
1 Introduction

Scott Barrett, Carlo Carraro and Jaime de Melo¹

Columbia University; University of Venice and Feem; Ferdi

For the first time ever, in Paris at COP21, almost all of the world's countries will commit to reducing or controlling their own greenhouse gas emissions. At the same time, cities, business organisations and major companies will also commit to reducing their own emissions. This will represent an important success of diplomatic efforts to address the climate change problem. However, preliminary assessment of the Intended Nationally Determined Contributions (INDCs) submitted so far shows that the agreement being prepared for adoption in Paris in late 2015 will need to create incentives for parties to pledge to do more in the immediate future. Incentives will also be needed for parties to *actually do more*. These incentives may come not only from within the United Nations Framework Convention on Climate Change (UNFCCC) process, but also from other sources, such as the effort currently underway to amend the Montreal Protocol to limit hydrofluorocarbons (HFCs). The emerging regime for limiting climate change will therefore consist of multiple agreements, policies, and actions adopted at the local, regional, and global levels.

In Paris, but also beyond, attention will probably focus on whether similar countries are making similar pledges to limit their emissions. It will also focus on whether the sum total of all pledges will put the world on track towards meeting its common goal. The current goal is to prevent mean global temperature from rising by more than 2°C relative to the pre-industrial level. Attainment of this goal may already be beyond our reach, but the bigger point is that limiting temperature change to any level will require reducing carbon dioxide (CO₂) emissions to zero, or removing CO₂ directly from the atmosphere. This is an unprecedented global challenge.

¹ Thanks to Arild Angelsen, Ottmar Edenhofer, Brian Flannery, Patrick Guillaumont, Thomas Stocker, David Victor and Mitsutsune Yamaguchi for helpful comments.

From a top-down perspective, the approach needed to meet this challenge is straightforward. To limit concentrations, cumulative future emissions must stay within a fixed ‘carbon budget’. This perspective reduces negotiations to a zero-sum emission game, one in which a smaller emission reduction for one player necessarily implies a larger reduction for another. In other words, the top-down perspective puts the spotlight on equity and fairness, assuming away the problems of efficiency and effectiveness. However, the top-down approach cannot be implemented directly in a world in which states are sovereign. In contrast, the bottom-up approach takes as its starting point that states are likely to act so as to advance their self-interests, unless they are given incentives to limit their emissions further for the sake of their collective interests. The challenge in this case is to provide these incentives. The process of assessment and review negotiated for Paris is one way to provide such incentives – by creating opportunities for ‘naming and shaming’. The Paris approach is thus a blend of the top-down and bottom-up approaches, simultaneously pushing countries away from the non-cooperative outcome and pulling them towards the full cooperative outcome.

However, the gap between these two outcomes is vast and will be difficult to close. The non-cooperative outcome, being grounded in self-interest, holds a strong attraction. By contrast, the ideal outcome requires deep cooperation and may be beyond the reach of our existing institutions. What we need is a regime for limiting climate change that is workable and effective, rather than workable and insufficiently effective (as might be the case with Paris) or effective if implemented but politically unacceptable (as would be true of an ‘ideal’, top-down climate agreement). This volume presents a number of analyses, ideas, and proposals for how to design, build, and sustain such a workable and effective regime. The contributions look to – but also beyond – Paris, identifying the paths that the evolving climate regime can and should take.

This book’s main goal is to provide hints, guidelines, and policy recommendations for a workable and effective climate agreement. Most chapters focus on effectiveness. However, one of the merits of the book is that it also provides sound analyses of fairness (and therefore workability) of a climate agreement. The concern with distributional issues cannot be neglected. Countries will agree on reducing their own greenhouse gas (GHG) emissions only if they believe that the burden of this emission reduction effort is fairly shared among all the world’s regions.

The book is organised into seven sections. Aimed at a non-specialist audience, each chapter is short, pragmatic, and can be read independently. Part I identifies the challenge, focusing on the science of climate change, the 2°C goal, and the state of the climate negotiations. Part II provides a perspective on how some of the key players see this issue – from Africa to China, from Europe to India, and from Japan to the United States. Part III describes how the self-interests of players like these can be leveraged by the design of international institutions to provide meaningful and effective collective action. Part IV moves from a focus on institutions to the design and implementation of policies. Part V is concerned with technology options, discussing not only how policies can stimulate the development and diffusion of key technologies, but also how some technologies (such as geoengineering) present their own challenges for the design of policies and institutions. Part VI addresses the distributional issues around burden-sharing and the need for the poorest countries to develop even as the world moves towards a new energy future. Finally, Part VII is concerned with how to address these issues with international finance.

Part I: The challenge

Climate change is a monumental challenge for policy (Arrow 2009). As we approach the Paris Conference (COP21), many participants and observers are filled with hope but are also concerned that the new agreement will fall short of the ‘ambition’ needed to stabilise greenhouse gas concentrations at a ‘safe’ level.

This apprehension about the future is shared not only by the scientific community, but also by business and political leaders, and by the general public in most countries. If too little is done to limit emissions, the impacts of unabated climate change could prove disastrous in many regions of the planet. Part I thus leads off with a state-of-the-art assessment of the scientific, economic, and policy aspects of climate change.² The

2 In their chapters, several contributors refer to IPCC reports, occasionally the same ones. To save space, end-of-chapter references only cite the co-lead authors for each publication. Readers wishing to refer to the full documents will find the full citation in the references to this Introduction.

purpose is to explain what is at stake in Paris. Part I ends with a summary of where the negotiations stand now, as we head into Paris.

As President Barack Obama recently said, “[s]cience, accumulated and reviewed over decades, tells us that our planet is changing in ways that will have profound impacts on all of humankind”.³ This is also what Stocker, Co-Chair of IPCC Working Group I, tells us in Chapter 2. The scientific assessments carried out by the Intergovernmental Panel on Climate Change (IPCC) have delivered robust and rigorous scientific information for the complex negotiations to limit climate change and its impacts and risks, particularly those that threaten the livelihoods of humans and the functioning of critical ecosystems.

However, climate change is not only a threat to ecosystems, glaciers, coastal zones, and agricultural yields; climate change is above all a threat to our economic systems and our societies. It is not only a threat to future generations, but also a problem for the present. Combating climate change is therefore important for sustaining and improving the standard of living of all the world’s peoples.

In Chapter 3, Edenhofer, former Co-Chair of IPCC Working Group III, and his collaborators emphasise not only the risks and costs of climate change, but also the risks and costs of mitigation, namely of reducing GHG emissions to limit the impacts of climate change. In principle, the risks of mitigation differ fundamentally from the risks of climate change in terms of their nature, timescale, magnitude, and persistence. Humankind has the technological means to solve the problem. However, this requires a large-scale transformation in the way we produce and use energy, as well as how we use land. A further delay in mitigation action substantially increases the difficulty of, and narrows the options for, this transformation. For example, delays will inevitably increase mitigation costs and will require an even wider adoption of CO₂ removal technologies later in the future. Time is therefore another important challenge, though there are numerous reasons why countries may want to adopt climate policy unilaterally.

Delays and policy uncertainties are discussed by Flannery in Chapter 4, which focuses on the state of climate negotiations. Political leaders express confidence that a deal in

³ <https://www.whitehouse.gov/climate-change>

Paris is achievable, but the real challenge is to design pathways and procedures for incremental mitigation efforts in the years following COP21. Residual acrimony and distrust from Copenhagen hamper the process, which must resolve many complex and contentious issues, such as the legal form of an agreement, compliance, the role (if any) for GHG markets and offset projects, intellectual property rights, compensation for loss and damage, transparency and associated measurement, and monitoring, reporting and verification (MRV) and review procedures. Overshadowing all remains the question of how the principle of ‘common but differentiated responsibilities’ (CBDR) will manifest itself throughout the agreement, from mitigation to reporting and from review to finance.

Nevertheless, some aspects are solidifying. Mitigation efforts will not be negotiated; rather, they are being submitted as INDCs, and, ultimately, recorded. Total financial aid appears set by the Copenhagen pledge of developed nations to mobilise US\$100 billion per year by 2020, provided that private-sector finance complements official assistance. Also, negotiators appear resolved to creating a durable framework based on cycles of review and renewal over intervals of, perhaps, five or ten years.

Despite these efforts, however, the Paris agreement is unlikely to put the world ‘on track’ to limiting warming to less than 2°C (or 1.5°C). Only recently have political leaders begun to temper expectations. They will need to manage expectations thoughtfully to avoid a backlash from a range of nations, stakeholders and media, and to restore the credibility of the UNFCCC as an effective process. The Paris agreement will be but another (although very important) step in a long journey. It is crucial to set the rules of this journey, through effective monitoring, verification, and comparison of domestic implementation, rather than complaining about the likely incomplete effectiveness of the Paris agreement.

Part II: Views from the regions

Perceptions about the relevance of past contributions to climate change to future obligations vary greatly across regions and countries, as do the political processes leading to countries’ negotiating positions. To give a sense of this diversity, we invited ‘views’ from two regions and three countries, asking contributors to describe briefly

likely country/regional positions and to assess the set of desirable/feasible policies. These contributions, reflecting the mosaic of interests across countries and regions, are collected in Part II.

If Africa contributes the least to climate change, in Chapter 5 Mekonnen notes that it is also the region that is estimated to lose the most (in relative terms) as a result of climate change (2-4% of GDP) in the coming 10-50 years, as 50-80% of the land, livestock and population in this region are already in drylands, with the poor being the most exposed to climate shocks. Of the 48 least developed countries (LDCs) that are most vulnerable to natural and economic shocks, 34 are in Africa. Citing evidence that past shocks from extreme temperatures have only affected agricultural productivity in low-income countries, Mekonnen foresees a lack of resilience to the high projected costs of damage from extreme temperatures. Growth-oriented domestic policies will shape countries' strategies, with mitigation activities that exploit Africa's latecomer advantage in the building of infrastructure needed for the rapid urbanisation projected across the continent. This will necessitate external financing that far exceeds current committed levels and that should be allocated on the basis of indicators to climate vulnerability. Mekonnen urges greater cooperation at the regional and continental levels, including greater participation in the Lima Challenge established by a group of tropical forest countries.

In Chapters 6 and 7, Fei and Somanathan, respectively, document that domestic policy priorities guide China's and India's climate policies, which, until recently, were defensive towards an international climate agreement, with both countries being members of the 'Like-Minded Countries' (LMDC) group. Both countries are preoccupied with growing energy demands (rural-urban migration approximately triples per capita energy consumption) and energy security. China has only very recently come to realise that balancing energy security and environmental protection presents a huge challenge for its energy system. China and India are also coming to terms with the growing evidence of damage from climate change and from poor air quality.

Somanathan attributes India's slow start at mitigation to internal political costs and to the lack of action by developed countries. India's ambitious National Action Plan of 2008 and more recent announcements have established very ambitious targets for electric generation of installed renewable energy capacity of 175 GW by 2022 (close to current

worldwide installed capacity). Sizable steps have also been taken towards carbon and oil pricing, with revenues earmarked for removing unmetered and subsidised electricity in agriculture, which accounts for 18% of electricity consumption. But Somanathan warns that any politically feasible increase in the carbon price will require compensation that will only be possible with offsets from developed country carbon-trading programmes.

Fei acknowledges that without China's active engagement, the world will be unable to limit climate change. From the perspective of the bottom-up approach, this implies that China's climate policy will be rooted in its three domestic priorities: development, air quality, and energy security. These three targets are a tall order, since better air quality calls for a sharp reduction in coal consumption, which is currently necessary for energy security, especially as energy demand is set to grow under rapid urbanisation. In its international position, China also wishes to align its greater mitigation ambitions with its desire to stand with other developing countries, notably as a member of the LMDC group. Fei sees encouraging signs in the recent fact that a transition towards a low-carbon economy is no longer viewed as a costly effort driven by international pressure. He concludes that market-based policies and measures are needed to reduce the economic and political costs of command and control measures regulating the state-owned energy enterprises that dominate energy-intensive industries.

The EU and Japan both participated in the Kyoto Protocol. In Chapter 8, Yamaguchi and Akimoto tell of Japan's successful experience in reducing emissions by 12% from 1990 levels during the Kyoto Protocol period under a totally voluntary 'agreement' between the government and industry sectors. They conclude that careful consideration of a country's political, economic, and cultural environment should weigh heavily in the design of its climate policy strategy. They also note that, under the Kyoto Protocol, Japan had to compete fiercely with rapidly industrialising countries in the region that did not face an emissions cap. Japan also had to prepare its INDC in the aftermath of the Fukushima meltdown. The government's new '3E+S' plan (economy, energy security, environment, and safety) will be a huge implementation challenge, as the Japanese people do not want a return to nuclear energy and marginal abatement costs are very high in the energy-efficient Japanese economy. Acknowledging the extremely high costs of stabilising temperature at any level, Japan has launched the Innovation for Cool Earth Forum (ICEF) to develop innovative technologies. As to diffusion of

highly energy efficient technologies, Japan has promoted sectoral approach focusing on energy-intensive sectors.

The EU took leadership on climate change in the negotiations leading to the Kyoto Protocol. Following Europe's failure to put a tax on CO₂ in 1990 – a step that would have required unanimity among members on the tax rate – Brussels set up the EU Emissions Trading System (ETS), which only required majority approval. In Chapter 9, Guesnerie notes that legal and political feasibility concerns, rather than economic considerations, dictated this choice. The economic recession, political pressure and lobbying for free emissions quotas rapidly led to an oversupply of licenses and to the collapse of the market price, even though climate policy in Europe succeeded in reducing EU emissions (the EU is likely to reach its -20% target in 2020). Having extolled the superiority of a carbon tax over a cap-and-trade (CAT) system on economic grounds, Guesnerie recognises that reaching a worldwide carbon price is beyond political feasibility, but that linking separate carbon markets might help us on the path towards a unique carbon price. Climate clubs could also help if credible punishment is in the offing to prevent free-riding, an option to be considered for EU climate diplomacy but still beyond reach under the current difficulties of the EU ETS.

Kotchen reviews the US position in Chapter 10. In spite of increased awareness among the public that global warming is due to human activities, scepticism and sharp differences between the executive and legislative branches of the government that led to the non-ratification of the Kyoto Protocol continue to complicate the US international position on climate for the Paris summit. The US nonetheless managed to reduce CO₂ emissions by 10% in 2013 from 2005 levels, with half of this reduction due to the recession and the rest coming from a lowering of the carbon content of energy through a shift to natural gas and an increase in overall energy efficiency. Because most aspects of the Climate Action Plan are taking place under executive authority (see also Chapter 17), they are subject to legal challenges (these do not apply to the Californian and north-eastern states' initiatives, which account for more than half of the US economy). Kotchen notes that legal challenges will be stronger if there is a lack of ambitious INDC commitments by other countries at COP21. In the longer run, however, he foresees that the greatest challenges to advancing an ambitious agenda will be from the large and growing developing countries rather than from domestic politics. While developing

countries are waiting for substantial increases in climate finance prior to starting to mitigate, Kotchen is optimistic that both Democrats and Republicans will recognise the value of climate-related assistance to poor countries. The key to success from the US perspective, then, is that all countries submit reasonably ambitious emissions reductions plans and that the agreement be viewed as the beginning of a process of pledge and report (rather than commit and comply), leading to transparency and regular reporting of emissions.

Part III: Architecture and governance

The chapters in Part III focus on the architecture of institutions designed to reduce global emissions of greenhouse gases. Some chapters are concerned with the UNFCCC/Paris process, but others go beyond this approach and look to other opportunities to limit emissions.

In Chapter 11, Bodansky explores one of the key legal issues facing the climate negotiations. Many observers have long argued that an agreement to limit emissions must be legally binding. However, under international law countries are free to participate in any agreement or not as they please, and making an agreement legally binding may cause some countries not to participate. The Kyoto Protocol was ‘legally binding’, but that didn’t stop the US from declining to ratify the agreement, or Canada from withdrawing from it later. Bodansky notes that there is no clear evidence that a legally binding agreement has more of an effect on state behaviour than a non-legally binding agreement. Probably more important than the legally binding nature of an agreement are its precise terms, particularly with regard to the agreement’s ability to enforce participation.

In the run up to COP21, countries have been submitting their INDCs. As previously emphasised, one issue is whether the aggregate of emission reductions implied by these pledges are on the right track to meet the goal of limiting mean global temperature change to 2°C. Another issue is whether similar countries are making similar pledges. Are countries pledging to contribute their fair share? In Chapter 12, Aldy and Pizer focus on this second question. They find that it is a difficult question to answer, because the INDCs are expressed in different ways and no single metric exists for effort. They

suggest that comparability of pledges should be based on multiple data sources and analyses by a set of independent experts.

While the emission limits pledged by countries will not be legally binding, one plan under consideration is to make provisions for monitoring, reporting, and verification legally binding. It is essential to know whether countries' actual behaviour is tracking their pledges and, as Wiener notes in Chapter 13, greater accountability can also cause behavioural change. States may be more likely to meet their pledges if their actions can be observed. Indeed, Wiener argues that monitoring, reporting, and verification should extend beyond emission levels and related outputs, to include policies and measures for reducing emissions, investment in technology R&D, financing, adaptation, and geoengineering. In Paris, countries may be reluctant to go as far as Wiener recommends, but as time passes and future climate agreements come to address more and more issues, the provisions for monitoring, reporting, and verification agreed in Paris may also need to change.

The Kyoto Protocol tried to address climate change in a top-down way, and failed. Paris will try to build cooperation with a larger role for the bottom up. Victor and Keohane do not think this will quickly lead to deep changes in emissions, but they do see a silver lining to this cloud. As they note in Chapter 14, Paris could “help governments and other critical players determine what is feasible through coordination and it could establish some momentum in negotiations, so that countries not making serious efforts could be embarrassed as laggards”. In an optimistic scenario, they say, “this process could, through a series of increasingly serious steps, move pledge and review to a more coordinated and effective effort in the long run”. The approach they advocate involves “experimental governance,” requiring, first, that goals be related to actions; second, that participants who fail to act face significant costs; and third, that connections be made between various national pledges and the overall goal.

In Chapter 15, Stewart, Rudyk and Oppenheimer suggest that the world can do more than just build on the Paris agreement. States and other actors – including firms, NGOs, international organizations, and subnational authorities – can pursue a ‘building block strategy’ that relies on clubs, institutional linkages, and dominant market actors. These efforts would not undermine the UNFCCC approach, but would complement it by pursuing related approaches. Examples include multilateral banks agreeing not to

finance new coal-fired electricity generation projects, industry groups setting standards for wind turbines that confer upon them a competitive advantage, and the sharing of technical information on opportunities to reduce emissions.

In Chapter 16, Mavroidis and Melo maintain that a reform of the World Trade Organization could also help. They argue that interpretations of the trade rules reflected in previous decisions constrain the ability of countries (alone or in groups) to develop climate change-friendly policies, such as labelling of an energy-efficient technology and efforts to limit fossil fuel subsidies. The WTO, they believe, needs to be reformed towards a ‘positive contract’ whereby countries have less leeway, and they propose reforms in that direction at the plurilateral and multilateral levels. Trade rules will then serve the purpose of reducing emissions and not just liberalising trade. They also explain that proposals for a climate club relying on tariffs would face legal obstacles under the current WTO rules, but that there are alternative ways to stimulate emission reductions by a subset of the WTO membership – a ‘coalition of the willing’ seeking to limit emissions.

Our own assessment of the situation, consistent with all of these chapters, is that the Paris agreement is unlikely to be an obstacle to making progress in limiting emissions, and could even help. It could help directly by encouraging participation, increasing ambition, and developing systems for MRV and for promoting experimentation and learning. It could also help indirectly by not standing in the way of, or by even promoting, complementary efforts, such as for taking action in particular sectors or for reforming the world trade rules. The climate change problem is simply too big and complex for a single approach to suffice.

Part IV: Policy options

Whatever is agreed upon in Paris and beyond in terms of a new climate regime, success in limiting emissions will ultimately require ‘putting a price’ on carbon by some means. Such a price will not only reduce emissions directly, but stimulate investment and even R&D into new technologies. The contributions in Part IV concern policies that ‘put a price’ on carbon. The chapters in Part V address technology-related policy issues.

Conceptually, the need for carbon pricing has long been understood. The difficulty has been in translating concepts into real policies. As Gro Harlem Brundtland noted regarding the outcome of the Rio 1992 conference, “[w]e knew the basic principles on which to build: cost-effectiveness, equity, joint implementation and comprehensiveness but not how to make them operational” (cited in Schmalensee 1998). Fortunately, in the years since then, many efforts have been made to adopt carbon pricing, and we are starting to have a better idea of what has worked and the hurdles ahead. The contributions here cover two approaches. Under the regulatory approach, which is based on law and engineering, economics can enter through the back door, in the implementation stage, as in the US Clean Power Plan (CPP). Under the ‘straight’ economic approach, based either on taxing emissions or imposing a cap on emissions and allowing trading, politics can enter in the design stage, as demonstrated by the experience of allocating entitlements under the EU emissions trading system.

In Chapter 17, Burtraw notes that the structure of the CPP is relevant for an international audience of policymakers because the process it inaugurates, in which implementation flexibility is strong, mirrors the one that is taking place in international negotiations. Recounting the political failure in the US of adopting a legislative approach to cap-and-trade to meet President Obama’s pledge in Copenhagen in 2009 to cut emissions by 17% from 2005 levels by 2020, Burtraw reviews evidence showing that this pledge will be met by the CPP. He also thinks that the regulations adopted by the US Environmental Protection Agency are unlikely to be politically overturned. Importantly, Burtraw notes that the flexibility in the CPP gives regulated entities (i.e. the US states) the tools to negotiate a cost-effective outcome and empowers and reinforces the actions of first-movers and bottom-up leadership. It is in this sense that the CPP may bring about a cost-effective outcome ‘through the back door’.

The challenges of carbon pricing are starkly exposed by Sterner and Köhlin in Chapter 18. All the evidence – *primo loco* in Sweden, which has a carbon price of over \$100/tCO₂ and a carbon intensity of GDP that is only a third of the world average – is that a carbon tax (when applied at a sufficiently high rate as in Sweden), along with complementary measures, is very effective at reducing emissions and encouraging the development of

substitutes for fossil fuels.⁴ But Sweden stands out as an exception. In most countries, taxes are unpopular, so politicians, helped by strong lobbying activity by the fossil fuel industry, deny the need to act and procrastinate. And at the international level, burden sharing and fairness also account for the lack of progress in taxing carbon.

Against this background, Sterner and Köhlin review four variations to direct carbon pricing: (1) the removal of fossil fuel subsidies; (2) fuel taxation; (3) cap and trade, and direct regulation; and (4) the promotion of renewable energy, as has been done by Germany over the last 15 years. They conclude that the negotiation process in Paris might want to include many instruments for different parts of the climate change complex, possibly using a price floor to complement the quantitative commitments made so far.

Taxing carbon started 25 years ago and is now widespread, with 40 national and 20 sub-national jurisdictions engaged in taxing carbon or involved in cap and trade (CAT) schemes. These efforts apply to a significant share of global emissions, and amount to an average price of carbon \$7Gt/CO₂. In Chapter 19, Wang and Murisic review this experience, focusing on 15 cases of implementation. They argue that hybrid elements in both the carbon tax and CAT schemes appear to blur the differences between the two approaches. Among the lessons they draw from their survey, they urge an expansion of bottom-up initiatives to foster greater cooperation on carbon pricing that would help promote transparency in the process of price-setting and also overcome concerns about carbon leakage.

The hybrid architecture that will emerge from the Paris negotiations will include bottom-up (INDCs) and top-down (MRV) elements. Policy instruments will differ across jurisdictions. Linkages across jurisdictions (e.g. acceptance of allowance or

4 The advantages of a tax are well known: (1) the transparency of the price system reaches billions of people that do not have to worry about their taking climate-friendly decisions; (2) it goes a long way towards re-establishing Pareto optimality; (3) it is more easily verifiable than other approaches; (4) if the tax is the same, or there is an agreement on convergence, the leakage problem is quasi-solved; (5) the thorny issue of burden sharing is greatly reduced; (6) because of the nature of the underlying uncertainty, the welfare benefits from the price system are greater than those associated with a quantity system; and (7) moving towards a uniform carbon tax would reduce the incentives and possibilities for lobbying activity (see, for example, Cooper 2008).

credits in another jurisdiction or crediting for compliance) that are required for this architecture to be effective are discussed by Stavins in Chapter 20. Linkage facilitates cost-effectiveness and can have potential political advantages, though to be effective, sufficient environmental integrity is required among the parties that are linking. Stavins recognises that the policy architecture developing under the Paris agreement will have elements that inhibit linkage (e.g. overly restrictive rules on allowable trading or adding objectives such as a sustainable development condition under the CDM), while other elements should facilitate linkage (e.g. international compliance units to help the tracking, reporting and recording of allowance unit transactions at the national level). If linkage has a sufficiently important role in the agreement and if operating rules are not too strict, mitigation costs would be reduced, which in turn would encourage ambition later on. As an example, Stavins would like to see the explicit inclusion of a statement that parties may transfer portions of their INDCs to other parties.

With countries contributing their INDCs individually, convergence to multilateral carbon pricing will be a long time coming. Effective carbon prices are likely to differ markedly, making leakage (i.e. the increase in foreign emissions that result from domestic actions) a real concern. In Chapter 21, Fischer examines the three channels through which leakage occurs: energy markets via the price for fossil fuels; the competitiveness channel as higher energy prices are transmitted to producers; and the innovation channel if carbon mitigation policies induce innovation. She also considers various ways in which policies can limit leakage, including border carbon adjustments, output-based rebating, exemptions, and sectoral treaties as alternatives. She notes, however, that all of these alternatives are unattractive, so long as they are adopted unilaterally. Fischer recommends a coordinated – perhaps multilateral – approach to anti-leakage measures.

Part V: Technology options

Stabilising temperature requires stabilising concentrations of greenhouse gases in the atmosphere, or offsetting the effect of rising concentrations through reducing radiative forcing by reflecting sunlight away from the earth. In turn, stabilising concentrations requires progressively reducing emissions to zero, or offsetting positive emissions with an equivalent removal of CO₂ directly from the atmosphere. These are the only possibilities.

So far, the climate negotiations have focused exclusively on the mainstream option of reducing emissions. However, emissions have increased steadily since negotiations began in 1990. Past efforts to limit emissions – let alone to bring them to zero – have failed. Paris will improve on this record, but bringing global emissions to zero will clearly be a great challenge. For this reason, it seems sensible to begin to consider the other ways to limit climate change.

This section puts the emphasis where it has always been – on mainstream efforts to limit emissions. The technological potential to reduce emissions remains very large. The last chapter however considers alternative ways of limiting global mean temperature change.

The world can certainly make a start in reducing emissions now, using the technologies already at hand (Pacala and Socolow 2004). However, as Toman explains in Chapter 22, new technologies will be needed to close the gap between the cost of fossil fuels and alternative energy sources as the scale of effort increases over time. Standard policy approaches, such as the adoption of a carbon tax, will help. But direct funding of research and development and demonstration will also be needed. Current funding of research into alternative energy technologies is very low and needs to be scaled up; Toman suggests that it needs to be as much as 20 times greater than the current level. This is a gap that the current round of negotiations is not seeking to bridge – at least not directly.

There are different ways to reduce emissions, including energy conservation and substitution of nuclear power for fossil fuels. However, these approaches are limited for various reasons, which is why so much attention has been given to renewable energy. In Chapter 23, Bosetti describes the current situation and explains why this must change in the future if emissions are to be reduced substantially. In recent years, solar and wind energy have grown enormously, but this growth is starting from a very small base. If the world is to have a chance of limiting climate change to 2°C, renewable energy will need to be scaled up to a much higher level. In addition, CO₂ will need to be removed from the atmosphere. One such option involves using biomass, a renewable form of energy, to produce electricity, and then capturing and storing the carbon released in the process of combustion. However, the problem here is scale. More fundamentally, a key problem for renewables is that the economics of adopting these technologies depends on the

economics of the fossil fuel alternatives – a reason why R&D is needed, as discussed above, in addition to policies like carbon taxes that favour renewables over fossil fuels.

Even if renewable energy reaches its potential, more will need to be done to limit temperature change to 2°C. If the world continues to burn fossil fuels, the emissions associated with this can be reduced substantially by capturing the carbon emissions and storing it somewhere other than in the atmosphere. As Tavoni discusses in Chapter 24, the problem is that carbon capture and storage technology is an add-on cost. It will only be economic if accompanied by policies like carbon taxes that favour the use of the technology.⁵ So far, and in contrast to renewables, carbon capture and storage technology has not taken off. In many countries, plans have been drawn up to build such plants but then cancelled. The reasons have been cost, the falling price of natural gas, and local objection to storing CO₂ near power plants. However, carbon capture and storage has one other advantage over other technologies: use of this technology reduces the ‘leakage’ associated with reductions in fossil fuel use by a coalition of countries (see Chapter 21).

All of the above chapters indicate that limiting temperature change to 2°C is an enormous challenge. Including analyses of other options, such as nuclear power, will not change this picture; nuclear and all the other options also have their limitations.

This is why Barrett and Moreno-Cruz consider in Chapter 25 alternative ways of limiting climate change – ways that would work independently of the world’s energy system. The first approach is carbon geoengineering, which involves removing CO₂ from the atmosphere directly. The approach they focus on is industrial, with the potential to remove CO₂ at virtually any scale. One problem with this technology is storage, but unlike carbon capture at the power plant, there is more flexibility in locating direct CO₂-removal technologies away from population centres. New ideas on re-using the captured CO₂ are also emerging. The bigger problem with this technology may be its high cost. However, carbon geoengineering is the only true backstop technology

5 Not only is CCS costly, it also requires a vast infrastructure at the scale required to make a meaningful difference to global CO₂ emissions. This is true for the logistics of pipelines and reservoirs and compounded if the approach is to use biomass plantations for BECCS. Obtaining permits to construct and operate the entire system may be even a bigger challenge than cost, and it is not “just” an economic issue.

for addressing climate change. The other approach is solar geoengineering, in which sunlight is reflected away from the earth, offsetting the effect of rising concentrations. This technology can control mean global temperature but it isn't a backstop, as it would affect the climate differently than limits on concentrations. Most obviously, it would not limit ocean acidification. Ironically, a problem with this approach is its low cost. Solar geoengineering would likely be cheap, meaning that it may be in the interests of a single country to deploy it. The primary problem with this technology is therefore governance.

To conclude, taken together, the chapters in this part of our book all suggest that there are no easy technological options for limiting global temperature change. More R&D efforts are certainly needed.

Part VI: Development and burden sharing

Developing countries, especially the very poorest, have contributed the least to climate change. As they will be hardest hit by its effect, the poorest will need to put aside large amounts of resources for adaptation purposes. At the same time, many easily implementable mitigation activities in the near future can be carried out at least cost in the poorest countries. Burden sharing, including the availability of finance for the poorest countries to mitigate and adapt while fulfilling their aspirations to grow, continues to be the main obstacle to reaching a compromise at the COP meetings. Without discussion on loss and damage, the Technology Mechanism, the Green Climate Fund and the Adaptation Fund, developing countries would not have accepted to break down the firewall between Annex I and non-Annex I countries, as was agreed in Durban in 2011. In short, developing countries would not have agreed to submit their INDCs along with all other countries.

Developing countries, especially the poorest, feel that it is iniquitous to expect that they will slow their development when they will be the hardest hit, while the rich are responsible for most of the excess of carbon stock and have the means to pay for mitigation. Any agreement/outcome on burden sharing reflected in the INDCs will reflect perceived future damages, the costs of mitigation and adaptation, and, for the developing countries, the amount of finance for adaptation that will be forthcoming.

Part VI covers damages, costs, and non-financial aspects of burden sharing. Part VII covers mobilisation of finance, the split between mitigation and adaptation, and the split between developed and developing countries.

In Chapter 26, Hallegatte and his co-authors explain that the poorest countries have been the most severely hit by climate shocks so far, and are projected to be more vulnerable in the future because they are situated in the hottest regions. Moreover, within these countries, the poorest communities are at greatest risk. They settle in the riskiest areas, for reasons of affordability, represent the least resilient segment of society, and receive smaller shares of social protection. To achieve low-carbon resilient development, Hallegatte and his co-authors urge long-term planning for investment, especially in urban areas, improved access to health care, and the adoption of well-targeted social safety nets.

To meet their national development targets, including those related to growth, social development, and access to natural resources such as water, low-income countries will need to devote considerable resources to adaptation. In Chapter 27, Kaudia recognises that the growth-related objectives of the high-emitting, fast-growing middle-income countries is driving a wedge in the negotiation pathways of the different groups of low-income countries (the Alliance of Small Island States, the Africa Group of Negotiators, and the Least Developed Country group) and those of the (largely middle-income) LMDC group. This will make it difficult to build a common position in the negotiations.

Kaudia states that low-income countries' submissions have been pushed by developed countries. In Kenya's case, and for many other low-income countries, forestry has the highest GHG abatement potential. While domestic policies that are in the national interest should be pursued anyway, Kaudia argues that submissions by low-income countries should be voluntary and contingent on financial resources and technological capability enhanced by involvement from developed countries that, so far, have not honoured the principles of fairness and equity enshrined in the UNFCCC. The principle of common but differentiated responsibilities (CBDR) should then be the underpinning principle if the world is to reach the objective of a socially inclusive and sustainable development path that is equitable, as the low-income countries are the most vulnerable to climate change.

The contribution of forest conservation to climate change policies is reviewed by Angelsen in Chapter 28. A decade ago, high hopes were placed on reductions in rates of deforestation, with its low cost (at \$5 per tCO₂, reducing deforestation rates by half would only cost \$9-10 billion per year) and a promising outlook for results-based payments mechanisms. Ten years on, vested interests still hold the power to block the policy reforms that are needed to shift the balance of interests towards forest conservation. A flawed process for allocating concessions and land rights – reflecting a lack of ownership at the national level combined with REDD+ processes run at the international level – has resulted in few results on the ground. Yet, forest conservation will have to play a central role in the contribution of REDD+ countries to the global effort to limit climate change.

To extend REDD+ activities beyond the initial vision of a vehicle of international transfers, Angelsen singles out improvements leading to national commitment policies, pressure from consumers on corporations, and ‘entrepreneurial authority’ coming from private actors defining new standards. Combined with assessment and review, REDD+ would become an integral part of countries’ national contributions to the global efforts to curb climate change. For forest conservation to generate the hoped-for contribution to arresting climate change, Angelsen concludes that REDD+ countries will have to take the driver’s seat – something they may be reluctant to do until financial resources from developed countries are truly forthcoming.

Starting from the observation that coal is both a high emitting source of CO₂ and an inefficient source of energy that is only extracted by a few countries, whereas energy is consumed by all countries, in Chapter 29, Collier proposes shutting down coal production progressively, starting in the high-income countries (US, Germany, Australia) and then moving down the ladder (middle-income countries would be required not to expand production once closure starts). On equity grounds, this would be better than freezing discovery and new investment, as suggested by the Board of the World Bank. If the parties involved were to cooperate by “harnessing the moral energy generated by popular concern about climate change”, Collier argues that it would be easier to curb coal supply than demand.

The challenges of urban adaptation come on top of massive and as yet unmet development needs, especially in the least developed countries. Globally, cities account

for over 70% of global GHG emissions while supporting 54% of the world's population. In addition, 90% of the projected population increase by mid-century is expected to be headed towards cities, especially in developing countries where vulnerability to climate impacts is highest. In Chapter 30, Bigio reviews the mitigation and adaptation strategies that are needed to reduce the carbon footprint of urban growth. To address the magnitude of the challenge, he proposes applying the average carbon replacement value for key construction materials of Annex I countries to all new urban construction expected to take place in the 21st century. This would require one-third of the available carbon budget for limiting climate change to +2°C (40% of the budget share has already been emitted during the period 2000-2011). Bigio identifies the synergies that can be achieved between urban adaptation to climate change and mitigation achieved by investing in energy-efficient infrastructure, both of which can improve the welfare of the urban poor. Obtaining finance and using it effectively is a big challenge ahead, as most urban growth momentum is expected to occur in small and medium-sized cities where governance and institutional capacities are usually weakest.

In Chapter 31, Coninck and Bhasin review the role that technology development and transfer, or 'technology cooperation', could play in facilitating climate change mitigation and adaptation. This process was initiated with the establishment of the Technology Mechanism (TM) in Cancun in 2010. However, due to lack of funding, vested interests, and lock-in, the TM has not yet achieved the hoped-for technological cooperation. One reason for this is that technology transfer requires more than scaling up R&D. As Coninck and Bhasin point out, "technology = hardware + software + orgware", where "orgware" stands for institutional policy and policy capabilities. Moreover, the TM's Technological Executive Committee is populated with climate negotiators who reproduce the deadlocks observed in climate negotiations. The authors identify provisions that would help developed countries see that it is in their self-interests to assist developing countries to enhance their capabilities. A 'technology window' in the Green Climate Fund, combined with making technology part of the portfolio of agreements, would help establish technology as one of the essential building blocks identified by Stewart and co-authors for the transformation in the energy sector that is needed for a workable climate regime.

Part VII: Climate finance

It is clear that most of the economic effects of the policies proposed in earlier chapters require a ‘redirection’ of future investments towards low-carbon options. Around \$90 trillion will need to be invested in infrastructure in the world’s urban, land use and energy systems in the next two decades; this amounts to about \$5-6 trillion a year. About \$1.6 trillion will need to be invested every year in energy supply, half to meet energy demand and half to replace existing plants. How these investments are managed will shape future patterns of growth, productivity, and living standards. It is therefore necessary to redirect these investments towards low-carbon technological and organisational solutions. This is what most earlier chapters were concerned about.

Nevertheless, additional investment will also be necessary to transition our economic and social systems towards a low-carbon future. The first questions are therefore: What is the size of the required additional investments, and what is the sectoral distribution of these investments? Massetti addresses these questions in Chapter 32, in which he analyses the distribution of investment needs across countries and over time. He also provides an overview of the expected financial flows from carbon pricing. These financial flows are crucial to cover the costs of the investment needs and to finance the necessary transfers to developing countries.

Massetti’s main message can be simply summarised as follows: additional investments to cope with societal transformations required to achieve the +2°C target amount to about \$0.6 trillion a year from now to 2030, i.e. 0.75% of world GDP in 2013. By contrast, a +2°C-consistent carbon tax would generate up to \$1.3 trillion per year of revenues in OECD economies in 2030. This is equivalent to 2.1% of OECD aggregate GDP in 2013. Non-OECD countries may need (as a median estimate) about \$50 billion in power generation capacity per year until 2030.

These figures seem to suggest that, provided adequate carbon pricing is introduced, financial resources may be sufficient to address the climate change problem. However, the macroeconomic dimension is just one facet of the problem. Implementation always remains the big issue. The regulatory framework and economic incentive schemes should be designed to favour the development of climate finance, both in the public and private sectors. Another key challenge is indeed assuring confidence that projects

will deliver an appropriate, risk-adjusted rate of return and that they can be built and operated with all necessary approvals and permits in a timely fashion.

Chapter 33 by Buchner and Wilkinson discusses the above issues. They review needed improvements in the regulatory environment such that climate finance will extend beyond national borders (currently three-quarters of climate finance is spent in the originating country/region). So far, the ‘alternative sources’ of finance identified in 2009 (carbon markets and prices, taxes on transport and international financial transactions, and the green bond market) have been disappointing. Buchner and Wilkinson conclude that strong government leadership will be needed to steer finance towards a low-carbon future, and suggest steps to take in that direction in Paris.

Since the aftermath of the 2008 crisis, the world is awash with savings and the cost of finance is low. This should be favourable for financing a transition to a low-carbon economy, but the investments are not forthcoming. In Chapter 34, Hourcade argues that we need new tools to kick-start this transition. The creation of government-backed ‘climate remediation assets’ would provide the guarantee that is currently lacking for private investments. New financial tools are indeed needed to trigger a massive wave of low-carbon investments, and carbon prices alone cannot do the job. Hourcade points out that, in the absence of a benevolent lender, high upfront costs of low-carbon projects, under uncertainty about the cost of equipment and the duration of the maturation phase of the projects, mean that investments that could be profitable are frozen. The creation of ‘climate remediation assets’ based on a governments’ public guarantee, along with carbon pricing, would remove this barrier to investing in low-carbon activities.

The distribution of financial resources is a final issue that needs to be addressed. How should additional – beyond official development assistance, or ODA – concessional climate finance be allocated between countries? Assuming that the split of funds between mitigation and adaptation has been decided, Guillaumont discusses in Chapter 35 the principles that should guide the distribution of funds for adaptation. These principles should be informed by an assessment of a country’s vulnerability to weather shocks and natural hazards resulting from changes in the climate. Any resulting index should also be independent of a country’s policies. He presents such an index of countries’ vulnerability to climate change that he then plugs them into a formula similar to the ones used by the multilateral development banks for the allocation of ODA funds. A

large dispersion in per capita allocations result within and across country groupings, reflecting the great heterogeneity in exposure to climate shocks across countries.

Research on climate finance is still in its infancy. Nevertheless, the four chapters in this section emphasise research directions and policy proposals that could effectively address the problem of identifying the sources of funding to cover the costs of climate related investments.

Final reflections

Climate change is a formidable challenge – probably the most difficult challenge the world has ever faced. There are some positive signs, such as the spread of carbon pricing worldwide and the large number of countries submitting their own INDCs at COP21 in Paris. However, with few exceptions (such as Sweden), far too little is being done. The world has set a high bar for action – the +2°C target – but the INDCs submitted so far fall short of the pledges that are needed to meet this goal, particularly because INDCs refer only to 2025-2030, and it is not clear that countries will even meet their pledges. Clearly, the commitments adopted in Paris will be just the first step in a long journey. Additional emissions reduction efforts will need to be implemented in the coming years, and more effective policy measures will need to be adopted, both domestically and internationally. The adoption of robust systems for measurement, reporting, and verification will facilitate compliance, but without supporting enforcement measures, countries are unlikely to achieve large emissions reductions. What is missing is both enforcement and vision. It is not enough to agree on a temperature target. It is now urgent to agree on a societal transformation path, which, in market economies at least, can be driven only by a change in relative prices. Countries should therefore agree on a reference carbon price – to be implemented progressively and through country-specific measures – that would drive investments towards low-carbon options.

The development of new technologies that lower the cost of alternative energy sources relative to fossil fuels will also help to reduce emissions, but contributions to R&D need to be scaled up considerably. The current level of public R&D investment in energy technologies is only a quarter of the equivalent level in the 1980s. Therefore, a four-fold increase in investment would not be unrealistic.

Distributional concerns must also be addressed. To be effective, any new agreement must be perceived by its parties as being fair. A priority for investment must be development of the world's poorest countries without increasing global emissions – a task that will require massive investment and financial support from the industrialised countries. This is not development assistance in the conventional sense of the term; it is development assistance that pays off globally, for the countries that contribute financially as well as for the recipient countries. Cooperation must therefore occur in multiple areas simultaneously – for reducing emissions, for undertaking R&D, and for financing investment and development. The scale, breadth, and complexity of the task are unprecedented, but we have no alternative but to face this challenge directly.

The negotiations leading up to COP21 in Paris have raised many of these issues. The arrangements adopted in Paris will need to be developed and improved upon over time. Additional efforts will also need to be pursued – whether ‘building blocks’, trade restrictions, or measures of some other description. The UNFCCC process will remain central to any global effort, but it will not be the only game in town. The climate problem is too complex, too far-reaching, and too important for any one institutional arrangement to address on its own. This book provides some guidance for how the world can navigate the uncharted territory that lies ahead of us. It is our hope that it will also stimulate even more ideas for how the world can develop a workable and effective climate regime.

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About the authors

Scott Barrett is the Lenfest-Earth Institute Professor of Natural Resource Economics at Columbia University in New York City, with appointments in the School of International and Public Affairs and the Earth Institute. He taught previously at the Johns Hopkins University School of Advanced International Studies in Washington, DC and, before that, at the London Business School. He has also been a visiting scholar at Princeton, Yale, and Université de Paris 1 Panthéon-Sorbonne. He is the author of *Environment and Statecraft: The Strategy of Environmental Treaty-Making* and *Why Cooperate? The Incentive to Supply Global Public Goods*, both published by Oxford University Press. He received his PhD in Economics from the London School of Economics.

Carlo Carraro is Professor of Environmental Economics at Ca' Foscari University of Venice. He holds a PhD from Princeton University. He was President of the University of Venice from 2009 to 2014 and Director of the Department of Economics from 2005 to 2008. In 2008, he was elected Vice-Chair of the Working Group III and Member of the Bureau of the Nobel Laureate Intergovernmental Panel on Climate Change. He was re-elected in 2015 for a second term. He is Scientific Director of the Fondazione Eni Enrico Mattei (FEEM), Director of the International Centre for Climate Governance (ICCG) and member of the executive board of the EuroMediterranean Center on Climate Change (CMCC). He is Co-Chair of the Green Growth Knowledge Platform (GGKP) Advisory Committee and Editor of the *Review of Environmental Economics and Policy*, the most important international journal in its field.

Jaime de Melo, Emeritus Professor at the University of Geneva, is Scientific Director at Ferdi, an invited professor at the Johns Hopkins University Bologna Center, and a non-resident scholar at Brookings. He worked at USAID from 1972 to 1976, taught at Georgetown University from 1976-80 and at the University of Geneva from 1993-2012. From 1980 to 1993, he held various positions in the research Department at the World Bank. He serves on several editorial boards and was editor-in-chief of the *World Bank Economic Review*, 2005-2010.