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Ancillary Benefits of Climate Policy

New Theoretical Developments and Empirical Findings

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ISSN 2352-0698 ISSN 2352-0701 (electronic)
Springer Climate
ISBN 978-3-030-30977-0 ISBN 978-3-030-30978-7 (eBook)
https://doi.org/10.1007/978-3-030-30978-7

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Do we need ambitious climate policies to create a good future for humanity? We clearly do—such goes the premise that has given rise to rounds and rounds of global negotiations spearheaded by the United Nations. This process has now entered its fifth decade since its genesis: the First World Climate Conference was held in February 1979, then organized by the UN's meteorological organization. Lately, global climate diplomacy has developed a momentum that many could not foresee. It produces regulations and voluntary commitments aimed at all the world's countries, and both the EU and Germany have already made concrete pledges to contribute. The Fridays For Future youth demonstrations have been mobilizing young people in more than 120 nations. Climate change is at the top of the political agenda, and many industry players have ceased to resist the development and begun instead to promote predictable, efficient climate policies.

But the countermovement is gaining traction, too. The USA, the world's largest economy, has recently announced its withdrawal from the Paris Climate Agreement next year. Brazil appears to be wavering on the issue of climate protection, while populist parties openly question the entire concept in many countries. Should we do nothing instead? Some believe that idleness is indeed the best approach, and their voices grow louder by the day. The Internet with its ubiquitous echo chambers and climate change denial blogs amplifies them effectively. Politicians have no choice but to take these factors seriously: climate policy is about much more than the climate itself. It is about democratic legitimacy and, not infrequently, about political survival.

The onus is on those in charge to navigate the ongoing struggle among the various factions of global civil society and make the right promises. Those promises must be ambitious enough that they can inspire voters and stakeholders to embrace change. At the same time, they must be realistic enough to prevent a crisis of legitimacy in the climate protection movement: their benefits must be clearly defined and put in perspective to their costs; feasible future approaches must be presented in accessible ways. Situated at the intersection between science and politics, climate research carries out crucial groundwork to facilitate progress.

This book is a valuable contribution to its efforts. It provides a realistic overview of the ancillary benefits (or co-benefits) of climate protection: the positive “side effects” of climate policy beyond their immediate chain of effects (lower greenhouse gas emissions—less climate change—less damage to the climate). In the heat of political discourse, these effects are often used as a pretext for careless, even false promises: transforming our energy system will bring about better jobs, greener parks, cleaner air, greater democracy, and so on. Such hollow words are easily debunked by opponents of climate protection and ultimately contribute little to the cause. The following selection of research papers by authors from four continents provides a scientific assessment of these co-benefits. Their findings establish a solid basis for convincing arguments, which may well encourage policymakers to dare take ambitious action.

Explaining the benefits of climate policy can be tricky: after all, its purpose is to prevent or lessen something that is negative, poorly understood, and difficult to quantify. Demands for ambitious measures can easily take a negative tone, as arguments emphasize the “threat” of climate change. But society is increasingly aware that the excessive exploitation of global resources, such as the atmosphere, spells trouble for prosperity in the twenty-first century. In turn, the fair and efficient use of global resources secures prosperity. But in the twenty-first century, the notion of prosperity must be different to that of the preceding two centuries. It is this hypothetical new idea of prosperity that will allow us to quantify the co-benefits of climate policy adequately.

This work skillfully highlights the importance of the Sustainable Development Goals in this context. Ending poverty, securing food, and giving everyone access to healthcare and education are demands and guiding principles that fuel political debate and motivate voters and politicians alike. Research into the co-benefits of climate policy has inspired important discussions in welfare states such as Germany, showing clearly that society is interested in fair income distribution, healthy ecosystems, and sustainable consumerism. Ultimately, this book employs specific scientific perspectives to discuss a very simple, fundamental topic: climate policy as a guarantor of a high standard of living.

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Preface

While concerns about accelerating global warming preoccupy the public—as one can observe from the recent school strikes as protest against too few climate protection efforts—the Paris Agreement on Climate Change is starting to take effect in several areas of our planet. Yet, while in Europe, levels of carbon dioxide emissions are declining, in order to reach the 2° goal and even more the 1.5° goal of the agreement, global climate protection efforts have to be strengthened considerably. This becomes even more urgent as concentrations of methane, which is another very potent greenhouse gas besides carbon dioxide, have increased in an unexpectedly strong way in recent years.

Owing to the vital need for action to protect the climate, there have been intensive efforts to find additional incentives to raise protection levels. Apart from the generation of incentives via policy instruments like emission trading schemes, climate policy has other effects, so-called ancillary effects, which tend to raise the attractiveness of climate protection. The aim of this volume is to deal with these effects and the various associated benefits for economy and society.

The fact that besides its underlying objective a policy measure may have other impacts has regularly been present in the research of the editors of this volume, even beyond the context of environmental protection. We have addressed such issues in different ways, and in doing so, we have included the implications of different degrees of "publicness" or the extent to which the ancillary effects take the form of a public good. Inspired by this research and the high relevance of these issues for climate policy, we had the idea to compile a book including recent research concerned with joint production effects. Although the chapters in the book focus on the joint effects of climate policy, it is straightforward to apply the models and techniques used in this book also to joint production in other fields, for instance to research on philanthropy, performing arts, green goods consumption, terrorism, and military alliances.

In the process of drafting and publishing this book, many people were involved to whom we owe our thanks. We are in particular grateful to Theresa Stahlke who supported us in organizing the submission and review processes. She also gave valuable comments on several parts of this book. We would also like to thank

Johannes Glaeser at Springer Nature, who was involved in the publication process in a very helpful and constructive way. Finally, we thank Lisa Broska, Anja Brumme, Kristina Govorukha, Philip Mayer, and Anja Zenker for valuable suggestions on parts of the book. Of course, none of these people are responsible for any errors or omissions in this book.

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Contents

Analysis of Ancillary Benefits of Climate Policy

Wolfgang Buchholz, Anil Markandya, Dirk Rübbelke, and Stefan Vögele

The main pillars of climate policy are adaptation to and mitigation of climate change. The primary objective of adaptation policies—in turn—is to make adjustments in ecological, social, or economic systems that prevent adverse impacts (like losses in agricultural yields) of climate change or take advantage of this change (like using an ice-free Northwest Passage, providing a shipping shortcut between the Pacific and Atlantic Oceans). In the case of policies to mitigate climate change, the primary aim is basically climate protection by reducing the emissions of greenhouse gases.

A large strand of scientific literature focuses on the analysis of these primary objectives of climate policy by assessing their associated benefits and on investigating the tools to bring about an efficient combination of adaptation and mitigation.

Yet, since the early 1990s at least (see e.g. Ayres and Walter 1991; Pearce 1992), another category of benefits accruing from climate policy has also aroused the interests of researchers, namely the ancillary benefits, which are brought about in

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W. Buchholz et al. (eds.), *Ancillary Benefits of Climate Policy*, Springer Climate,
https://doi.org/10.1007/978-3-030-30978-7_1

addition to the primary benefits of mitigation or adaptation.[1] So, if a mitigation policy reduces greenhouse gas (GHG) emissions via a decrease in the burning of fossil fuels, this will generally be accompanied by the reduction of other pollutants like particulate matter and sulphur dioxide. As such extra benefits were not primarily intended, they are frequently ignored in scientific studies on climate policy, although such co-effects tend to be of significant size.

A large number of empirical studies on ancillary benefits include assessments of benefits enjoyed from the reduction of those local or regional air pollutants that regularly accompany GHG emissions (e.g. Burtraw et al. 2003; Rive and Rübbelke 2010; Markandya and Wilkinson 2007; Markandya et al. 2018). Among the reasons for the high importance of air pollution reduction benefits in the ancillary benefits literature is the high level of associated positive health effects and—quite simply—the fact that this ancillary benefit category is easier to assess than most others. Nemet et al. (2010) survey studies considering air-quality-related ancillary benefits and find that a range of studies assessed them to be of a similar order of magnitude to greenhouse gas abatement cost estimates. Bain et al. (2016) analyse different types of ancillary effects and although they confirm that these benefits could motivate action on climate change, they assess that ancillary benefits associated with pollution reduction are among those types of benefits that are the weakest motivators of action.

For that reason alone, it makes a lot of sense not to take into account only pollution-related benefits, but to consider the broad "umbrella" of multiple benefits.[2] Other (not air-pollution-related) ancillary benefit categories include, amongst others, traffic-related benefits (e.g. from reduced noise, traffic congestion, road surface damage),[3] benefits enjoyed from the prevention of soil erosion and biodiversity loss, from positive effects exerted on the labour market and on competitiveness, and from a rise in domestic energy security.

Co-effects of climate policy may not be beneficial throughout, i.e. there may also be ancillary costs. An example where such ancillary costs arise is the following: Wind turbines, on the one hand, substitute renewable energy for fossil fuels and thereby reduce GHG emissions and provide primary benefits, but on the other hand, they also threaten the wildlife as their rotor blades may hit and kill birds or bats and thus cause ancillary cost. Krupnick et al. (2000: 71) give another example: A switch to hydroelectric power could create many negative externalities to river ecosystems involving ancillary costs. Other authors (e.g. Halsnaes 2002: 61) point

[1]There are several terms conveying the idea of ancillary benefits, e.g. co-benefits, secondary benefits or spillover benefits. As Markandya and Rübbelke (2004: 489) explain, "*[t]he main difference is the relative emphasis given to the climate change mitigation benefits versus the other benefits. For some policies these 'other benefits' may be as important as the GHG reduction benefits, in which case the term 'co-benefits' is more appropriate*".

[2]That is why Mayrhofer and Gupta (2016b) call co-benefits an "'umbrella' concept".

[3]Younger et al. (2008) discuss "built environment strategies" (focusing not only on the component transportation, but also regarding buildings and land use) that affect climate change and health outcomes. Such a strategy in the transport sector would e.g. be the promotion of telecommuting.

to the possibility that certain climate protection activities may trigger a decrease in employment.

During the 1990s, ancillary benefits studies were mainly of empirical nature and assessed the magnitude of such benefits. Ekins (1996) reviews the early estimates of the size of ancillary benefits. Some papers also discussed policy implications, e.g. Heintz and Tol (1996) consider the implications in the context of climate finance. Yet, the examination of policy and strategic implications of ancillary benefits and the research on the theory behind this concept have received quite little consideration in the literature and this does not only hold for this period of the 1990s. As Mayrhofer and Gupta (2016b) find out more recently, articles on the theory behind the co-benefits concept are underrepresented (merely 5% of the literature they reviewed) and only 20% of the papers address ancillary benefits in a qualitative way.

In 2000, the OECD made efforts to promote research on ancillary benefits and published a seminal proceedings book including contributions by leading experts in this field (OECD 2000). The objective of this publication project was to serve as a reference to those scientists "*seeking to develop integrated policies to meet a range of policy objectives simultaneously*" (OECD 2000). The scientific literature on ancillary benefits has significantly grown since then and benefitted from the concepts conveyed by the OECD book project.

In the past 20 years, scientists from different disciplines not only prepared numerous empirical studies considering different ancillary effects in different world regions but also subjected theoretical aspects to closer inspection. In their study on carbon offsetting and climate-friendly consumption, Schwirplies and Ziegler (2016) interpret warm-glow (see Andreoni 1990) as a co-effect of climate protection. In doing so, they address both theoretical as well as empirical aspects. Buchholz and Sandler (2017) also take into account "psychological" co-effects and investigate their influence on the effects of climate-friendly leadership of a country. Buchholz et al. (2014) consider social esteem as a co-benefit of public good provision (like the provision of climate protection) where the level of social esteem and thus of the co-benefits is influenced by a non-governmental agency. Bahn and Leach (2008) and Pittel and Rübbelke (2017) model ancillary effects in dynamic settings. Harlan and Ruddell (2011) consider both ancillary benefits of policies to mitigate and to adapt to climate change. For an experimental approach to investigate both global and local co-benefits of climate change mitigation efforts, see Löschel et al. (2018).

Strategic implications of ancillary benefits at the international level also increasingly caught researchers' attention (see e.g. Finus and Rübbelke 2013). Ancillary benefits have in many cases properties of a private good for climate-protecting countries, which may (favourably) affect strategic behaviour of countries in global public good provision (Pittel and Rübbelke 2008). Furthermore, if one takes "private" ancillary benefits of climate change mitigation into account, then the effects of climate finance and transfers may differ from those that would arise in the case where only pure public effects of mitigation are considered. So the famous Warr neutrality (Warr 1983) of income redistribution tends not to hold anymore. Altemeyer-Bartscher et al. (2014) consider international side-payments to raise global climate protection levels while taking into account the positive impact that ancillary effects may exert on the scope for financing such side-payments. Pittel and Rübbelke (2013) investigate in particular the potential effects of adaptation transfers where one could regard induced fairness improvements as a co-effect of such transfers, which in turn tend to influence countries' behaviour in international negotiations.

Flachsland et al. (2009) consider distributional aspects related to ancillary benefits that arise by linking cap-and-trade systems. They argue that outsourcing of climate protection activities to other regions will bring about a loss of ancillary benefits in those regions that outsource their abatement activities. Similarly, Krook-Riekkola et al. (2011: 4992) point out for the case of climate policy in Sweden that "*an increase in emission reductions abroad also implies a lost opportunity of achieving important welfare gains from the reductions of a number of regional and local environmental pollutants*".

There are also instances of global co-effect generation by global environmental policies, i.e. a generation of effects that do not exclusively benefit the region hosting an environmental protection project. Velders et al. (2012) give the example of the Montreal Protocol that controls ozone-depleting substances. In doing so, it helps to stop the depletion of the stratospheric ozone layer and with it protects the planet against dangerous solar ultraviolet radiation. As most ozone-depleting substances are also potent GHGs, the Protocol serves a twin goal, i.e. combating the global threats of stratospheric ozone layer depletion and of climate change. Thus, it produces two global characteristics jointly. Velders et al. (2012) discuss how the substantial climate benefits of the Montreal Protocol can be preserved in the future.

In accordance with Lancaster (1971: 1), who stresses that "*[g]ood theory should be as universal as possible*", Ürge-Vorsatz et al. (2014) recommend the analysis of co-effects in a multiple-objective/multiple-impact framework. Hence, one should capture all relevant effects in order to incorporate related benefits and costs into decision-making schemes. According to Ürge-Vorsatz et al. (2014), this can be achieved not only by standard cost–benefit analysis but also by integrated assessment models or by a multi-criteria analysis. Creutzig et al. (2012) conduct a multi-criteria analysis of co-benefits enjoyed from decarbonising urban transport in European cities. They consider this kind of assessment to be a useful complement to cost–benefit analysis of climate change mitigation. Dubash et al. (2013) apply the multi-criteria technique to co-benefits of Indian climate policy, while de Bruin et al. (2009) examine options to adapt to climate change in The Netherlands by this method. West et al. (2013) investigate co-effects of global climate change mitigation on future air quality and human health in an integrated assessment framework. Oxley et al. (2012) use such a framework to examine co-benefits in the UK's road transport sector. Cost–benefit analysis of ancillary benefits is extensively conducted,[4] e.g. by Bollen et al. (2009) who—however—suggest in their paper that climate change mitigation is an ancillary benefit of air pollution policy (as they

[4]Longo et al. (2012) use the contingent valuation method to elicit the WTP for ancillary and global benefits of climate change mitigation policies.

find in their analysis framework higher benefits from local air pollution control than from greenhouse gas control). Li (2006) uses a multi-period cost–benefit framework in order to examine the economic and social welfare implications of local health benefits of climate change mitigation in Thailand.

From a different methodological perspective, Mayrhofer and Gupta (2016a) argue that in co-benefit research, "*the institutional context and choice architectures in which the idea of co-benefits is embedded*" should get more attention in the future as these aspects have been largely ignored so far. In order to overcome these shortcomings, these authors make use of the framework of discursive institutionalism and draw on the concept of storylines.

Even though the description above is far from complete, it gives an idea of the multiplicity and variety of research topics in the context of ancillary benefits and of developments in this scientific field.

In this book, drawing on these past contributions, some more recent research efforts on ancillary benefits of climate policy will be presented.

The book is organised such that in the *first part* we address ancillary benefits derived from development co-effects. The first two chapters in this part are concerned with the links between ancillary benefits and sustainable development in particular against the background of the Paris Agreement on Climate Change. The third chapter takes a more theoretical stand in its investigation of effects of climate policy on long-term economic growth.

Campagnolo and De Cian (2019) raise the question whether the Paris Agreement on Climate Change can support the attainment of the Sustainable Development Goals (SDGs). In general, there can be synergies and trade-offs between climate policy and sustainable development. The authors evaluate the impact of the Paris Agreement implementation on a set of SDG indicators by 2030 using a computable general equilibrium model. Their methodology of combining empirically based relationships between macroeconomic variables and sustainability indicators makes it possible to explore the sustainability consequences of mitigation policy on 16 SDGs.

Michaelowa et al. (2019) focus in their analysis on sustainable development co-benefits of activities for climate change mitigation under the market mechanisms of the Paris Agreement. In the past, there have been criticisms regarding limited co-benefits of projects initiated via the Clean Development Mechanism (CDM) of the Kyoto Protocol. In response to this, the CDM regulators provided a voluntary tool for sustainable development benefit assessment. For the new market mechanisms under Article 6 of the Paris Agreement, the rules currently negotiated foresee a continuation of the voluntary approach. Nevertheless, the rising political concern regarding sustainable development co-benefits is likely to trigger efforts by buyers of emission credits to ensure significant co-benefits of the underlying activities.

In his chapter, Golub (2019) explores the transition of low- or middle-income economies from carbon intensive technological structures to cleaner structures. In this context, development traps are a hazard but as the author argues, timely climate policy may facilitate the transition and positive ancillary development effects could be induced. The analysis takes into account that different forms of uncertainties may arise.

Conceptual and theoretical approaches are in the focus of the *second part* of this book.

In a game-theoretic framework, Takashima (2019) presents new theoretical findings concerning the effects of ancillary benefits on international environmental agreements reached by two types of asymmetric countries. As this analysis shows, ancillary benefits are a key factor for enhancing the feasibility of sustained, full participation in an international environmental agreement.

Brumme et al. (2019a) elaborate on the adequacy of the impure public good approach developed by Cornes and Sandler (1984) for analysing ancillary and primary benefits. They describe how this theoretical approach evolved and outline its key concepts and techniques. As the authors argue, the analysis of climate policy in this framework is fruitful, but also quite intricate. Therefore, they stress the importance of developing new tools to facilitate the analysis and the interpretation of results. They see one way for doing so in the application of the aggregative game approach developed by Cornes and Hartley (see e.g. Cornes and Hartley 2007; Cornes 2016; Dickson 2017; Cornes et al. 2019).

Schwirplies (2019) refers to the impure public good framework in her review of literature on climate policy co-effects like monetary savings, internal satisfaction, health benefits, and fairness enhancement. In her study, she examines whether actors from the public and private sector should lay more emphasis on ancillary benefits when promoting climate protection measures.

Brumme et al. (2019b) employ the aggregative game approach in order to trace back the impure public good model to the conventional pure public good model and thereby illustrate a way to facilitate the application of the impure public good approach to the analysis of climate policy. In this chapter, differences between the impure and the pure public good model become evident, e.g. the emergence of non-contributors in the Cournot–Nash equilibrium is less likely in the impure than in the pure public good model.

Vögele et al. (2019) use a multi-criteria approach to analyse ancillary benefits of decarbonising the transport sector. They employ the example of e-mobility and consider a broad range of relevant beneficial and adverse factors. From their findings, they draw the conclusion that due to ancillary effects certain stakeholders will exert resistance if they are pushed towards e-mobility.

In the *third part* of this book, we take stock of some novel developments in the research on ancillary benefits like the examination of ancillary benefits of adaptation to climate change or of carbon capture and storage. Furthermore, scientific literature on climate policy effects in specific sectors like forestry, health and international shipping is surveyed.

The first two chapters in this part are concerned with ancillary benefits and costs of adaptation to climate change.

Sainz de Murieta (2019), after a brief discussion of ancillary benefits of mitigation, examines different groups of ancillary effects of adaptation to climate change. In her analysis, she distinguishes between three categories of ancillary benefits:

economic, social and environmental co-benefits of adaptation. Furthermore, she takes into account that adaptation can also involve ancillary costs. The author points out that co-benefits of adaptation are underrepresented in the scientific literature compared to those of mitigation. Furthermore, she argues that there is little evidence about the extent to which ancillary benefits in general are incorporated into decision-making processes.

Reif and Osberghaus (2019) provide a synthesis of the literature on beneficial and harmful impacts of measures to adapt to climate change. The authors discuss the ancillary effects of adaptation in five different fields, i.e. mitigation, ecological systems, economic development, decisions under uncertainty, and disaster resilience. The difficulties to assess co-benefits and conflicts of adaptation, which arise due to the complex interlinkages between the domains, uncertainties and unquantifiable values, are illustrated.

Torvanger (2019) reviews the literature on ancillary benefits of carbon capture and storage (CCS). The author categorises different key groups of ancillary benefits of CCS. Among these are the use of carbon dioxide for synthetic fuels, chemicals, plastics, and building materials. Learning from CCS applied to industry and fossil-based power sources can enable two negative emission technologies: bioenergy combined with CCS, and “Direct Air Capture”.

Markandya and Sampedro (2019) assess present action on reducing greenhouse gases to be sub-optimally low. They argue that the presence of ancillary benefits has not played a major role in driving the discussion on raising climate protection levels. In their chapter, they take a closer look at the reasons for this and offer some suggestions on ways to give health co-benefits a greater role in climate policy.

Seroa da Motta et al. (2019) review estimates of the ancillary benefits from land use mitigation options in Brazil. Furthermore, they present an integrated REDD+ framework that catalyses the transfer of financial resources to the land use sector, while ensuring that non-REDD+ options continue to receive financial resources for the innovation and decarbonisation of activities in different economic sectors (energy, industry and transport). As the authors argue, ancillary benefits will promote national and regional economies in supporting water flows regarding urban and rural supply and hydroelectricity.

Doundoulakis and Papaefthimiou (2019) review ancillary benefits of climate policies in the shipping sector. A special feature of the international shipping sector is that emissions cannot be attributed to an individual country, which is due to the global nature of activity and the complexity of shipping operations. The chapter considers different regulations concerning air pollution caused by the shipping sector and discusses potential effects. While doing so, they illustrate and categorise potential co-benefits that arise from the current regulatory framework of the international shipping sector.

The *fourth part* of this volume is particularly concerned with ancillary benefits in urban areas.

Liu et al. (2019) see the combat of global warming and regional air pollution control as two major challenges for China’s environmental policy. They conduct an empirical analysis of co-benefits of carbon dioxide emissions mitigation and air pollution control in 30 provincial capital cities in China. From the results of this study, they derive policy recommendations for haze and carbon reduction in China's urban areas.

Sethi (2019) addresses the low performance of cities in emerging economies concerning parameters of social development, equity, functional autonomy and financial capacity. As he argues, the co-benefits approach has proved to be a key analysis mechanism and he stresses the importance of assessing the magnitude of such benefits in emerging economies. The author discusses assessment tools, lessons learned in the past from research on ancillary benefits and remaining knowledge gaps. In case studies, the applicability of urban co-benefits concepts in India, China, Brazil and Turkey are tested.

Mathy et al. (2019) present and describe a specific project that strives for identifying measures to reduce significant atmospheric pollution in cities and its impacts. Synergies between short-term public health issues related to air pollution and the reduction of greenhouse gas emissions play an important role in this context. As the authors argue, the key tasks of the project are to better comprehend population's exposure to pollution, improve the understanding of the determinants of mobility behaviour and support public decision-making.

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Part I
Ancillary Benefits and Development Co-effects

Can the Paris Agreement Support Achieving the Sustainable Development Goals?

Lorenza Campagnolo and Enrica De Cian

1 Introduction

With the advent of the United Nations' 2030 Agenda and the Paris Agreement in 2015 (United Nations (UN) 2015), a growing number of studies have been exploring the synergies and trade-offs between climate policy and sustainable development. Synergies and trade-offs can go in both directions. On the one hand, the mitigation literature in the context of the new scenario framework of the Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs, O'Neill et al. 2017; van Vuuren et al. 2014) highlights how deep decarbonization (Rogelj et al. 2019) can be achieved more easily under sustainable scenarios, such as the SSP1 narrative, which poses lower challenges to mitigation and adaptation. On the other hand, climate mitigation policies can generate a wide range of non-climate ancillary benefits or obstacles in achieving the Sustainable Development Goals (SDGs, Roy et al. 2019). Aligning mitigation policies with SDGs is key for ensuring social acceptability of the required structural transformation and for fostering the more ambitious action required to contain global warming below 1.5 °C in 2100.

This chapter contributes to the emerging literature on the synergies and trade-offs between mitigation and sustainable development by evaluating the impact of the Paris Agreement implementation on a set of SDG indicators by 2030 using a Computable General Equilibrium (CGE) model. A macroeconomic framework provides a system perspective analysis, highlighting the aggregate impacts of mitigation policy on multiple sustainable development dimensions at the same time, while

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W. Buchholz et al. (eds.), *Ancillary Benefits of Climate Policy*, Springer Climate,
https://doi.org/10.1007/978-3-030-30978-7_2

taking into account the general equilibrium adjustments induced by price changes. Ex-ante assessments, such as those based on simulation or numerical models, make it possible to explore the implications of mitigation policies of different ambition, broadening the evidence beyond the policies actually implemented in the past. They can examine synergies and trade-offs into the future, and provide a benchmark for policy evaluation and design while accounting for policy and socioeconomic uncertainty. This chapter develops projections of selected SDG indicators in a reference and mitigation policy scenario, contributing to expand the existing literature on mitigation pathways in the context of sustainable development. The major limitation of the few existing integrated assessment approaches available to date is the focus on economic and technological indicators, a choice that is driven by the limited ability of quantitative models to represent the social dimensions of sustainable development (McCollum et al. 2018b; von Stechow et al. 2016). The method presented in this chapter combines regression analysis to estimate empirically-based relationships between 16 economic, social, and environmental SDG indicators and the key socioeconomic variables represented in the CGE model. Gender inequality is the only goal left unexplored (SDG5).

The remainder of the chapter is organised as follows: Section 2 synthesises the most recent literature on the mitigation co-benefits and side effects on sustainable development. Section 3 describes the ex-ante approach used to assess the SDG implications of the Paris Agreement. Section 4 discusses the advantages and limitations of our methodology in the sustainability assessment of policy implementation and concludes, highlighting some directions for future research concerning the co-benefits of mitigation and adaptation policies.

2 Mitigation Policy and Sustainable Development: Recent Contributions from the Literature

The SDGs define broad and ambitious development targets for both developed and developing countries encompassing all sustainability dimensions (economic, social, and environmental), including minimising climate change impacts (SDG13), with the ambition of informing pathways towards inclusive green growth. The tight linkage among the economic, social, and environmental dimensions is reflected in the connections across different goals integrated into the broader framework. Given the multiple interactions among different SDGs, integrated approaches, such as those based on Integrated Assessment Models (IAMs) or integrated energy-economy climate models, can quantify the synergies and trade-offs between target-specific policies, such as mitigation, and all other goals with a system perspective (von Stechow et al. 2016, 2015).

Despite the growing number of efforts, current integrated modelling research remains confined to sectoral studies offering a limited view on the possible co-effects and focusing on a narrow set of specific objectives. Most of the literature, recently reviewed in the IPCC Special Report 1.5, has focused on food security and hunger (SDG2), air pollution and health (SDG3), clean energy for all (SDG7), water security (SDG6). Only McCollum et al. (2018a) conduct a systematic review of the literature to evaluate the nature and strength of interactions between SDG7 and all other SDGs. The review relies on forward-looking, quantitative scenario studies focusing on multiple objectives. SDG7 is connected to the implementation of mitigation policies through the specific targets on access to modern energy services, increased share of renewables and improved energy intensity. Since these targets are basic requirements of any mitigation policy, McCollum et al. (2018a) indirectly shed some light on the interaction between mitigation policy and SDGs. It is interesting to note that, the model-based literature reviewed in the paper is not able to identify contributions assessing social indicators (such as poverty SDG1, education SDG4, gender equality SDG5, reduced inequalities SDG10). In order to provide some evidence on these dimensions, McCollum et al. (2018a) select historical, empirical, or case-study papers.

The social indicators for which most evidence is found are SDG2 and SDG3. Regarding SDG3, good health and well-being, most literature focuses on reduced air pollution (Rao et al. 2016; Markandya et al. 2018) and diminished impacts of climate change and environmental degradation (Ebi et al. 2018). Mitigation policy stimulates the development and the diffusion of renewable technologies that appear decisive in improving energy access especially in remote and not connected areas (McCollum et al. 2018a). Regarding SDG2 (undernutrition reduction), the literature on the impacts of uncontrolled emission growth and temperature rise on agricultural production and on undernutrition prevalence is wide (Hasegawa et al. 2016; Nelson et al. 2010; Lloyd et al. 2011). Achieving mitigation targets helps reducing these side effects, but at the same time can generate some trade-offs pushing large-scale deployment of bio-energy, competition for land, and increased food prices. These are trade-offs that can be mitigated by decarbonization strategies oriented more towards demand-side actions (Grubler et al. 2018) or through the adoption of complementary distributional policies. The literature on the link between mitigation and poverty (SDG1) and inequality (SDG10) reduction is also quite scattered. On the one hand, as in the case of SDG2, poor people are the most exposed to climate change impacts that can be 70% higher for the bottom 40% of the population than for the average (Hallegatte and Rozenberg 2017). Therefore, mitigation can have a pro-poor and equalising effect. On the other hand, emission cuts, by setting a price on carbon, can have regressive implications if an adequate revenue recycling scheme supporting the poorest layers of the population is not predisposed (Hassett et al. 2009; Metcalf 1999). The social dimension of SDG7, achieving universal energy access, can also be hindered by a mitigation policy that increases energy prices in fossil fuel-intensive countries and burdens poor households. At the same time, the efficiency improvements, especially of renewable energy technologies, combined with pro-poor incentives can reduce this tarde-off (Dagnachew et al. 2018; Jakob and Steckel 2014). Direct effects of mitigation policy on SDG4 (quality of education) and SDG16 (preserve peace) have not been explored, though the literature on the link between global warming and conflicts is growing (Hsiang et al. 2011).

With respect to the economic indicators (SDGs 8, 9, 17), a broad literature on the interaction between technology and environmental externalities (Carraro et al. 2010) highlights the positive impacts of climate policy on innovation and technology diffusion (SDG8, decent work and economic growth). With respect to employment opportunities the evidence is mixed. Green jobs are mostly high-skill, entail higher wages, and tend to be concentrated in high-tech areas (Vona et al. 2018b). Although there are distributional implications, impacts on overall employment seem to be modest (Vona et al. 2018a). Despite the multiple channels through which mitigation policy can stimulate growth (Hallegatte et al. 2012), the IAM-based mitigation literature highlights the macroeconomic costs of stringent mitigation actions, mostly due to early retirement of capital, higher energy costs for producers and consumers, terms of trade effects (Paltsev and Capros 2013). The regional distribution of impacts on economic performance can also be expected to be uneven, mostly due to terms-of-trade effects, which would penalise net exporters and work in favour of net energy importers. In developing countries prioritising poverty-related issues, emission costs could divert funds necessary to development policies.

Even mitigation with a compensatory scheme by industrialised countries can lead to a "climate finance curse", sluggish investments and technological change in energy-intensive sectors and, ultimately, slower economic growth (Jakob and Steckel 2014). Regarding SDG17, the IPCC 1.5 report highlights that the diffusion of new technologies related to decarbonization strategies requires transnational capacity building and knowledge sharing and could contribute to international partnership (Roy et al. 2019). Impacts on industry, innovation, and infrastructure (SDG9) are mixed and sector-specific, with a tendency to penalise energy-intensive sectors and infrastructure. Transforming the industrial sector towards a renewable-based and more efficient system aligns with the goal of upgrading energy infrastructure and making the energy industry more sustainable (McCollum et al. 2018b).

With respect to the environmental indicators, there is strong positive interaction between mitigation and SDG11, sustainable cities and infrastructure. This is driven by the multiple co-benefits of the behavioural and technological transformations mitigation policy might induce. According to Reis et al. (2018), meeting the 1.5 °C policy target may limit spikes of pollutant concentration (except PM2.5) above the safe thresholds in all countries. Furthermore, mitigation commitments might stimulate the development of renewable energy technologies and energy-efficient urban infrastructure solutions boosting urban environmental sustainability by further improving air quality, reducing noise and energy expenditure (McCollum et al. 2018a).

A strong positive interaction with high agreement and confidence is also found with water availability and quality (SDG6), natural resource protection (SDG12) through the reduced depletion of several natural resources, life below water (SDG14) through the reduced risk of ocean acidification, life on land (SDG 15) through reduced deforestation, though some weak trade-offs are also found especially for SDG 14 and 15 (McCollum et al. 2018a). The scaling up of renewable energy would lower the water demand for energy (e.g. for cooling power plants), though some specific options (e.g. hydropower) could induce trade-offs through competition for water use. A mitigation pathway that more strongly relies on bio-energy might have higher requirements in terms of water for irrigation, reducing availability for other sectors.

To conclude, the existing literature seems to suggest that the degree of competition between mitigation objectives and sustainable development depends on the type of transition pathway adopted. While energy supply or land and ocean mitigation options tend to entail a larger number of trade-offs and risks, demand-side measures can significantly reduce the risks associated with mitigation policies, as they tend to bring about a larger set of co-benefits. Yet, actual synergies and trade-off will be unevenly distributed across regions and nations (Roy et al. 2019).

3 An Ex-Ante Assessment of the Paris Agreement

3.1 Framework Description

The Aggregated Sustainable Development goals Index (ASDI) framework developed in this chapter aims at offering a comprehensive assessment of current well-being and future sustainability based on 27 indicators related to 16 Sustainable Development Goals.[1] As describe in Fig. 1, ASDI combines an empirical, regression approach based on historical data (grey) with a modelling, future-oriented framework (black) to offer an internally-consistent set-up that makes it possible to analyse future patterns of sustainability indicators and their inter-linkages.

The **selection of the SDG indicators** was informed by the work of the UN Inter-agency Expert Group on SDG Indicators (United Nations (UN) 2017a), which listed 232 indicators to be used in assessing SDGs, and follows these guidelines: (1) relevance for the SDG they refer to, (2) connection with one of the SDG Targets, (3) sufficient data coverage for each country, (4) linkage to the macroeconomic variables that are output of the model. These are the main constraints on indicator selection of any systemic and multi-approach analysis of Agenda 2030 (von Stechow et al. 2016), including the ASDI framework here described. On the one side, the global perspective of the proposed modelling exercise requires the broadest coverage of indicators, dismissing some promising indicators for which sufficient data coverage is not yet available for a large number of countries. On the other side, given the goal of generating future projections of the selected sustainable indicators, we have to exclude indicators that could not be linked to any of the model variable outcomes or not showing a significant correlation with them. For this reason, at the moment, our analysis does not cover SDG5 (gender equality). We were not able to find a robust relation linking a gender-related indicator to an endogenous

[1] SDG5 on gender inequality is not explored.

Fig. 1 ASDI framework

variable generated by the model. Table 1 lists the selected indicators and classifies them in the sustainability pillar they pertain to: economy (ECO), society (SOC), and environment (ENV). Among them, 16 are computed using model results, 7 requires regression analysis to be linked to them (SDG1, SDG2, SDG3a, SDG3b, SDG4, SDG7a, SDG10), and the remaining 4 are kept constant at historical levels (SDG14, SDG15a, SDG15c, SDG16).

The **collection of historical data** of indicators relies on several international databases (World Development Indicators (World Bank (WB) 2018), UN database (United Nations (UN) 2018), and World Income Inequality Database (WIID3.4) (United Nations (UN) 2017b)) and covers all available countries for the period 1990–2015. Historical data are used for initializing indicators in the base year of the model (2007) and for estimating the basic relationships between model's variables and indicators in the regression analysis phase.

The **regression analysis** phase makes it possible to obtain projections of those indicators not directly generated by the model: poverty headcount ratio (SDG1), undernutrition prevalence (SDG2), physician density (SDG3a), Healthy Life Expectancy (HALE) (SDG3b), literacy rate (SDG4), Palma ratio[2] (SDG10), and electricity access (SDG7a). Using independent cross-country panel regressions (reported in Annex I), we identify the historical correlation between indicators and some socioeconomic variables.[3] The selection of the relevant explanatory variables for each indicator is based on the existing literature. Regarding SDG1, poverty prevalence has a negative correlation with unequal income distribution and a positive one with average income per capita level (Ravallion 2001, 1997; Ravallion and Chen 1997). Undernourishment prevalence (SDG2) is reduced when economic conditions (Headey 2013; Heltberg 2009; Fumagalli et al. 2013) as well as food production (Headey 2013) improve, and when inequality goes down (Heltberg 2009). Physician density (SDG3a) has a positive relation with total health expenditure per capita and a negative one with private health expenditure share. The healthy life expectancy (SDG3b) increases with the level of population education (Gulis 2000), urbanisation (Bergh and Nilsson 2010), physician density (or more in general public expenditure in health) (Kabir 2008), electricity access (Youssef et al.

[2]The Palma Ratio is defined as the ratio of the top 10% of population's share of Gross National Income (GNI), divided by the poorest 40% of the population's share of GNI (Cobham et al. 2016).

[3]Our future sustainability scenarios are built under the assumption that the estimated relationships will hold also into the future up to 2030.

Table 1 ASDI indicators

SDG	ASDI indicator	Pillar	SDG	ASDI indicator	Pillar	SDG	ASDI indicator	Pillar
SDG1	Population below $1.90 (PPP) per day (%)	SOC	SDG8a	Annual GDP per capita growth (%)	ECO	SDG13a	Concentration of GHG emissions from AFOLU(tCO_2e/sq.km)	ENV
SDG2	Prevalence of undernourishment (%)	SOC	SDG8b	GDP per person employed ($PPP2011)	ECO	SDG13b	Compliance to Conditional NDCs (%)	ENV
SDG3a	Physician density (per 1000 population)	SOC	SDG8c	Employment-to-population ratio (%)	ECO	SDG13c	Gap from equitable and sustainable GHG emissions per capita in 2030 (tCO_2eq)	ENV
SDG3b	Healthy Life Expectancy (HALE) at birth (years)	SOC	SDG9a	Manufacturing value added (% of GDP)	ECO	SDG14	Marine protected areas (% of territorial waters)	ENV
SDG4	Youth literacy rate (% of population 15–24 years)	SOC	SDG9b	Emission intensity in industry and energy sector ($kgCO_2e$/$)	ENV	SDG15a	Terrestrial protected areas (% of total land area)	ENV
SDG6	Annual freshwater withdrawals (% of internal renewable water)	ENV	SDG9c	Share of domestic expenditure on Research and Development (% of GDP)	ECO	SDG15b	Forest area (% of land area)	ENV
SDG7a	Renewable electricity (% of total population)	ENV	SDG10	Palma ratio	ECO	SDG15c	Endangered and vulnerable species (% of total species)	ENV
SDG7b	Primary energy intensity (MJ/$PPP07)	ENV	SDG11	CO_2 intensity of residential and transport sectors over energy volumes (tCO_2/toe)	ENV	SDG16	Corruption perception index	SOC
SDG7c	Access to electricity (% of total population)	SOC	SDG12	Material productivity ($PPP2011/kg)	ENV	SDG17	Government gross debt (% of GDP)	ECO