

At various points in this thesis, I have suggested (or alluded to) follow up work that could complement and build upon the work presented here, helping to further the understanding of SDG-forest interactions, and develop policies and strategies accordingly. In the following paragraphs, I reiterate the recommendations made elsewhere in this thesis, and make further suggestions of work that could help to overcome some of the limitations and uncertainties described in the previous section.

The 63 SDG targets identified in Chapter 2 of this thesis as having known or suspected impacts on forests vary in terms of the research effort they have received and, consequently, the levels of confidence associated with each. For the possible reasons discussed in Chapter 2, there appears to be a research bias towards impacts that are damaging in nature, with less focus having been given to those that are potentially beneficial. In order to develop a more holistic and balanced understanding of the implications of achieving the SDGs for forests, further research into these lesser-understood areas should be seen as a priority. Matters of health (SDG 3), education (SDG 4) and gender equality (SDG 5) stand out in particular as having the potential to deliver co-benefits for forests, but which currently remain poorly understood. Similarly, the 41 targets evaluated as ‘unknown’ in Chapter 2 may nevertheless still have roles to play in affecting the natural environment, and would be worthy of investigation in this regard.

An overarching objective of future work in this area should be to improve understanding of the mechanisms through which interactions occur and impacts manifest. This will likely be most readily achieved through observations at a very local scale, where the operating mechanisms can be more easily observed and understood directly, including through communications with local actors and stakeholders. However, because local-scale investigations can typically only provide insights that are specific to their focal area, their findings may not necessarily scale up to be representative of how interactions operate at different locations (Hettig et al., 2016). Consequently, gaining a holistic understanding of this topic would require multiple small-scale studies at varying locations across the world, followed by meta-analyses to ascertain to what extent the relationships (and underlying mechanisms) apply at different geographical scales and locations. Although there have been previous meta-analyses relating topics of development and forest change, for example looking at factors that drive and stop deforestation (Busch and Ferretti-Gallon, 2017), or how different governance factors affect deforestation (Wehkamp et al., 2018), explicitly placing such a study in the context of the SDGs would significantly increase its global policy relevance.

Past meta-analyses in this area have generally relied on data sourced from pre-published studies, which are not likely to have been conducted in a coordinated or standardised way. This can limit comparability at the meta-analysis phase, and so ideally, local-scale studies of SDG-forest interactions would, as best possible, be standardised in their data collection protocols to allow easy comparison between localities. The quantitative indicators associated with the SDG targets could provide an ideal basis for this. Moreover, the assessment framework presented in Chapter 4 could be used to guide these studies, by providing an indication of which aspects of the development agenda are most likely to show significant progress within the timeframe of interest, and its contents and thresholds revisited and updated in an iterative manner. Importantly, such studies should be informed by local experts and stakeholders, who will be best placed to anticipate future interactions and to interpret the outcomes observed, including the likely complex mechanisms through which they manifest.

Follow-up studies, based on information collected in the manner described above, could then be used to quantitatively assess the relationships identified, including the likelihood of their occurrence at a given location and the most influential factors in determining this. Such analyses would likely be correlative in nature, but would have a stronger basis from which to infer causality than if they were based on data that were collected without paying explicit attention to the underlying mechanisms. With such knowledge, and by applying a forward-looking assessment process, such as that used in Chapter 4, it should be possible to develop pre-emptive policies and interventions that facilitate synergies and minimize trade-offs from imminent development progress, while accounting for local contexts.

So far, the suggestions made in this section have only been concerned with unidirectional, first-order (i.e. involving two variables) interactions, essentially looking at how changes in a given aspect of the development agenda affects forests. However, in order to gain a truly holistic picture of SDG-forest interactions it will be desirable to consider possible feedback loops, as well as higher-order interactions involving multiple targets. This knowledge could then be used to perform network analysis or more complex systemic methods, that provide a more holistic picture of dynamic ways that forests interact with the wider development agenda.

To date, most studies aiming to explore second-order interactions or feedback loops have first assessed first-order interactions using expert elicitation or correlational approaches, and then included these more complex mechanisms into network analysis based on crude assumptions. Bali Swain and Ranganathan (2021), for example, inferred feedback loops based solely on correlations between two targets. Similarly, both Lusseau and Mancini (2019) and Weitz et al. (2018) assumed that second-order interaction would naturally arise from first-order ones, and based on this, quantified the wider effects of a given target on the whole network.

This leaves a lot to be desired, however, as such approaches do little to actually verify the existence of these more complex mechanisms, and are not specific to any particular outcome (e.g. forests), making it difficult to translate their findings into policy recommendations. Here again, local-scale observations, informed by local actors and stakeholders, would be a better approach to verifying and understanding interactions involving multiple components of the development agenda. Interaction terms in regression models and other correlational approaches can be notoriously difficult to interpret (Bedeian and Mossholder, 1994; Burks et al., 2019), and so, by collecting data in this way, follow up tests to examine higher-order interactions at larger scales would again have a greater basis upon which to infer causality from their findings. Moreover, because there may be a time lag between some initial change in the development agenda and a subsequent effect elsewhere across the network, collecting data through direct observation would help follow-up analyses to account for this in their models.

Ultimately, fully understanding the dynamic nature of SDG interactions, including those pertaining to forests, will require deep knowledge of both first- and higher-order interactions, as well as causal feedback mechanisms, operating across all aspects of the agenda. While this is undoubtedly challenging, given the infinite possible ways in which different elements of the SDGs could interact under different contexts, furthering understanding in this area is nevertheless possible. With concerted efforts from experts working in other areas of sustainable development to conduct research of the type presented in thesis and suggested above, the resulting information, when combined, would likely provide highly informative insights, as well as a basis to develop robust systemic models, which could more reliably inform development policy. Such an effort would require considerable collaboration between experts from all areas of the sustainable development community, which I discuss next.

At multiple points throughout this thesis, I have noted the need for better dialogue and integration between sectors, and this should not be understated. Dialogue between those with an interest in forest conservation and all actors involved in activities that can result in synergies or trade-offs for either party will be valuable for promoting the former and avoiding the latter (Adams and Judd, 2016). This should extend to include all actors ranging from international policymakers, through national and local governments and the private sector, to local landowners and stakeholders. The work presented here indicates where better inter-sectoral integration could be particularly beneficial for forests, including for risk avoidance (e.g. dialogue with those involved in food production), selecting the most sustainable options (e.g. dialogue with those involved in poverty reduction), or developing conditions that are favourable for conservation (e.g. dialogue with those involved in law-making or enforcement). However, this may appear to suggest that inter-sectoral dialogue should involve only two groups at any one time – those interested in forest conservation and those linked to sectors with some direct implication for forests, which is not the case. Rather, and in keeping with the 'indivisible' design of the SDGs (United Nations, 2015), dialogue and collaboration between all sectors is desirable. From a research perspective, developing a shared understanding of system dynamics in this way could help to elucidate higher-order interactions and possible feedback loops that involve multiple sectors, which can inform more robust systemic mapping and modelling efforts. More broadly, inter-sectoral collaboration can help to promote more adaptive management, a wider sense of responsibility and ownership and over decisions and their outcomes, and increased transparency in many areas (Adams and Judd, 2016; Tengberg et al., 2021). While the need for better integration of the SDGs is well acknowledged (Adams and Judd, 2016; United Nations Economic and Social Council, 2016), many cases exist where these still operate in siloes (Kanie et al., 2019; Kirton and Warren, 2021), and so further efforts are clearly still required.

Lastly, this thesis has focused specifically on forest ecosystems, and while many of the findings made will apply to natural systems other than forests, many will not, and numerous other important interactions are likely to exist. As such, I recommend similar in-depth investigations into the ways that achieving the SDGs can affect other ecosystem types. In particular, work focusing on marine and coastal systems, wetlands, mountains and drylands, which are all mentioned in the SDG targets (Inter-Agency and Expert Group in Sustainable Development Goal Indicators, 2016), should be seen as priorities.

5.5. Conclusions

The conservation of forests, and indeed other natural ecosystems, should not be seen as separate from other aspects of the development agenda, and vice versa. The ways that these can interact are diverse and often complex in nature, and this thesis has attempted to further understanding of this topic by (i) consolidating, through systematic review, the relevant literature on the topic; (ii) quantitatively exploring the relationships between each of the SDGs and changes in forest cover; and (iii) assessing the development trajectories of a range of tropical countries and considering how this could potentially affect forests. Although significant knowledge gaps on this topic remain, particularly around the mechanisms underpinning how development progress can affect forests, including indirect impacts and causal feedback loops, this work has been able to reach some important conclusions.

The findings of this thesis provide some reasons to optimistic. The number of SDG targets that can have potentially beneficial impacts on forests outnumber those with potentially damaging ones, and a range of others can have mixed impacts, suggesting that with careful forethought, potential exists to promote beneficial over damaging impacts in many cases. The fact that higher attainment on the majority of SDGs correlates with lower levels of forest loss (including forest gains) is also reassuring, and suggests that once countries eventually achieve many of the development goals relating to human well-being and prosperity, goals relating to the environment should also follow suit. Nevertheless, the findings also indicate a need for caution, as aspects of the development agenda with high potential for damage certainly exist, and, in many developing countries, these appear to be among the highest priorities. Importantly, much of the damage to forests that is associated with the SDGs appears to occur through the process of attaining a higher status, rather than once a higher status has been achieved. Despite some setbacks in the last two years, progress towards achievement of the SDGs has generally been positive, yet environmental goals have been consistently lacking compared with other aspects of the agenda (Sachs et al., 2022). In order to address this imbalance, better integrating matters of the environment into national development strategies should be seen as an urgent priority, and not as an afterthought at a later time.

Matters of context, scale and level of analysis are important when considering SDG interactions. These points have been noted in past publications (De Neve and Sachs, 2020; Lusseau and Mancini, 2019; Nilsson et al., 2018, 2016), and are evident here in the context of forests. Chapter 2 of this thesis presented a range of SDG-forest interactions based on research and observations from multiple locations and at a range of scales, yet the findings presented in Chapter 3 showed that these do not necessarily scale up to the goal level, at least at a global scale. Moreover, Chapter 3 showed how relationships between the SDGs and changes in forest cover differ at global and regional levels. Policymakers and development practitioners need to keep all of the above in mind when developing and implementing policies and interventions. Ideally, these groups would prioritise components of the development agenda that help to provide enabling environments, and help to mitigate the potential for damage caused by progress in other areas, and the work presented herein can help with this process. However, in order to better understand the nuances that exist between locations and contexts, consultations with local stakeholders will be invaluable, and in order to ensure that any identified synergies are maximised and trade-offs minimised, dialogue between the conservation sector and all others will be critical.

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