Technology rules!

Can technology-oriented agreements help address climate change?

Heleen de Coninck

Animum debes mutare, non caelum

VRIJE UNIVERSITEIT

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Summary

This thesis deals with climate change, technology and reciprocity. Climate change is defined as the climatic consequences of human-induced higher atmospheric concentrations of greenhouse gases[1]. Climate change has a number of adverse impacts, such as more frequent and stronger droughts and sea level rise, both of which would threaten people's livelihoods. These effects can be prevented by reducing greenhouse gas emissions to the atmosphere or sequestering greenhouse gases; this is called climate change mitigation. Greenhouse gas emissions have been rising consistently over the past decades, and it is projected that they will continue to rise rapidly, leading to potentially catastrophic climate change if unabated.

Low-carbon technology is one of the means to mitigate climate change and defined as know-how, methods, procedures, experience of successes and failures, physical devices and equipment to reduce greenhouse gas emissions. Technology thus encompasses hardware, software and orgware. For instance, for wind energy technology, the hardware is the wind turbines themselves, software could be the human capacity to operate and maintain wind turbines, and orgware could be the enabling legislation.

The increasing urgency of climate change evidenced in scientific assessments like the IPCC has placed the problem firmly on the international policy agenda. Many countries have adopted mitigation commitments and are implementing policies and actions. Despite all this action, it is unclear however whether a new international treaty on climate change, envisaged to be agreed in December 2009 in Copenhagen, will have wide coverage and will be environmentally effective.

A characteristic of successful international agreements is reciprocity – a perceived equivalence of benefits between parties to an agreement. This is particularly required for international environmental agreements, where there is no international enforcing entity that can hold parties to their promises. Hence, for a successful climate agreement, it is necessary to explore ways of balancing benefits between parties. One way, explored in this thesis, would be to agree on low-carbon technologies directly, rather than indirectly through emission reduction targets and economic incentives. This leads to the central research question: Can technology-oriented agreements provide greater reciprocity and thus improve the effectiveness of the international regime for climate change mitigation?

From a political economy point of view, a stable climate is a public good, which because of cooperation problems is underprovided. Climate change can only be fully addressed through collective action of many nations in the world: no country can solve the problem by itself. International cooperation on climate change, however, is extra difficult because of a deep distributional imbalance: the vulnerability for climate change impacts is highest in countries which hold little responsibility for the problem, while the cost of mitigating climate change is highest in less affected countries. In international relations, such an imbalance is called "asymmetric externalities", as opposed to symmetric externalities, where all parties have a roughly equal stake in the causes and the solutions of the problem. The consequence of the climate change problem structure is that countries with high greenhouse gas emissions and low climate change damage costs have a strong incentive to free-ride on an agreement to reduce emissions. This is the central barrier to international cooperation on climate change: a specific agreement to reduce emissions is not in the interest of those countries that should most urgently act.

1 This is a simplified version of the definition in the United Nations Framework Convention on Climate Change: "change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods."

The only way of providing countries facing high mitigation costs with incentives to reduce emissions is to give them something in return; in other words, to provide reciprocity. In a feasible international agreement, all parties involved should perceive sufficient reciprocity to incur the cost of the treaty. This means that reciprocity might have to be higher for those parties with high mitigation costs and low climate change impacts. Only if all sides perceive sufficient reciprocity, an agreement can be self-reinforcing, i.e., attractive for countries to sign and want to carry out the terms of agreement. Self-reinforcing agreements are helpful in any policy, but particularly in international environmental agreements where no entity exists that can coerce nations to participate or comply, for instance through a fine or another intervention.

Agreements on emission reductions do not offer reciprocity to all parties, so there are weak incentives among parties to comply. This became clear as Kyoto Protocol was implemented. The Kyoto Protocol is an agreement to reduce emissions, and was agreed despite the distributional characteristics of climate change. However, the effectiveness and the contribution it has made towards providing the public good was weakened because of the distributional problem structure. The defecting countries face high costs of mitigation and have economic interests that prevailed over the need to reduce emissions.

The Kyoto experience provides lessons for the involvement of emerging developing economies in a future climate agreements. Even if only one major industrialised country would defect from the future agreement to reduce emissions, emerging economies would have no incentive to incur costs for reducing emissions, even though they have a strong interest to prevent further climate change. After all, the problem is not going to be solved unless all major industrialised countries commit to emission reductions.

Parties can perceive reciprocity in three ways: through the benefits of preventing climate change, through associated benefits of emission reductions in other policy fields, and through other means of compensation or reward. The post-2012 literature and climate negotiations have so far focussed mainly on economic instruments, such as an international cap-and-trade system or a global carbon tax. Although these instruments in theory are more cost-effective, they are unlikely to make agreements self-reinforcing. Their exclusive focus on the short-term costs of commitments and mitigation actions hides the long-term, intergenerational benefits of preventing climate change.

The reciprocity that needs to be provided to countries for reducing emissions could be decreased if there are associated benefits of emission reductions and mitigation actions in other policy fields. Such co-benefits of climate mitigation might provide an incentive for parties to agree on emission reductions, and comply with them. Energy efficiency and renewable energy, for example, can lead to improved security of energy supply and better air quality. In order to decrease the reciprocity needs, these co-benefits need to be visible and as specific as possible. They also need to be recognised as co-benefits by countries. This thesis provides an exploration of co-benefits and possible linkages of climate policy with other fields. The conclusion, however, is that their specific reciprocity of co-benefits is insufficiently recognised to enable an emission reductions-based agreement.

If not through emission reduction targets, what might one agree on that mitigates climate change and provides reciprocity? One could look at what mitigation actions inherently are. Many mitigation actions imply innovation and diffusion of technology. There is general agreement that the emission reductions required to address climate change will need to be achieved through major investments in a portfolio of technologies.

If accelerated innovation and diffusion of technology is to provide reciprocity, it should not only be seen as a means to reduce greenhouse gas emissions; it should be seen as a reward for a country signing up. Economic innovation literature suggests that accelerated innovation and diffusion of technology provides economic benefits as it shifts the production function – it allows for the possibility to generate more income and create employment opportunities with less input of resources. Other motivations for considering technology in international climate agreements range from improving the efficiency of markets for technological innovation to expanding opportunities for international agreement and spurring necessary socioeconomic and technological change. Theoretically, therefore, technology provides more reciprocity than emission reduction agreements. But how can technology be practically incorporated in an international agreement on climate change? This thesis introduces technology-oriented agreements; those international agreements that are aimed at advancing research, development, demonstration, and/or deployment of low-carbon technology.

Technology-oriented agreements have been implemented successfully to address problems other than climate change. They tend to fall into four categories: knowledge sharing and coordination; research, development and demonstration (RD&D); technology transfer; and technology mandates, standards, and incentives for deployment. Existing technology-oriented agreements appear in all categories and provide important lessons. They vary substantially in their designs, circumstances and perceived success. A conceptual conclusion, based on experiences and more general features of the different kinds of technology-oriented agreements, is that knowledge sharing, RD&D and technology transfer agreements are not likely to achieve significant greenhouse gas emission reductions on their own, and are better seen as complements, contributing to effectiveness of other policies.

Other technology-oriented agreements, focussed on implementation of the technology through mandates, incentives and standards, do appear to have the potential to be effective in environmental terms as a substitute for emissions target-based agreements. Such technology-oriented agreements would need to be applied on a sector-by-sector, if not technology-by-technology basis, which can be limiting practically. Such an approach may make the most sense in certain specific settings, in particular for highly trade-sensitive sectors, for sectors not otherwise covered by emissions trading programs, for sectors that can benefit from international coordination such as building codes, appliance standards, regulation of vessels for international transportation. Also situations where significant co-benefits can be recognised are better served by technology-oriented agreements.

Technology-oriented agreements are further explored in a number of hypothetical yet concrete treaties between a selection of countries. The agreements explored are in the field of sugarcane-based bioethanol, CO_2 capture and storage, nuclear energy, ammonia production, personal vehicles and cement. Although some of these agreements could be self-reinforcing and look promising, technology-oriented agreements are not a panacea. Costs can be high, compliance is by no means a certainty, and fragmentation and poor design could threaten environmental effectiveness.

A specific case of technology in the climate change framework is technology transfer to developing countries. Effective international instruments to facilitate technology transfer have been investigated by comparing the technology transfer effects of the Kyoto Protocol's market-based Clean Development Mechanism (CDM) and the Global Environment Facility, a technology fund. The outcome demonstrates that about half of project activities in the CDM use new or improved technologies that originate from outside of the host country, usually with knowledge transfer and capacity building. However, the CDM was not effective in all sectors nor in all countries; projects in end-use sectors such as transportation and energy efficiency are a small part of its project portfolio and the CDM selects those developing countries with the most conducive investment climate, leaving out least developed countries that arguably have the greatest need for investments in sustainable development. For technologies in sectors not prone to market mechanisms, a specialised technology mechanism or fund that would address institutional aspects of technology – including the development of technological innovation systems and enabling environments – is likely to be more effective. If a market mechanism is can overcome the collective action problems of emission reductions, it can provide a strong pull for mature technologies that face a level-playing field. In other cases, technology-oriented agreements appear better suited to address technology-specific barriers and market failures and can provide more reciprocity to parties involved. This conclusion appears to apply globally, but is magnified in the context of technology transfer to developing countries.

In conclusion, this thesis explored whether reciprocity in international climate agreements could be improved through international agreements focused on innovation and technology. In particular, the thesis analyses the role of technology-oriented agreements from different perspectives and explores their potential impacts. The main result is that technology-oriented agreements can provide more reciprocity than emission reduction targets, a finding that needs to be recognised in the climate negotiations. A number of recommendations can be made to enable technology-oriented agreements. First, technology-oriented agreements should reflect the characteristics of the technology they address and be aligned with the (vested) technological interests that prevail in the sector, to ensure a positive payback function of the agreements to important parties. Second, a smart combination of market-based and technology-oriented agreements would work best both for climate change in general and for technology transfer to developing countries, if collective action problems can be overcome. Third, if indeed market-based and technology-oriented instruments are combined, their co-existence under one regime is recommended over a fully fragmented regime. This is necessary to prevent problems related to lack of transparency and sketchy accountability that would compromise environmental effectiveness of the climate regime. And last, if technology-oriented agreements are applied as a replacement or as a geographically or functionally complement, they should be designed for technology implementation, to ensure both environmental and technological effectiveness.

Samenvatting

Dit proefschrift gaat over klimaatverandering, technologie en wederkerigheid. Klimaatverandering is de structurele verandering van het gemiddelde weertype of klimaat als gevolg van menselijke activiteiten die een verhoging van broeikasgasconcentraties in de atmosfeer veroorzaken. Klimaatverandering heeft allerlei nadelige gevolgen, zoals frequentere en ernstigere droogtes en zeespiegelstijging. Het kan worden voorkomen door de uitstoot van broeikasgassen te verminderen of de opname van die gassen uit de atmosfeer te vergroten; dit heet klimaatmitigatie. De uitstoot van broeikasgassen is de afgelopen decennia sterk gestegen en zal, als hier niets aan gebeurt, blijven stijgen, wat rampzalige gevolgen kan hebben.

Klimaatvriendelijke technologie kan worden ingezet voor klimaatmitigatie. De definitie van klimaatvriendelijke technologie is alle knowhow, methoden, procedures, successen en mislukkingen, apparatuur en installaties die tot doel hebben broeikasgasuitstoot te reduceren. Technologie omvat dus hardware, software en zogenaamde “orgware”. Voor windenergie bijvoorbeeld, zijn de windturbines de hardware, is de kennis van een onderhoudsmonteur onderdeel van de software, en is de wetgeving rondom windenergie de orgware.

Naarmate steeds meer wetenschappelijke rapporten het belang van klimaatverandering benadrukken, is het onderwerp hoger op de beleidsagenda gekomen. Veel landen hebben al emissiedoelstellingen vastgesteld en andere beleidsmaatregelen geïmplementeerd. Desondanks is het onduidelijk of een nieuw international verdrag over klimaatverandering, dat in december 2009 in Kopenhagen moet worden uitonderhandeld, steun krijgt van de belangrijkste landen en voldoende milieuwinst kan behalen.

Succesvolle internationale overeenkomsten hebben één ding gemeenschappelijk: ze bieden wederkerigheid. Alle betrokken partijen moeten het gevoel hebben dat ze ongeveer evenveel beter worden van het verdrag. Vooral internationale milieuverdragen moeten aan deze voorwaarde voldoen, aangezien er geen internationale instantie bestaat die landen aan hun beloftes kan houden, zoals de WTO dat wel kan bij schending van handelsverdragen. Een succesvol klimaatverdrag moet dus de voordelen voor partijen zichtbaar maken en in balans brengen. Een mogelijkheid daarvoor is om afspraken te maken over de innovatie en de inzet van technologie in plaats van emissiedoelstellingen. De onderzoeksvraag van dit proefschrift is dan ook: Kunnen technologieovereenkomsten wederkerigheid leveren en zo de effectiviteit van een internationaal klimaatmitigatieverdrag vergroten?

Vanuit economisch perspectief is een stabiel klimaat een publiek goed. De markt heeft als kenmerk dat het onvoldoende publieke goederen levert vanwege collectieve irrationaliteit. Klimaatverandering kan alleen dan worden voorkomen als landen samenwerken. Geen enkel land is in staat om het probleem in z’n eentje op te lossen. Internationale samenwerking op het gebied van klimaat lijdt echter niet alleen onder collectieve irrationaliteit. Het behalen van voldoende milieuwinst is extra moeilijk door de structuur van het probleem: de gevolgen van klimaatverandering zijn het ergst in de landen die het probleem niet veroorzaken, terwijl de kosten voor mitigatie het hoogst zijn in landen die weinig van de gevolgen merken. In het vakgebied internationale betrekkingen heet dit wel “asymmetrische externaliteiten”: het tegendeel van de situatie waarin alle betrokkenen ongeveer evenveel bijdragen aan het probleem en de oplossing. Het gevolg van deze belangenstructuur is dat landen met een hoge broeikasuitstoot en weinig klimaatgevolgen een sterke prikkel ondervinden om hun uitstoot niet te verminderen en dus om niet mee te doen aan een klimaatverdrag. Dat staat internationale samenwerking op internationaal klimaatgebied danig in de weg en leidt ertoe dat die landen die het hardst nodig zijn om het probleem op te lossen het minste belang hebben bij die oplossing.

Verdragen met emissiedoelstellingen bieden weinig wederkerigheid, dus de prikkel om het verdrag na te leven is ook niet sterk aanwezig. Dit werd duidelijk bij het Kyoto Protocol, dat emissiereducties voor industrielanden oplegt. Het was een opmerkelijk resultaat dat het Kyoto Protocol überhaupt werd afgesproken, gegeven de ongelijke probleemstructuur rondom klimaatverandering. De problemen begonnen bij de uitvoering. In de landen die het verdrag niet ratificeerden of de voorwaarden tot nu toe niet hebben nageleefd, bleken de kosten te hoog of kregen andere belangen de overhand. En als enkele grote industrielanden, zoals de Verenigde Staten, al niet meedoen met een internationaal klimaatverdrag, heeft het voor grote ontwikkelingslanden, zoals China, geen enkele zin om wél emissiedoelstellingen op zich te nemen, hoe graag ze ook iets aan klimaatverandering willen doen.

De enige manier om landen met hoge mitigatiekosten te verleiden om emissies te reduceren is om ze wisselgeld te bieden, oftewel voor wederkerigheid te zorgen. Voor een succesvol verdrag moeten alle betrokken landen voldoende wederkerigheid ervaren om de kosten acceptabel te houden. Dit zou kunnen betekenen dat landen die hoge mitigatiekosten verwachten en weinig voordeel hebben bij een klimaatverdrag veel compensatie moeten krijgen. Het doel is om het verdrag "zichzelf versterkend" te maken, oftewel aantrekkelijk om te ondertekenen en na te leven. Beleid gericht op het "zichzelf versterkend maken" is verstandig onder veel omstandigheden: het is robuuster, inspecties op naleving zijn minder nodig en de maatregel is minder gevoelig voor politieke veranderingen. Op nationaal niveau is er echter altijd een overheid die een boete kan uitdelen of een vergunning kan intrekken als een bedrijf of instelling de regels niet volgt. Voor internationale milieuverdragen is het essentieel om zelfversterkend te zijn, omdat er geen internationale instantie is die de naleving kan afdwingen.

De meeste literatuur over post-2012 klimaatbeleid gaat over emissiereducties en economische instrumenten, zoals verhandelbare emissierechten of een belasting op broeikasgasemissies. Het grote voordeel van dit soort beleidsmaatregelen is de kosteneffectiviteit: de markt zoekt de goedkoopste oplossing. Het nadeel is echter dat ze zichzelf niet versterken omdat ze zich alleen op de kosten van klimaatmitigatie richten en de baten niet zichtbaar maken. Ze leveren weinig wederkerigheid.

De compensatie die nodig is in een klimaatverdrag kan worden verminderd als de inschatting is dat het verdrag substantiële bijkomende voordelen heeft. Als die voordelen groot genoeg zijn, kunnen ze landen overtuigen om akkoord te gaan met een klimaatverdrag. Energiebesparing en hernieuwbare energie kunnen bijvoorbeeld energievoorzieningszekerheid verbeteren. Bovendien leiden ze tot minder luchtvervuiling, waardoor de overheid minder kosten hoeft te maken om die luchtvervuiling te voorkomen. Het probleem is echter dat die positieve bijkomstigheden wel duidelijk zichtbaar en gespecificeerd moeten zijn, anders worden ze niet erkend door de deelnemende landen. Mogelijke bijkomende voordelen van mitigatiedoelstellingen op het gebied van luchtkwaliteit, energievoorzieningszekerheid, internationale handel en armoedebestrijding blijken echter onvoldoende of onvoldoende herkenbaar om voldoende wederkerigheid te bieden voor de kosten van vergaand klimaatbeleid.

Als emissiereductiedoelstellingen het niet kunnen, zijn er dan afspraken te bedenken die wel de benodigde wederkerigheid bieden? Emissiereducties zijn nodig, maar wat zijn ze precies? Voor veel emissiereductie activiteiten moet klimaatvriendelijkere technologie worden ontwikkeld en gebruikt. Zonder een hele reeks van technologieën zijn de benodigde emissiereducties niet te realiseren. Dus wat zou er gebeuren als we afspraken zouden maken over ontwikkeling en implementatie van klimaatvriendelijke technologie? Zou dat wel de wederkerigheid kunnen bieden waar we naar op zoek zijn?

De economische innovatieliteratuur suggereert dat intensivering van innovatie en versnelde implementatie van technologie economische voordelen kunnen opleveren voor landen. De theoretische verklaring daarvoor is dat innovatie de productiefunctie verschuift, en dus meer productie mogelijk maakt per eenheid input. Innovatie kan dus leiden tot meer inkomen en meer werkgelegenheid. Vooral landen met een actieve innovatie- en fabricagesector kunnen in technologieovereenkomsten exportpotentieel herkennen. Omdat ze specifieker zijn, kunnen in technologieovereenkomsten bijkomende voordelen ook beter worden herkend. Daarnaast zijn emissiemarkten in theorie wel kosteneffectief, maar in de praktijk spelen marktfalen en specifieke barrières voor innovatie en implementatie van technologie een grote rol. Het opnemen van specifieke technologieovereenkomsten in een klimaatverdrag zou een gedeelte van die problemen kunnen oplossen. Het lijkt er dus op dat technologieovereenkomsten meer wederkerigheid bieden dan emissiereductiedoelstellingen – immers, ze leiden ook tot emissiereducties, zijn in het belang van technologie-exporteurs en kunnen ook nog de efficiëntie van marktinstrumenten vergroten. Maar hoe zouden die technologieovereenkomsten er in de praktijk uit kunnen zien?

Internationale technologieovereenkomsten zijn niet nieuw. Ze worden al gebruikt voor specifieke andere milieuproblemen. Ruwweg zijn er vier categorieën technologieovereenkomsten: overeenkomsten die kennis delen en coördineren; overeenkomsten die zich richten op onderzoek, ontwikkeling en demonstratie van technologie; overeenkomsten betreffende technologieoverdracht naar ontwikkelingslanden, en overeenkomsten die implementatie van technologie nastreven, en standaarden, verplichtingen of financiële prikkels geven. Er is veel variatie in hoe bestaande technologieovereenkomsten zijn vormgegeven, wat ze kosten, onder welke omstandigheden ze worden uitgevoerd, en hoe succesvol ze zijn. Alleen technologieovereenkomsten van het vierde type, gericht op implementatie, kunnen voldoende bereiken om klimaatverandering te voorkomen. De andere types kunnen wel helpen, maar zijn op zichzelf niet milieueffectief.

Bepaalde typen technologieovereenkomsten zouden emissiereductiedoelstellingen dus kunnen vervangen. Ze zouden wel per sector, of zelfs specifiek voor een bepaalde technologie moeten worden afgesproken. Als dat voor een aantal technologieën moet gebeuren, kan dat moeilijk onderhandelbaar en praktisch onuitvoerbaar worden. Het beste kunnen dergelijke technologieovereenkomsten in specifieke omstandigheden worden ingevoerd, bijvoorbeeld in specifieke sectoren waarin emissiehandel onvoldoende prikkels geeft of waar marktfalen een grote rol speelt; in handelsgevoelige sectoren; of voor technologieën die veel baat hebben bij internationale afspraken. Voorbeelden zijn internationale voorschriften voor energiegebruik in gebouwen, of energienormen voor huishoudelijke apparatuur en auto's.

We kunnen technologieovereenkomsten verder uitwerken in fictieve maar realistische afspraken tussen een klein aantal landen. De voorbeelden die in dit proefschrift zijn uitgewerkt hebben betrekking op ammoniaproductie, biobrandstoffen, CO_2 afvang en opslag, kernenergie, cementproductie en personenwagens. Alhoewel sommige van deze hypothetische verdragen zichzelf kunnen versterken, blijken technologieovereenkomsten nog niet zo gemakkelijk te ontwerpen. De kosten zijn vaak erg hoog en de verdragstekst moet rekening houden met mogelijke negatieve neveneffecten van technologieën zoals de biodiversiteitimpacts van biobrandstoffen. Daarnaast kan het naast elkaar bestaan van allerlei technologieovereenkomsten leiden tot overlap, interactie en fragmentatie van het klimaatregime, wat de transparantie niet ten goede komt. Alhoewel het een stap in de goede richting is, is met de huidige gegevens niet onomstotelijk vast te stellen of de naleving van deze technologieovereenkomsten kan worden gegarandeerd.

Technologieoverdracht naar ontwikkelingslanden is een speciaal type technologieovereenkomst. Er is veel geschreven, maar niet veel bekend, over wat het beste werkt voor technologieoverdracht. Marktmechanismen, zoals het Clean Development Mechanism (CDM) van het Kyoto Protocol, blijken in veel projecten technologieoverdracht wel te kunnen realiseren, maar schieten tekort in sommige sectoren en in veel ontwikkelingslanden. Met name in de armere landen en de eindgebruikersectoren (transport en gebouwen) speelt CDM nauwelijks een rol. Een technologiespecifiek fonds dat institutionele aspecten van technologieoverdracht (inclusief innovatiesystemen en andere omgevingsfactoren) kan aanpakken zou tot betere en zelfs kosteneffectievere resultaten kunnen leiden. Zoals eerder geconcludeerd voor technologieovereenkomsten in het algemeen is een slimme combinatie van marktmechanismen en technologieovereenkomsten mogelijk de beste oplossing. Voor technologieoverdracht naar ontwikkelingslanden geldt dat vanwege de uitvergrote barrières voor realisatie van technologie nog sterker.

Dit proefschrift leidt tot de conclusie dat technologieovereenkomsten wederkerigheid in internationale klimaatovereenkomsten kunnen vergroten. De klimaatonderhandelingen zouden dit gegeven beter kunnen onderkennen. Echter, om effectief te zijn in het reduceren van emissies moeten technologieovereenkomsten wel aan een aantal voorwaarden voldoen. Ten eerste zouden technologieovereenkomsten zo moeten worden vormgegeven dat ze zo goed mogelijk aansluiten bij de belangen van landen en bedrijven die actief zijn in die technologie. Dat zou de kans vergroten dat het verdrag wordt nageleefd. Ten tweede kunnen marktmechanismen en technologieovereenkomsten slim worden gecombineerd om tot een beter resultaat te komen. Vervolgens, indien deze verschillende mechanismen worden gecombineerd in een verdrag, kunnen ze het beste samen in een overkoepelend klimaatverdrag worden ondergebracht, om fragmentatie en ondoorzichtigheid te voorkomen. En als laatste, indien technologieovereenkomsten in de plaats komen van een emissiereductiedoelstelling voor een bepaald land, dan moeten ze implementatie van technologie als belangrijkste effect hebben. Alleen dan kan de milieueffectiviteit van een nieuw klimaatverdrag worden gegarandeerd.

Chapter 1 Purpose, conceptual framework and methodology

1.1 Introduction

Environmental problems are deeply intertwined with technology. The causes of environmental problems are often found in technological developments, including development of know-how, equipment and organisation, where they have enabled industrialisation and other intensification of economic activities. However, the innovation and diffusion of technology has also enabled the solving of environmental problems (e.g., Andersen et al., 2007). Technology has become an inalienable part of human culture in many parts of the world (Hughes, 2004). While at the root of some of the most difficult current global environmental challenges, technology also holds the key to the solutions.

Climate change is one of such challenges, and has a similar relationship with technology. The root causes of climate change are found in the global use of technology to produce and convert energy, transport persons and goods, and farm. Historically, the first rise in global greenhouse gas emissions was associated with the organisational possibilities of exploiting forests for a range of productive uses, such as shipbuilding; the second was associated with the invention of the steam engine and the resulting industrial revolution. By now, across the world, diffusion of ever more innovative technology is leading to unprecedented development and prosperity, but also to rapid increases in greenhouse gas emissions, to such a degree that it is now widely accepted that this leads to a rise of global mean temperature, resulting in a range of adverse consequences (IPCC, 2007a).

At the same time, studies that investigate the possible means to reduce greenhouse gas emissions while maintaining economic prosperity require greatly accelerated rates of technology innovation and diffusion. This technology needs to be diverse and is not confined to hardware alone; examples include renewable energy installations, the organisational capacity to implement climate mitigation policy, and the social and physical infrastructure to enable the implementation of energy efficient appliances. Current technological advance, however, is not fast enough, and its positive effects are often undone by growth of overall output. Technological progress, for instance for safety or comfort, could even lead to more greenhouse gas emissions. Most studies indicate that the global dependence on fossil fuels for primary energy consumption will not decrease under a reference scenario in the decades to come, and that greenhouse gas emissions will continue rising at a fast pace (IEA, 2008a). There is consensus that far-reaching technological change is required to bring down emissions to a level at which the global mean temperature rise above pre-industrial levels would be kept below 2ºC (e.g., IPCC, 2007a; Vuuren et al., 2007).

Given the global scope of climate change, its characteristics of a global public good and the need for social action in response to climate change to be collective action, international cooperation is necessary. The current international institution to address climate change, the United Nations Framework Convention on Climate Change (UNFCCC) including its Kyoto Protocol, so far yields only limited progress, notably because it suffers from defection of a number of important players. International institutions and global governance to address global environmental problems are discussed extensively in the literature (see e.g., Mitchell and Keilbach, 2001; Biermann, 2007). A general conclusion is that when countries agree to address an environmental problem in an international treaty, mechanisms are implemented by the countries that experience most damage to reward compliance or to punish defection of those countries causing the problem. Indeed, there is no other way for enforcement of international agreements in the absence of an international institution that has the legitimacy to coerce, for instance through fines or other sanctions (Barrett, 1994). The inability to enforce compliance is a central problem in international agreements. In combination with the collective-action nature of the required response to climate change, participation in and effectiveness of any international climate agreement is challenging (Barrett, 1998; Victor, 2001).

Although much has been written about international environmental agreements, the literature on the question of how innovation and diffusion of technology is addressed in, and could strengthen, international institutions is limited. As this question is becoming increasingly relevant in the context of climate change, this thesis aims to contribute to the debate for the specific case of climate change.

1.2 Climate change, rational actors and reciprocity

1.2.1 Rational actors and public goods

This thesis takes a rational-actor approach to the problem of designing an international institution around climate change. Rational actors make decisions serving their perceived self-interest. In international relations, a rational-actor approach is commonly taken to explain and predict behaviour of states in international negotiations (Snyder, 2004). A rational actor framework provides an internally consistent framework that has considerable explanatory power, but also has serious limitations. Although theory assumes that rational actors optimise according to their interests, this is rarely the case in practice. Simon (1957) called this “bounded rationality” and argued that not an optimising but a “satisficing” strategy is often taken, in recognition that the optimal solution is not always apparent or achievable. Individuals, firms, governments and organisations often lack the information or the information processing means to optimise across all options. Transaction costs may be too high, information may be unavailable or too abundant (Akerlof, 1970). Where the limits of the rational actor approach are reached, this thesis will also include considerations of beliefs and availability of information.

As a stable climate is a public good, preventing climate change implies the generation of a public good. The main feature of public goods is that their benefits are non-excludable, meaning that “if any person in a group consumes it, it cannot feasibly be withheld from others in that group” (Olson, 1965), and non-rival; consumption by any person does not reduce consumption by another. Clean air, for instance, is a public good as a firm that decides to reduce pollution generates benefit for all breathing the cleaner air, not only for itself, and the consumption of clean air does not reduce its availability to others. Similarly, if one country would decide to resolve climate change, the benefits would accrue to all countries that would otherwise be harmed. An example of a private good (as opposed to a public good) is a consumer good, such as food, which can only be used by the owner and from which other potential users can be excluded.

If we apply a rational-actor approach to public good problems, the self-interested decision of the actors is to free-ride, resulting in the public good being underprovided (Olson, 1965). Hence, collective action is necessary to provide the public good. The literature on collective action is extensive and spans decades. Initially, it focussed on local problems, for instance on a hypothetical problem of cows belonging to one farmer trampling the crops of a neighbouring farm (Coase, 1960). It was demonstrated that how actors solve the issue depends, amongst others, on the cost structure of the solution relative to the damage costs. Consequentially, under conditions of incomplete information, how private actors or government would intervene also depends on the information available on the cost structure (Coase, 1986). For climate change, similar cost-benefit analyses have been carried out to clarify the cost structure, but uncertainties in the information have caused results to diverge strongly (Nordhaus, 1977; Tol, 1999; Stern, 2006).

1.2.2 Consequences of distributional characteristics of climate change

The willingness of countries to embark on collective action on climate change determines what kind of international institution would emerge out of negotiations. That willingness is influenced by the costs of the solutions relative to the damage costs, and this balance is unique for every country. Their geographical, demographic, economic and social heterogeneity and consequential interests result in an asymmetric climate change problem structure. Conversely, other problems, where all parties have a roughly equal stake in the cause of the problem and its solution, show a symmetric externality structure (Mitchell and Keilbach, 2001).

The single most important cause of climate change lies in the use of fossil fuels for energy use, supply and services (IEA, 2008b). Since the start of the industrial revolution, which was accompanied by a steep rise of energy use, most of the global energy consumption has taken place in industrialised countries (Matthes, 2008). As greenhouse gases generally have long residence times and therefore, under current emission patterns, cumulate in the atmosphere, industrialised countries have a historic responsibility for almost 80% of the human-made CO_2 concentrations currently in the atmosphere. Although this situation is changing and some developing countries have fast-rising emissions, because of the stock good characteristic of greenhouse gases, it takes them a long time to reach the same level of cumulative responsibility. For example, India will have emitted more than Japan only in 2031 (Botzen et al., 2008) although currently India's emissions are well above Japan's, and while Chinese greenhouse gas emissions exceeded those of the EU-27 in the year 2000 already, their cumulative responsibility only projected to catch up with the EU around 2050 (Matthes, 2008). The current perpetrators of climate change are therefore primarily the industrialised countries, while further in the future, emerging economies start playing a significant role.

The allocation of historical responsibility to act on climate change is relevant from a moral, "polluter pays" perspective, which holds that polluters should bear the costs of returning the environment to an acceptable state. In addition, industrialised countries are in a better position to reduce emissions: they have the economic means to invest in climate change mitigation and the innovative capacity to realise emission reductions. However, from a rational-actor perspective, the question at stake is where the costs of the solution are lowest (Coase, 1986). Many of the industrialised countries are currently "locked in" a greenhouse gas intensive economy, through long-term investments made years ago, such as in transport infrastructure, energy-intensive industries and power plants, as well as the general inertness of the socio-technical energy system (characterised, for example, by Geels (2005)). Their mitigation unit costs (or abatement costs, usually expressed in US$ per tonne CO_2-eq reduced) are therefore generally higher than those in developing countries (Weyant, 1999; 2004a). After all, developing countries still need to do most of their investments in the relevant sectors and do not need to prematurely phase-out greenhouse-gas-intensive technology (IEA, 2008a).

The main incentive to prevent climate change is the avoidance of harmful impacts that result from the rise in global mean temperature (IPCC, 2007b). The extent to which these impacts are harmful depends on a number of factors, which differ greatly per country. Supported by initially patchy empirical and modelling evidence, from the beginning of the emergence of the climate change problem, it was assumed that developing countries, and particularly the poor in those countries, would bear the gravest consequences of climate change (Schelling, 1992). Evidence continues to emerge that confirms this conclusion (IPCC, 2007b); modelling of impacts of climate change on global food supply, for instance, shows a higher risk of hunger, particularly in Africa (Parry et al., 2005). High-income countries are generally less vulnerable, as their populations rely less on climate-dependent resources and economic activities, and resources are available to adapt to climate change impacts. Climate research across the board so far continues to strengthen the hypothesis that most damage resulting from climate change will fall to developing countries, whereas some industrialised countries may even see net benefits from the consequences.

In summary, the climate change problem structure is characterised by deep distributional imbalance: First, the vulnerability for climate change impacts is highest in countries which do not hold responsibility for the problem, while second, the cost of mitigating climate change is highest in those countries which are least affected by its consequences. The result is that most costs would accrue to industrialised countries, while their actions benefit developing countries most. Although for the world as a whole it appears to make economic sense to ambitiously address climate change (Stern, 2006; IPCC, 2007c), for those countries with low damage and high mitigation costs, there is a strong incentive to free-ride on any agreement that has emission reduction as its sole goal.

1.2.3 Rational actors and institutional design

In the field of international relations (IR), a branch of political science that studies foreign affairs and global issues, the relation between problem structures and demand for international institutions has been studied extensively from both rational-actor and constructivist perspectives (Keohane, 1984; Young, 1994; Fearon and Wendt, 2002).

Rationalism in IR (sometimes also called neo-liberalism (Snyder, 2004)) takes the self-interested nation state as the central actor. The only reason why self-interested nation states would join international cooperation is when it has a net value to them. The consequences for negotiation and agreement can be illustrated by game theory, as has been applied in IR by political scientists such as Martin (1992), and by economists like Carraro and Siniscalco (1993) and Cesar and de Zeeuw (1996). Because states operate in their own perceived self-interest, problems related to non-cooperative behaviour and free-riding, particularly in international environmental agreements, are plenty. It follows that for problems with a mixed or unclear interest structure, agreements are difficult to bring about (Keohane, 1988). Some claim that, in the case that an effective international agreement is reached, it would be in everyone's interest to live by it, so compliance is predicted to be high and enforcement not necessary (Chayes and Chayes, 1993). Others, however, indicate that, when agreed reluctantly, risks of non-compliance are high (Downs et al., 1996).

Whereas rationalism treats the international institution as an outcome of the exogenous environment, constructivism regards the institution as an endogenous, dependent variable that has an impact on the environment itself (Wendt, 1992). An example of how constructivism affects international institutions is the role of information. If an international institution provides new information, such as the IPCC does for climate change, it can change beliefs of nation states. This is not incompatible with rationalism in IR, as with changing beliefs, the rational judgment of the situation is also modified. Fearon and Wendt (2002), supported by Herrmann (2002) and Adler (2002), therefore regard the rationalist and constructivist approaches to IR as different methodologies rather than different theories.

Generalising, this thesis characterises the demand for an international institution on climate change mitigation in the case of rationally acting states that satisfice on their perceived self-interests. They do so using information on costs of solutions versus damage costs of the problem, and adjust their positions based on continually changing insights and new information.

In addition to qualitative economic analysis and IR insights, formal quantitative game theory coupled with climate models (as opposed to the more generalised game theory exercised by Martin (1992)) has been instrumental in simulating decisions made by rational actors in the provision of the global public good of climate change. The global public good situation is characterised by an absence of an international government that can enforce compliance with supplying the public good (Barrett, 1994). Cooperation hence needs to be realised through the continuing consent of every single actor and the stability that institutions offer once agreement is reached. Game theory is a suitable tool to analyse the former. Most studies on international environmental agreements point towards non-cooperative game situations and instable coalitions (see e.g. Carraro and Siniscalco, 1993). For climate change, given its problem structure, this is also the case (Barrett, 1998; Buchner and Carraro, 2005).

Since the agreement of the Kyoto Protocol in 1997, empirical evidence on the stability of emission reduction coalitions has become available, allowing for theoretical conclusions to be tested in practice (IPCC, 2007d; EEA, 2008). The Kyoto Protocol is an international agreement with emission reduction targets for industrialised countries (UNFCCC, 1997a). It also has several innovative carbon trading mechanisms, particularly the Clean Development Mechanism (CDM), to increase compliance flexibility, provide cost-effectiveness, and enhance voluntary engagement of developing countries (Nordhaus, 2001). The Kyoto Protocol was agreed despite the problem structure of climate change described in Section 1.2.2, which seems to speak against the distributional aspects as a relevant determinant for a stable coalition.

The effectiveness of the Kyoto Protocol, however, was weakened because of the distributional problem structure. Although it was finally ratified by almost all countries around the world, several important industrialised countries defected by declining participation or by not complying with its terms. The reasons those countries state for defecting are high costs of mitigation and shifting interests. The US delegation signed the Kyoto Protocol when it was agreed in 1997, but the US government decided not to ratify the Kyoto Protocol in 2001. It was clear, however, even before the negotiations were finalised that the US Senate would not agree to the Kyoto terms for reasons of economic impacts of US domestic emission reductions, and the lack of commitments for developing countries (US Senate, 1997). Canada, which ratified the Kyoto Protocol in 2002, emits greenhouse gases well above its Kyoto cap, and is unlikely to comply. The main reason for Canada's non-compliance is the rise of the greenhouse gas intensive tar sands recovery to an industry of great economic significance since the Kyoto reference year of 1990 (Environment Canada, 2006). In both cases, economic interests prevailed over climate change concerns.

A coalition to reduce emissions is clearly instable (Barrett, 1998; Buchner and Carraro, 2005). Game theory suggests one remedy for such instable coalitions: by linking an instable public good coalition with a stable club good coalition, the overall coalition may be stable (Yi, 1997). Club goods, contrary to public goods, only provide benefits to the members of the club. An example of a club good is a joint research programme, where a member of a research consortium gains access to all complementary research assets of all member firms, thereby conferring a competitive edge against non-member firms and reducing the profits of non-member firms. The stabilisation of the coalition by linking works as follows. International environmental agreements, such as agreements on greenhouse gas emissions reductions, typically provide a public good. A technology-oriented agreement typically provides a club good. Climate change coalitions based on emission reductions are typically not stable because of free-rider incentives inherent in public goods, but technology-oriented agreements, if they can exclude non-members from benefiting from technology innovation and diffusion, could be profitable and stable. Linking the negotiations about club and public goods might therefore enhance the profitability and stability of the linked coalition in comparison to the separate public good coalition (Yi, 1997).

If actors negotiating an international climate agreement act rationally, the climate change problem structure leads to a central barrier to international cooperation: a specific agreement to reduce emissions is not in the interest of those countries that are required to reduce their emissions most urgently. The public good of a stable climate will thus tend to be underprovided, since the self-interested satisficing behaviour will imply free-riding. Formal game-theoretic models support this finding (Barrett, 1998; Nordhaus, 2001; Buchner and Carraro, 2005), despite the stylised version of reality that they need to take as such models can only simulate rational actors. Although linking to other issue areas could under specific circumstances stabilise the a climate change coalition, this was not done in the Kyoto Protocol and the Kyoto coalition did demonstrate instability. This situation is expected to persist as long as an international climate agreement fundamentally lacks an enforcement mechanism (Barrett, 1994), or lacks reciprocity that modifies the incentives provided for countries to participate.

1.2.4 Reciprocity and the climate agreement

Koremenos et al. (2001), in their introduction to a special issue on rational design of international institutions, takes a rational-actor approach and explains the formation of international institutions (such as a climate agreement) as follows: "[we] treat institutions as rational, negotiated responses to the problems international actors face". By implication, the rules of the institution must be what they call "incentive compatible", i.e. should provide participation incentives for all parties (Koremenos et al., 2001), in the absence of means to coerce. This can be applied to climate change and the discussion above, and leads to the conclusion that the only way of providing countries that incur high net costs of reducing emissions with incentives for participation in an international agreement is to provide them something in return; in other words, to provide reciprocity. As every single party should participate in the coalition to mitigate climate change, every single party should perceive reciprocity, regardless of whether it is a developed or a developing country.

Keohane (1984; 1986) argues that reciprocity is "the most effective strategy for maintaining cooperation among egoists". He defines two types of reciprocity. The first is specific reciprocity, which refers to exchanges of items of equivalent value in a specified sequence. If specific reciprocity is part of an international treaty, compliance is easily determined as there is limited room for interpretation and no ambiguity in the commitments made vis-à-vis another party. An example of this was the General Agreement on Trade and Tariffs (GATT), the predecessor of the World Trade Organisation (WTO). GATT (and WTO for that matter) has reciprocity as one of its guiding principles, has made the terms of reciprocity specific to the trade context, and has installed clear and enforceable conflict resolution mechanisms to enable countries to reciprocate in a specific way (Bagwell and Staiger, 1999).

In most international institutions, however, reciprocity is not specific. This may be because the issue area is too complex, because there are large uncertainties on the issue or the outcome, because the number of actors is exceedingly large (192 countries in the UNFCCC) and diverse, the equivalence of actions cannot be strictly established, or the sequence of events cannot be narrowly defined (Keohane, 1986). Many international cooperation problems have at least one of these characteristics. The second type of reciprocity, diffuse reciprocity, is therefore far more common in international institutions, and climate change is no exception. Despite the efforts to make climate agreements measurable and verifiable (UNFCCC, 1997a), it remains challenging to determine the equivalence of commitments, as the negotiations around the Kyoto Protocol have shown.

The broadest way of regarding diffuse reciprocity is Keohane's (1986) description of "conforming to generally accepted standards of behaviour". As such, diffuse reciprocity in its pure form is about social norms rather than about living up to specified obligations. In many studies on reciprocity, individuals are taken as an experimental subject. Assuming they act as rational actors, their behaviour can be used as a proxy of states in international negotiations. An example of diffuse reciprocity are groups of friends, which, according to Berenskoetter (2007), and Fehr and Gächter (2000), are based on reciprocated goodwill, and have little in common with a tit-for-tat situation in specific reciprocity. Larson (1988) relates psychological issues to international negotiations, and identifies trust as an important factor for reciprocity, and a condition for collective action based on diffuse reciprocity. She supports her claims with examples from the cold war and makes a number of interesting observations that can partly be applied to the climate change case. First of all, the motives and intentions behind a state's pledged concessions or defections determine whether other countries will reciprocate – whether they will reward or punish the behaviour of the acting state. If there is trust in the genuineness of motives and if the intentions correspond to those of the state that might reciprocate, there is a higher likelihood of cooperation.

Confidence of a state in whether a concession of another state is genuine is influenced by a number of factors (Larson, 1988). First, the actors should determine whether a move is part of a meaningful pattern, so whether positive reciprocity leads to more cooperation, or whether the other actor is likely to free-ride next time. There needs to be some consistency in the actions. Second, are there real costs associated with the move, is there some depth of cooperation? If a move by an actor implies only small costs, its intentions are less credible and reciprocation is unlikely. A third factor is additionality. Suppose that an actor is likely to do the concession anyhow for a certain reason, but attributes the move to another reason for which it requests positive reciprocal action from other actors. In this case, the move of the actor is less credible and less likely to be rewarded[2].

Most international agreements have elements of both specific and diffuse reciprocity. A review of international environmental agreements and their problem structures reveals that there are two mechanisms to reciprocate in order to ensure compliance with the treaty: coercion or positive exchange (meaning reward, or "transfer" in the economic literature (Altamirano Cabrera, 2007)) (Mitchell and Keilbach, 2001). Which mechanism is used in a treaty depends on the circumstances: on the position of the perpetrator and the position of the victim. In the case of a "strong victim", in a position to excert power over perpetrators, coercion, such as imposing sanctions, is an option. In the case of a weak victim state, rewards can provide reciprocity to the perpetrator, usually in the form of side-payments to compensate for the costs of addressing the problem. For rewards, however, the victims need to have the resources to provide the side-payments, which is often not possible for developing countries.

In the case of climate change, as argued in Section 1.2.2, the victims – countries experiencing the greatest climate vulnerabilities and damage costs – are mostly least-developed countries. These countries are neither strong nor rich and are hence neither able to enforce compliance by large-emitting countries, nor are they able to afford compensation through side-payments to these countries. Indeed, this option would be regarded as perverse to most of those involved in the international climate regime. Coercion or rewards are therefore not options (Barrett, 2003). As enforcement by the international environmental institution is also not possible (Downs et al., 1996), an effective international agreement to mitigate climate change will have to be set up in such a way that it is self-reinforcing, i.e., that it is "attractive for countries to want to sign, and want to carry out the terms of agreement" (Barrett, 1994). This means that the agreement needs to provide additional means of reciprocity.

Agreements can provide reciprocity to its signatories in three ways. First, the solution to the climate problem provides some inherent reciprocity for a state that has both high emissions and is prone to incur high net damage costs – that state would be certain to benefit from the agreement. It becomes more challenging for those perpetrators that perceive high costs and low benefits. For those states, reciprocity is not provided by preventing climate change.

[2] To relate this to the climate change, there are examples from both sides of the negotiation range from the Kyoto Protocol period. Germany and the United Kingdom, who pride themselves on taking on stringent emission reduction commitments, had actually already reduced their emissions significantly since 1990. Germany had reunified and benefited from economic restructuring in the former DDR, leading to a decline in emissions. The United Kingdom had just had its "dash for gas", which was accompanied by fuel switching from coal to gas, which coincidentally also reduced greenhouse gas emissions. With United States scholars and negotiators, these issues are often hailed as the "Kyoto windfalls" of the European Union and are used to argue that the Kyoto commitments are much harder on the United States than on the European Union. Another example is the Asia-Pacific Partnership on Clean Development and Climate (APP). When Bush Administration initiated the APP, it had a record of frustrating international efforts to reduce emissions, and there was no confidence that the United States had the genuine intention to address climate change. In addition, the costs of the APP were very low and there were suspicions that the United States had ulterior motives: the APP provided its industry involved in clean environmental technology access to large markets in emerging economies. These factors of intentionality, costs, and ulterior motives provoked the perception with the European Union that the APP was not a serious attempt to form a treaty that mitigates climate change.

The second path is through co-benefits and spill-over effects (Barker et al., 2007), or expected positive consequences of the mitigation actions agreed in the agreement, in other policy fields. Such co-benefits of climate change mitigation might provide an incentive for some parties to agree on mitigation actions, and comply with them. Energy efficiency and renewable energy, for example, can lead to improved security of energy supply and to better air quality. In order to contribute to reciprocity needs, these co-benefits need to be visible and specific, and they need to be recognised as co-benefits by countries. The extent to which co-benefits are helpful depends on the specific country context. This can go two ways: although most countries could distinguish co-benefits, others experience substantial negative effects associated with mitigation actions, in particular fossil fuel exporting countries. In general, the reciprocity that co-benefits provide is insufficient or insufficiently recognised by countries.

The third path of reciprocity relates to the inherent design of the agreement: what the agreement regulates, or the formal institutional goal. In the Kyoto Protocol, the formal institutional goal is the capping of emissions. Section 1.2.2 discussed that the inherent incentive provided by emission reductions as such is insufficient for a number of countries to ensure continued participation; it does not lead to a self-reinforcing agreement. By revising the formal institutional goal to low-carbon technology innovation and diffusion, emission reductions may be achieved through low-carbon technology, while reciprocity may still be perceived by those states otherwise deterred by the high costs of mitigation but interested in technological innovation. The next section focuses on the possibilities of technology innovation and diffusion as an alternative formal institutional goal in an international climate agreement.

The relation between the perceived costs, benefits, co-benefits and remaining required reciprocity is illustrated schematically in Figure 1.1.

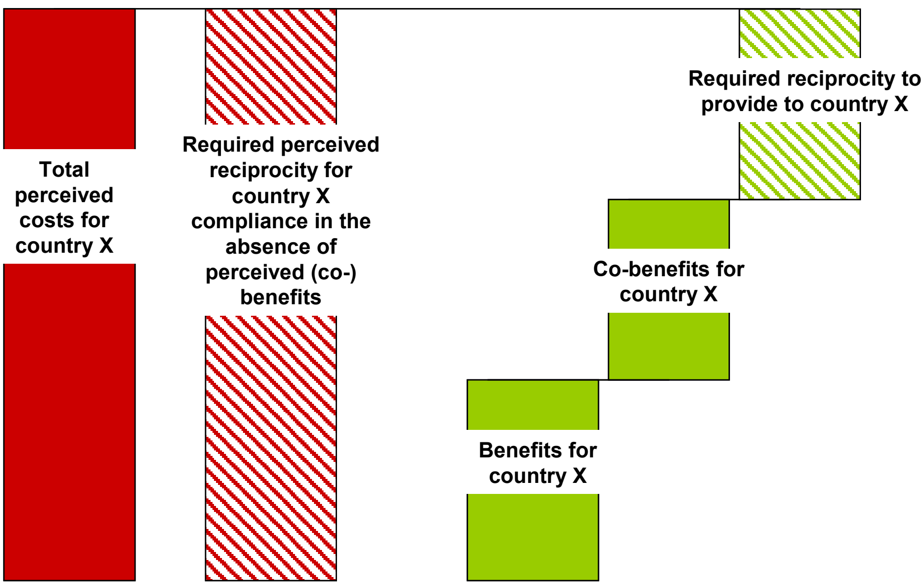

Figure 1.1 Simplified representation of the perceived costs of a problem and the reciprocity provided in the case of no perceived benefits or co-benefits by the perpetrating country X (left bars), and the reciprocity that needs to be provided if country X experiences benefits from solving the problem as well as co-benefits (right bars)

1.2.5 Technology as a potential means to provide reciprocity

What might be the reciprocity that could be provided along with mitigation actions? A look at the causal chain of climate change might be useful and what kind of formal institutional goal can be tied to each link in the chain. A simplified picture is given below.

Climate change causal chain	Example of formal institutional goal
Global Mean Temperature ↑	EU: keep global mean temperature rise below 2ºC
Greenhouse gas concentration ↑	EU: global 450 parts per million
Greenhouse gas emissions ↑	Kyoto Protocol: National caps: allocated amount relative to 1990 levels
Technology innovation and diffusion ↑	Various EU Member States; US States: Renewable portfolio standards as percentage of total electricity consumption
Economic activities and human behaviour	Mexico City (for air quality): "Hoy no circula": prohibit driving for certain number plates on certain weekdays

Figure 1.2 Climate change causal chain and how the different factors relate to potential formal institutional goals

Global mean temperature and greenhouse gas concentration are global units. As nation states are the actors in international agreements, and their perpetrating action is the emission of greenhouse gases, it is not possible to allocate commitments among nations for global mean temperature and atmospheric concentrations of greenhouse gases. The only possibility is that there is a collective agreement that climate change should remain, for instance, within a global mean temperature rise, but such an agreement would necessarily be legally soft, unspecific and ineffective as it is not possible to oblige a single country to prevent its share of e.g. 0,1ºC temperature rise. It would be comparable to Article 2 in the UNFCCC, which pledges prevention of "dangerous human interference with the climate system". In addition, global mean temperature and greenhouse gas concentrations as formal institutional goal would have the same incentive and free-rider problems as the current international regime that primarily regulates greenhouse gas emissions.

For a rational institutional design encouraging participation and compliance by coalitions of states, it is therefore necessary to look further down the climate causal chain, at what causes greenhouse gas emissions and what would generate emission reductions. We then arrive at technology as both a cause of and a solution to greenhouse gas emissions, and, lastly, economic activities and human behaviour. Both are factors that can be addressed, as the examples in Figure 1.2 illustrate, on the nation-state or at the sub-national or urban level. The question of the appropriate level of governance is investigated in an extensive literature on decentralisation versus coordination, and whether policy responses to global problems can be decentralised to lower authorities which are in a better position to align them with the local situation (see e.g., Hyden, 2002). In addition, the relation between a country (which negotiates an international agreement) and its firms (which are the holders of the both the greenhouse gas-emitting and greenhouse gas-reducing technologies) would have to be taken into account when a climate agreement has technology innovation and diffusion as its formal institutional goal (Bazilian et al., 2008). However, as the topic of this thesis is an international agreement on climate change, and such agreements are made between nation states, the governance level discussed here will be the nation state.

It is the focus of this thesis to explore whether innovation and diffusion of low-carbon technology can provide reciprocity in an international climate agreement by making it the formal institutional goal. This topic has emerged on the climate change negotiations agenda (UNFCCC, 2007; Bazilian et al., 2008). Throughout this thesis, technology, or technology innovation and diffusion, means "know-how, methods, procedures, experience of successes and failures, physical devices and equipment" (Dosi, 1982) to reduce greenhouse gas emissions. If accelerated innovation and diffusion of technology is to provide reciprocity, it should be seen not only as a means to reduce greenhouse gas emissions but as an opportunity for innovation and a more sustainable energy system (Bazilian et al., 2008).

The Dosi definition provides insight in what kind of returns, or reciprocity, technology innovation and diffusion could provide, and is roughly consistent (although the wording is different) with other taxonomies such as the "hardware, software and orgware" (Fodella, 1989). First, the hardware includes physical devices and practices but also infrastructure such as highways, railways, pipelines, or the electricity grid. The reciprocity hardware might provide is mainly favourable for those countries that would produce hardware and would be able to benefit from exporting, thus adding value and competitiveness, and generating employment. A clear example how this can lead to self-reinforcing policies can be found in the field of solar and wind energy in Germany and Denmark (Steiner Brandt and Tinggaard Svensen, 2006; Jacobsson and Lauber, 2006; REN21, 2008) – by creating industries and employment, new vested interests are created. In the context of low-carbon technology, given the current market (REN21, 2008), mainly developed and some well-placed emerging economies could be provided with reciprocity through enhanced exports, competitiveness and employment.

The software, secondly, includes know-how and methods, as well as experiences of successes and failures, summarised in the term human capabilities (Lall, 1992). Comparisons show that the lack of human capacity is a much greater barrier to technology adoption in developing countries than for developed countries (Worrell et al., 2000). As an area to provide reciprocity, human capabilities may be most desired by developing countries, which is also reflected in submissions by the developing country negotiating block, G77+China, to the UNFCCC (UNFCCC, 2008a).

Lastly, "orgware" (Fodella, 1989) refers to the institutional context, such as procedures and institutional infrastructure, on the international, national and local level. North (1990) defines institutions as "human-defined constraints that shape human interaction". The term "National Innovation Systems" provides a way to operationalise orgware, institutions and technology innovation (OECD, 1997). There is no single definition for National Innovation Systems, but the Lundvall (1992) definition is most commonly used: "the elements and relationships which interact in the production diffusion and use of new, and economically useful, knowledge (...) and are either located within or rooted inside the borders of a nation state". It includes the functioning of markets, firms, and research institutions, and the ability of governments to shape markets and manage projects. Pretty and Ward's assessment of social capital (2001) also combines elements of software and orgware. Whether the term used is orgware, National Innovation Systems and or social capital, there is a clear overlap between institutional issues and human capabilities present in a country (Reddy, 1991).

After reaching agreement on technology innovation and diffusion, countries that have or expect a strong market position for their industry in the field of the technologies that will be implemented as a result of the agreement are likely to be supporters and active implementers of the agreement. They are unlikely to free-ride. Although the source of their confidence may be first-mover advantages, defined as "the ability of pioneering firms to earn positive economic profits" (Liebermann and Montgomery, 1987), even if more countries boast industries in the same sector (e.g., several European, North American and Asian countries have wind turbine producers), a far-reaching agreement on that sector would signify growth in all those countries. Countries tend to be optimistic about their industry's ability to provide such leadership, and thus perceive first-mover advantages. Such perceived first-mover advantages could give confidence that the agreement leads to benefits for a country and its industry.

One of the reasons why technological change is so hard to bring about is all of these factors need to be aligned and managed at the same time, putting significant requirements on governments and are therefore difficult to realise (Rock et al., 2008). However, once a path of technological change is taken, it tends to reinforce itself. This self-reinforcing nature of technological change finds confirmation in economic and social-science literature, and has been referred to as 'path-dependency' (David, 1985), 'technological momentum' (Hughes, 1983), and 'technological lock-in' (Arthur, 1989; and Rosenberg, 1994). A treaty that aligns with (new or vested) interests of parties otherwise not interested in emissions reductions would therefore more likely be self-reinforcing. This would be one of the reasons why technology innovation and diffusion and their establishment in an international agreement could be seen as an opportunity, or a reward, rather than a cost.

Lastly, the economic literature around what explains differences in economic growth between countries provides support for technology innovation and diffusion as a reward. Why some countries are developing successfully while others lag behind has been the subject of decades of study, and this, according to Ruttan (2002), resulted in a conceptualisation of innovation to the economic literature that can be seen as technology innovation providing reciprocity. Innovation, in firms or in entire economies, shifts in the "Innovation Possibility Curve", which defines the amount of income that can be generated given and thus potential for economic growth (Solow, 1957). Learning processes that shift this curve enable income growth, which is an underpinning from economic theory for the hypothesis that technology innovation and diffusion could provide more specific reciprocity and could be an incentive for participation in an international climate agreement.

If cooperation around technology innovation and diffusion is introduced as a climate agreement building block, alongside or in place of emission reduction targets, the question of what kind of technology policy is effective arises. Technology policy is traditionally divided into demand-pull and technology-push policy (see, e.g., Mowery and Rosenberg, 1979). Although early empirical work seems to conclude that demand-pull arguments dominate innovation, this conclusion was severely criticised on methodological grounds, and a consensus has now emerged that that the one cannot work without the other and demand pull and technology push need to be applied in an appropriate mix (Mowery and Rosenberg, 1979; Ruttan, 2002). In technological change to mitigate climate change, the demand pull is generally assumed to be provided by carbon markets, regulations and changing market preferences for low-carbon goods and services, while technology push is given by for instance national R&D programmes and grant support. Also in an international agreement focusing on technology innovation and diffusion, an appropriate mix of pull and push measures can be applied, whereby a technology mandate or standard can be seen as a "technology-pull" which has been applied in a number of international environmental agreements (Coninck et al, 2008a).

If technology innovation and diffusion is to improve participation and compliance in an international climate agreement, it should provide reciprocity to all countries, developing and developed alike. Such universal reciprocity would have to work in all directions – industrialised countries should provide reciprocity to other industrialised countries, as well as to developing countries, developing countries should provide reciprocity to industrialised countries as well as to other developing countries. Their interests, however, diverge; the lack of detailed data on the different economic histories and geographical circumstance of different countries prohibit generalisations. Arriving at a consensus that is sufficiently appreciative for all parties is a delicate and complicated matter. Hence, it is a necessity to focus the analysis on a few large emitters as the most important players.

In most cases, country conditions are specific and it is not appropriate to generalise across countries even if they have similar characteristics. On the issue of technology transfer in the context of a post-2012 agreement, however, developing countries take a clear stance and argue without exception for a much greater emphasis on making available technology and enhancing human capabilities. Partly because of the rapidly changing economic and technological position of emerging economies, and despite the extensive literature that has generally been appreciative of both developing and developed countries' views on technology transfer (Reddy, 1991; Lall, 1992; IPCC, 2000a; Karani, 2001; Forsyth, 2005; Andersen et al., 2007), a deep divide between developed and developing country positions on technology transfer seems to remain. Ockwell et al. (2008) study these "discourses" based on the issues of Intellectual Property Rights (IPRs) and concludes that, although there is some evidence towards straightforward solution to the difficulties (Barton et al., 2007), the differences in discourses are the main source of the disagreement. To date, evidence regarding the role of IPRs in the climate change technology transfer area is very limited and provides an insufficient basis on which to conclude that IPRs currently pose a significant barrier to the transfer of climate-friendly technologies (e.g., Barton, 2007; Lewis and Diringer, 2007). On the specific issues of IPR, as an example, the different discourses remain a barrier to a way out of the debate (Ockwell et al., 2008).

1.3 Research questions and hypothesis

The overall objective in this thesis is to contribute to the academic debate on institutional design of international climate change agreements by exploring the role the international technology policy could play in strengthening such agreements. More specifically, it aims to explore whether technology-oriented agreements can provide for greater reciprocity and as such improve the effectiveness of the international regime for climate change mitigation. The central question this thesis attempts to answer is:

Can technology-oriented agreements provide greater reciprocity and thus improve the effectiveness of the international regime for climate change mitigation?

This thesis tests the hypothesis that, indeed, technology-oriented agreements can improve the international climate change regime by providing reciprocity. The central question can be decomposed into several sub-questions, which, respectively, discuss the theoretical context in which technology-oriented agreements could provide reciprocity, describe the structure and functions of technology-oriented agreements, compare them to the existing emission reduction-based climate agreement and inspect how technology-oriented agreements might be institutionally embedded.

Specifically, we are concerned with whether and how innovation and diffusion of technology would provide sufficient reward for countries taking a rational actor perspective to participate and comply, given their complex and continually changing interests. Second, the question arises what design characteristics define technology-oriented agreements realised to date, whether they have met their goals in the past, and with what environmental and cost effectiveness. Third, if technology-oriented agreements are to improve the effectiveness of the climate regime, how do they compare to the current climate regime? The current regime, the Kyoto Protocol, is based on emission reduction targets and the possibility of emissions trading. What are the advantages and disadvantages of the Kyoto Protocol, and how does it compare to technology-oriented agreements? Fourth, what is the institutional dynamic that arises when technology-oriented agreements become part of a climate regime? For this question, it matters whether technology-oriented agreements would be implemented on their own or alongside emission targets. If they are implemented independently, can they be environmentally and cost effective? If technology-oriented agreements are implemented alongside emissions targets, how would they influence the emissions target agreement and vice versa? Would there be a fragmentation of the climate regime by including various types of agreements, would this be a bad thing and, if so, how could this be addressed?

1.4 Methodology

A schematic overview of the approaches, methods from sociology, economics, engineering and international relations, chapters and topics is given in Figure 1.3. This scheme provides a high-level overview of approaches taken in this thesis. From left to right, the flow represents a rough approximation of the policymaking process: from theory and design to practical implementation and evaluation, to ex-ante evaluation.

On the left of the scheme, in Chapter 3, the theoretical underpinning for asking the central research question is given. This is done by applying the rational design of international institutions to climate change and by studying issue linkage with technology innovation and diffusion. By examining issue linkages between mitigation on the one hand, and energy security, air quality and poverty on the other, it is then evaluated whether issue linkage would provide co-benefits leading to participation and compliance (Chapter 4).

The middle two panels in the scheme summarise the empirical and comparative work in the thesis. Where other studies have covered the Kyoto Protocol performance, Chapter 5 discusses the performance of past technology-oriented agreements. Chapter 6 uses comparative analysis to contrast market-based variants of post-2012 agreements and policy instruments with technology-oriented approaches. Chapter 7 does the equivalent for specific technology transfer policies.

The forward-looking chapters in the right panel look explicitly at the institutional consequences of a post-2012 climate regime that is composed of various technology-oriented and emission reduction-based agreements. Chapter 8 designs six hypothetical technology-oriented agreements and discusses their reciprocity-related features. Chapter 9 discusses how technology-oriented agreements can be embedded into the current UNFCCC regime, what their interaction with emission reduction-based agreements would be, and explores consequences of regime fragmentation.

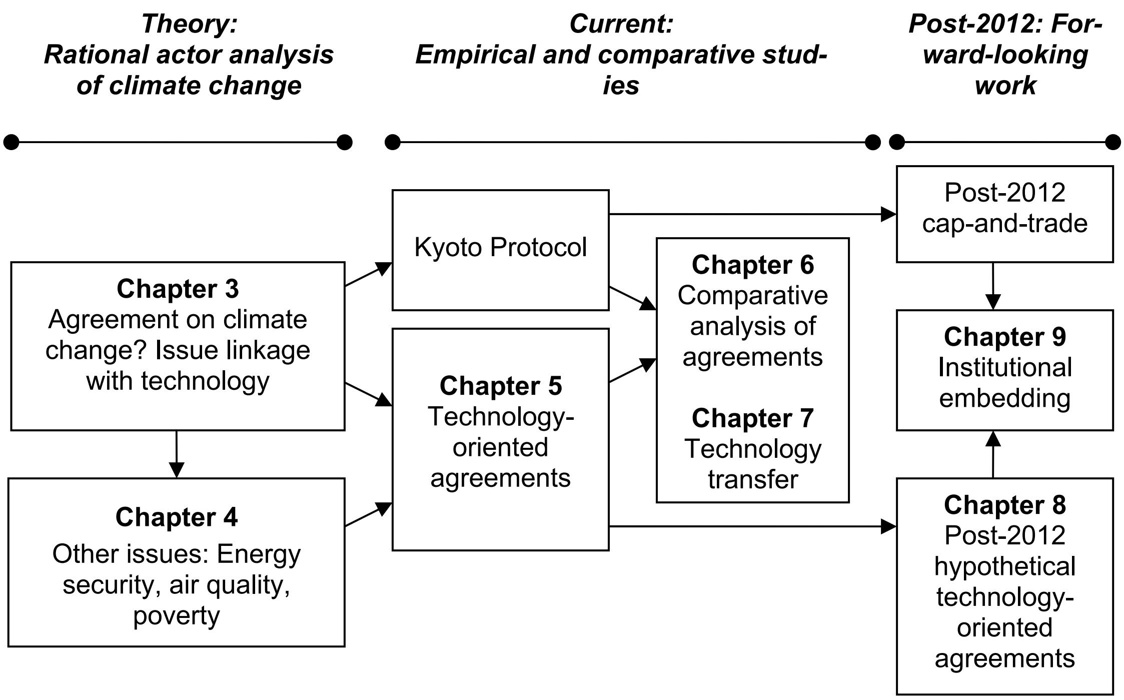

Figure 1.3 Schematic overview of the approaches, methods, chapters and topics in this thesis. Chapter titles and relations in this thesis contrasting emission reduction-based approaches for a post-2012 regime with technology-oriented approaches. Chapter 3 and 4 are primarily theoretical, Chapter 5 to 7 test the theory through empirical research, and Chapter 8 and 9 explore and project possible future developments and consequences.

1.4.1 Structure of the thesis: Theoretical work

Chapters 2, 3 and 4 explore theoretical arguments of why to regard technology innovation and diffusion as formal institutional goal and design feature for climate change agreements. Those chapters form a necessary basis to answer the more practical and policy-relevant research questions in Chapters 5 through 9.

Chapter 2 introduces some essentials on climate change for the reader that is unfamiliar with the basics. Chapter 3 builds on the rational-actor literature with regard to institutional design to explain why an international climate change agreement based solely on emission reductions is unlikely to generate sufficient participation and compliance. This argument has been made using game theory and was empirically investigated in papers on rational institutional design (Mitchell and Keilbach, 2001), describing how actors have found ways around the free-rider problem in existing international environmental institutions through applying either coercion or exchange.

Apart from solving the compliance problems within the climate change regimes, an agreement could be broadened or linked to other issue areas in order to generate the reciprocity that is required for the treaty to be come self-enforcing, i.e. "to be attractive for countries to want to sign, and want to carry out the terms of agreement" (Barrett, 1994). Chapter 3 will also explore the issue-linkage argument towards technology innovation and diffusion. From a rational-actor perspective, the view on the desirability of technology-oriented agreements is determined by the first-mover advantage-induced payback function on technologies that are developed and exported. In reality, however, rational actors face bounded rationality; they cannot act fully rationally as they do not have complete information or a perfect ability to act on information they do have. Firm actors (technology developers) continually search for opportunities to innovate with the aim of market advantage. Technology innovation is therefore an inherent incentive. Countries can be seen to behave similarly, with the aim of economic growth and development. The benefits of technology innovation and diffusion do not only accrue to the first mover alone; also subsequent innovators gain. The payback function, and hence the actor behaviour, is favourably changed because of larger *perceived* advantages with all actors, the attractiveness of a technology-oriented agreement would increase. Introducing incomplete information and uncertainty might therefore improve the perceived reciprocity in an agreement.

We have argued above that reciprocity is can also be provided by co-benefits. This is further investigated for climate change in relation to the fields of energy security of supply, air quality, and poverty in Chapter 4. The perspective taken is that of substantive policy and measures, and institutional issue linkages. Chapter 4 does not only look at mitigation (which is the focus of this thesis) but also at adaptation, whose characteristics lead to some quite different insights than for mitigation.

The fields investigated in Chapter 4 show that it is not easy to link climate change with any field providing co-benefits. Chapter 3 therefore explores whether technology innovation and diffusion could provide reciprocity. Technology-oriented agreements have been explored as such a potential issue linkage, but it was concluded that technology does not provide enough incentives for participation, nor sufficient greenhouse gas reductions on its own to reduce emissions substantially (Buchner and Carraro, 2005). This analysis, however, was based on the strict rational-actor grounds that game theory prescribes and was modest in valuing the gains of technology innovation and diffusion. Chapter 3 takes a more evolutionary approach and discusses technology innovation and diffusion when states act with bounded rationality.

1.4.2 Structure of the thesis: Empirical and comparative studies

Empirical data from past and present technology-oriented environmental agreements could help establish how technology innovation and diffusion could be incorporated in the climate regime. Chapter 5 first defines technology-oriented agreements (and outlines what they are not), describes a potential taxonomy, and discusses, based on a qualitative criteria analysis, the performance of international technology-oriented agreements in other environmental fields, such as renewable energy in the European Union, technology transfer in the Montreal Protocol and marine oil pollution treaties.

Once it is clear what technology-oriented agreements might be, their general characteristics can be compared with those of market-based regimes such as the Kyoto Protocol. In Chapter 6, comparative analysis is used to make distinctions between the main characteristics of market-based regimes and technology-oriented agreements, and the consequences of those differences for cost effectiveness and participation. The cases of market-based regimes are the Kyoto Protocol and a hypothetical global carbon tax, while the technology-oriented agreements are based on the types described in Chapter 5.

A special question relates to technology and its application in developing countries. Challenges around technology transfer are different in developing countries than in free-market, developed economies, as problems around knowledge and capacity, governance and institutions, and effectiveness of policymaking are of a different order. Chapter 7 performs an analysis similar to Chapter 6, but focuses on the issue of technology transfer to developing countries. The chapter will compare empirical technology transfer results of the Kyoto Protocol's Clean Development Mechanism, as an example of a market-based mechanism, with the results of the Global Environment Facility, a fund-based mechanism for technology transfer.

1.4.3 Structure of the thesis: Forward-looking work

Whether technology-oriented agreements would work in practice depends on a large number of factors and uncertainties. Informed by the theoretical considerations around the role of technology in the climate change regime, and the empirical findings of existing agreements, Chapter 8 explores what concrete technology-oriented agreements may look like through designing six hypothetical technology-oriented agreements: in the fields of ammonia production, sugarcane-based bio-ethanol, carbon efficiency in cars, cement, CO_2 capture and storage (CCS), and nuclear energy. For each of these hypothetical agreements, the main characteristics are set out, while assumptions on technological feasibility, economics, country participation and emission reductions allow for a political feasibility assessment based on a factor/constraints framework.

In Chapter 9, a different but potentially important question is posed. If technology-oriented agreements are implemented, how will they function in the complex institutional context? The premise of this chapter is that technology-oriented agreements might have to be embedded in a climate regime that simultaneously pursues cap-and-trade variants. The interactions will be discussed through a matching exercise between two of the technology-oriented agreements designed in Chapter 8 (the bio-ethanol and CCS cases) and two cap-and-trade variants by identifying their characteristics and where they impact on the goal attainment of the other type of agreement. The chapter will also explore the consequences of fragmentation of the climate change regime, which is an ongoing debate in international relations and international law. Chapter 10, finally, provides a discussion of the research questions and puts this thesis in the context of the ongoing climate negotiations.

The overview below summarises the research questions and the chapters where they are primarily addressed.

Research question	Chapters where the question is addressed
1. Would innovation and diffusion of technology would provide sufficient reward for countries taking a rational actor perspective to participate and comply, given their complex and continually changing interests?	Chapters 3, 4, 8, 10
2. What design characteristics define technology-oriented agreements? Have they met goals in the past and what have experiences been in terms of environmental and cost effectiveness?	Chapters 5, 8, 10
3. If technology-oriented agreements are to improve the effectiveness of the climate regime, how do they compare to the current climate regime of the Kyoto Protocol? What are the advantages and disadvantages?	Chapters 6, 7, 10
4. What is the institutional dynamic that arises when technology-oriented agreements become part of a climate agreement?	Chapters 3, 9, 10

Chapter 2 Background: setting the scene for technology and climate

Climate change, global warming, the enhanced greenhouse effect. They are all more or less popularised terms for the same problem: the rising global mean temperature of the world as a consequence of human-induced higher atmospheric concentrations of greenhouse gases. Although the nature of this thesis is predominantly political science-based, this chapter explains how climate change works physically and aims to give the essential background to understand the political responses and the terms used throughout.

2.1 The climate change problem[3]

The problem of climate change has several components: the physical causes, the estimation of impacts, and their distribution (IPCC, 2007a). The physical causes of climate change lay in the energy, or radiative, balance of the Earth (see Figure 2.1), and have been known for a long time (Arrhenius, 1896). Incoming solar radiation consists of short-wave ultraviolet radiation, which greenhouse gases cannot absorb. However, once reflected on the Earth's surface, the ultraviolet is converted into long-wave infrared radiation, which is in the absorption spectrum of molecules like carbon dioxide (CO_2) and methane (CH_4). The infrared radiation is thus partly absorbed by such molecules, leading to capture of energy in the atmosphere.

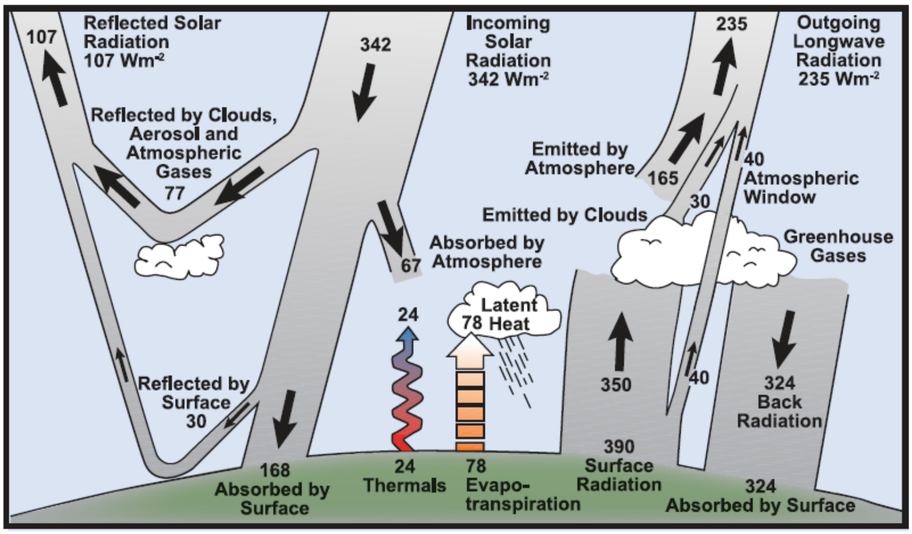

Figure 2.1 Overview of the Earth's annual and global mean energy balance. All numbers are in W/m² (IPCC, 2007d)

As the gases that absorb in the infrared act similar to the glass roof of a greenhouse, these gases are called greenhouse gases. Without them the average temperature on Earth would be much lower, around -15°C, and life on Earth, which relies on liquid, not frozen, water, would probably not have developed into its present form. Enhancing the concentrations of these greenhouse gases, however, leads to a shift in the energy balance of the Earth. This shift in radiative balance is called the enhanced greenhouse effect, and is held responsible for climate change.

The greenhouse gases, pictured on the far right in Figure 2.1, absorb the energy in the outgoing infrared radiation and transform it to heat. There are a number of greenhouse gases and also other substances in the atmosphere that can trap heat. The most important greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the halocarbons (CFCs, HFCs and

[3] Much of this section, including the pictures, is derived from Working Group I and II contributions to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007b; 2007d).

PFCs), as well as tropospheric ozone. Gaseous water is also an important greenhouse gas, but its phase distribution and short atmospheric residence time make it less relevant as a cause of climate change. In its liquid form in the atmosphere (clouds) water reflects solar radiation and has a cooling effect. A number of gases and aerosols can actually cool the Earth's surface by reflecting solar radiation, preventing its transformation to infrared and absorption by greenhouse gases.

As greenhouse gas concentrations increase, the amount of absorbed heat also increases. The question is whether the increase is sufficient to make a difference and to call the observed rise in global mean temperature "man-made". Figure 2.2 shows the annual increase in concentrations of CO_2 in various years, indicating that every year, the concentration has been rising by roughly 1 – 2 parts per million (ppm). CO_2 concentrations, in 2005 responsible for about 60% of current additional greenhouse gas forcing, have risen from around 280 ppm in 1850 to about 380 ppm in 2005; an increase of over a third. Methane concentrations have more than doubled in that same timeframe, and N_2O has increased by some 18% (IPCC, 2007d).

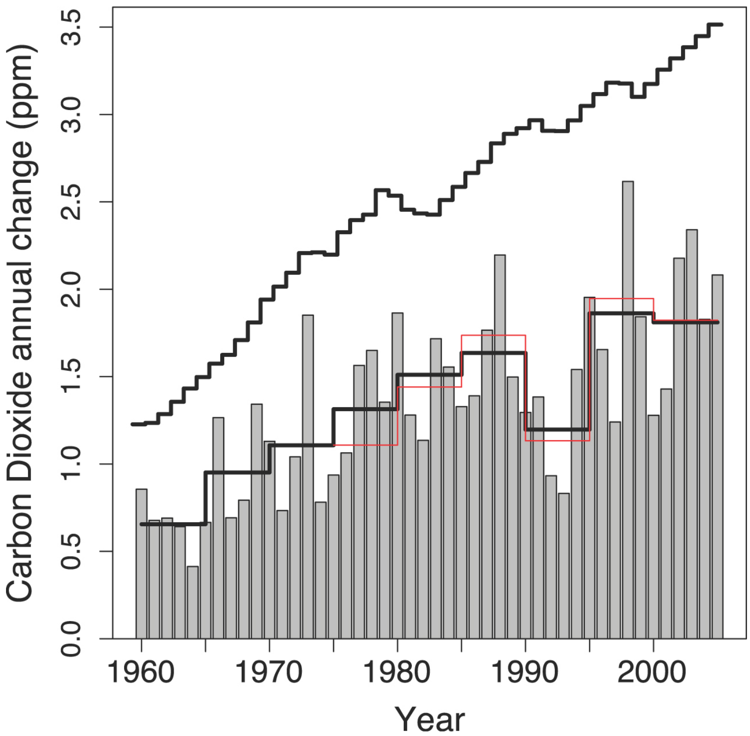

Figure 2.2 Compilation of changes in CO_2 concentration in the atmosphere based on measurements from 1960 – 2005, from different measurement stations. The grey bars are the annual concentrations, and the lower black and red lines the five-year mean which smoothens some of the short-term variations associated with large meteorological events such as El Niño. The top black line shows the change in concentrations had there been no uptake of CO_2 by the terrestrial biosphere and oceans. (IPCC, 2007d)

The relation between greenhouse gas concentrations and global mean temperature is shaped by a number of complex processes in the atmosphere, including interaction between the atmosphere, the biosphere, the oceans and other water bodies, and the cryosphere. It requires advanced and complex models to project global mean temperature changes from greenhouse gas emissions. Complicating factors are the capricious water cycle and complex variations in solar influx. Models cannot simulate such processes perfectly, but they are able to explain the measured temperature rise (see Figure 2.3) only by counting with the greenhouse gas concentrations (IPCC, 2007d; for an example of the underlying work: Barnett et al., 2005). This provides a strong indication that the temperature rise is indeed partly man-made. Other indicators, such as ecosystem responses, also show the human footprint (Parmesan and Yohe, 2003).

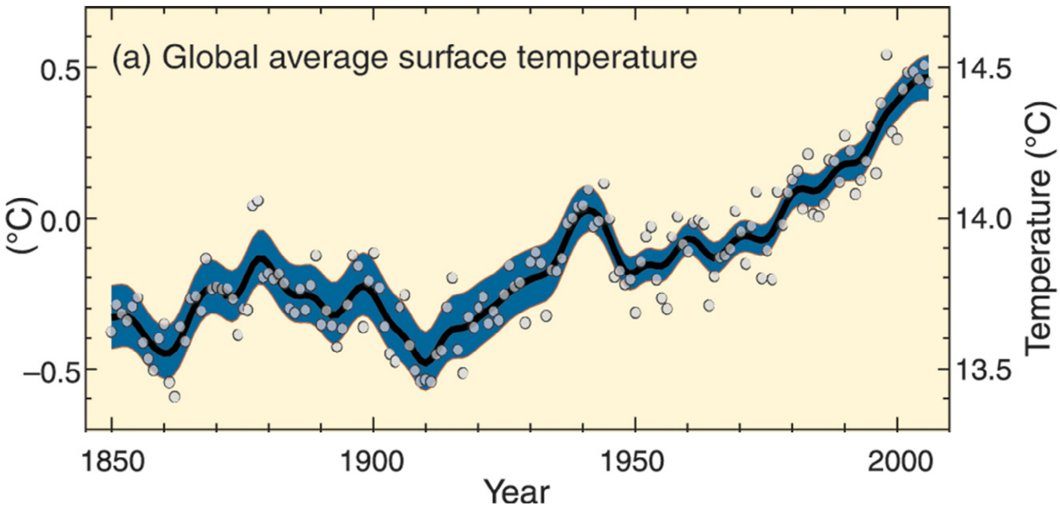

Figure 2.3 Global average temperature changes 1850-2004. The left axis shows the 1961-1990 anomaly; the right axis the actual temperature (IPCC, 2007d)

Although the IPCC's assessment shows that the global mean temperature rise cannot be explained without taking human factors into account, not all sceptics have succumbed to the climate change hypothesis. Ever since climate change reached the policy agenda, the field has been characterised by extensive debate. There have been allegations that doubts of the theory were mainly spread by fossil fuel industries and climate-sceptic governments, similar to the initial denial of the tobacco industry that its products harm health (Gore, 2006). Leaving this accusation aside, and looking at the arguments, one can see that the initially dynamic sceptics movement has currently run out of steam. The arguments however also show that large uncertainties about the climate system remain, and its inherent complexity might never allow us to claim full proof of the climate change hypothesis.

When the climate change hypothesis was first launched, the sceptics, unified in for instance the Heidelberg Appeal, resisted it by arguing that the additional greenhouse gases in the atmosphere were not man-made. When this was established beyond doubt, the argument shifted to the changing climate itself: based on satellite data (Spencer and Christy, 1990; Christy et al., 2000), it was argued, there is no temperature rise and the surface temperature series are not reflecting actual global mean temperature changes. By establishing longer and more robust temperature records, and by closing the gap between the satellite, weather balloon and weather station data, this argument could also be refuted (Vinnikov and Grody, 2003). The arrows were then pointed at what is to blame for the temperature rise – arguments were made that natural variation, such as variation in solar radiation, including short-term and long-term cycles, rather than man-made greenhouse gases, caused temperature rises. However, the models improved and became more comprehensive, and are now successfully simulating the observed temperature data, including the seemingly random variations (IPCC, 2007d). Convincingly, no global circulation model has been able to reproduce the rising temperatures without taking into account the human influence. Currently, the only sceptics who are still active point at the admittedly large uncertainties in climate modelling.

The next question, after whether there is such a thing as man-made climate change, is what the impacts could be, and whether the impacts are severe enough to justify the disruptive and expensive actions required to mitigate climate change. The science in the field of climate change impacts has progressed much over the past five years (IPCC, 2007b). Climate change impacts are complex because of the regional differences: as meteorological and geographical conditions vary from the one area to the other, so do the impacts of climate change. It takes an enormous amount of data to get a global picture of regional climate change impacts. Another issue is the range of sectors that are involved, leading to many different categories of impacts. Figure 2.4 summarises them in one picture, and outlines impacts associated to temperature change. It makes clear that impacts become more severe with greater temperature rises, that more sectors and regions come into play, and that more people would be affected. For instance, quite severe changes in vulnerable ecosystems, such as coral reefs, happen at only a few tens of a degree centigrade, but impacts on crop productivity only start at about 1 degree temperature rise relative to the 1980-1999 period. The general picture, however, is that from about 1 to 2 degrees, widespread, costly and irreversible effects are likely to take place.

Figure 2.4 does not show the possibility of large irreversible events that might respond to a threshold value of temperature rise. One such events might be a major change in the Atlantic thermohaline circulation due to rising temperatures and river discharge (Peterson et al., 2002), and the consequences of that for the global climate (Chang et al., 2008). Although it is not yet well understood how this may work, and which temperature rise might trigger this, the abruptness of such an event would lead to even higher costs as adaptation becomes more challenging.

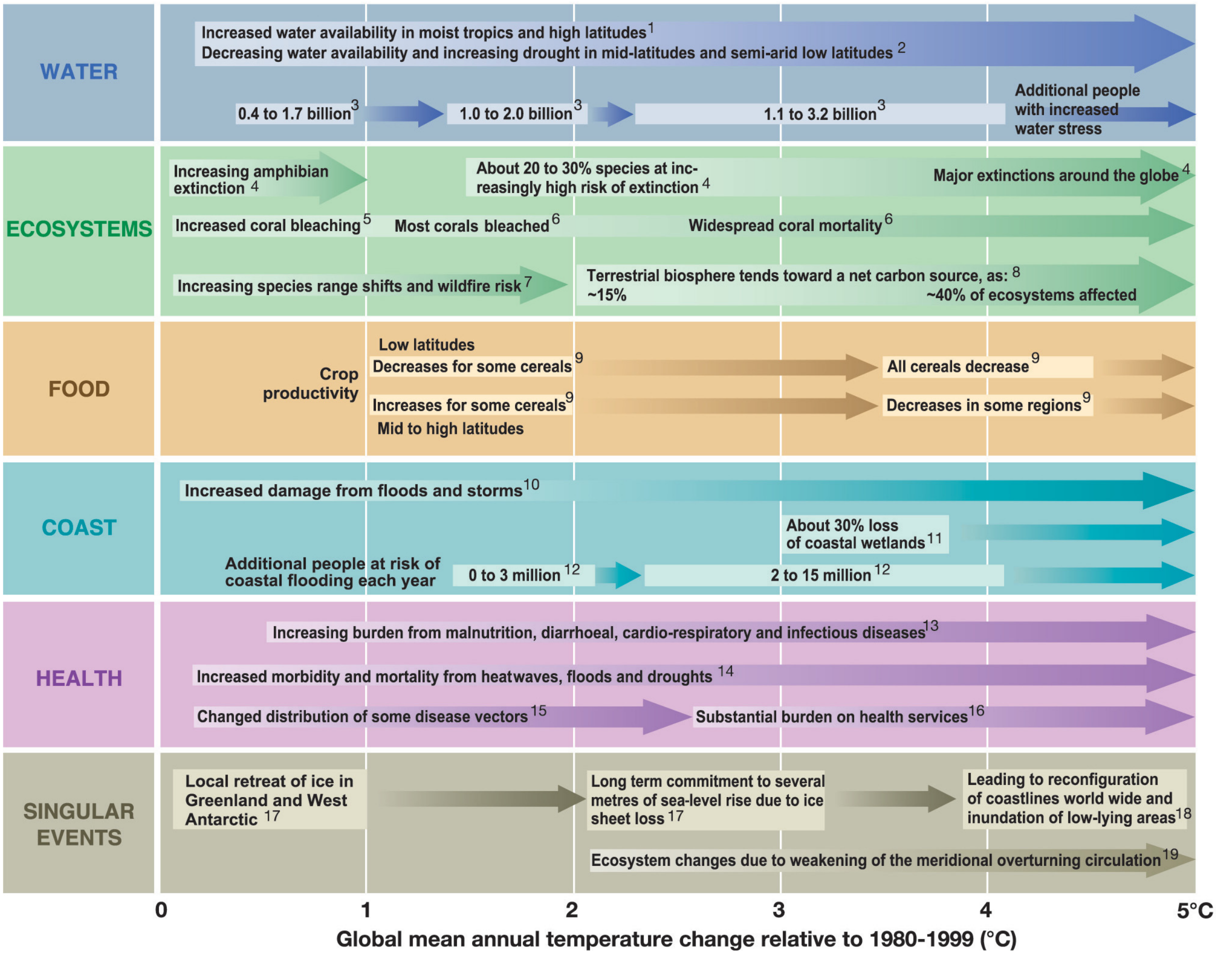

Figure 2.4 Estimated relation between global average rise in temperature and global climate change impacts (IPCC, 2007b)

Supported by initially patchy empirical and modelling evidence, from the beginning of the emergence of the climate change problem, it was assumed that developing countries, and particularly the poor in those countries, would bear the gravest consequences of climate change (Schelling, 1992). Recently, more evidence emerged that confirms this conclusion (IPCC, 2007b). One of the areas of research is agriculture, one of the most important sectors in many developing countries as a large part of the population still relies on subsidence farming for their livelihoods, and the most sensitive to climatic changes. Mendelsohn et al. (2006) assume a parabolic relation between temperature and market impacts and model the economic effects of climate change on various sectors. They conclude that the location at lower latitudes of most developing countries is unfavourable in the light of climate change. These countries find themselves on the declining part of the parabolic hill, as opposed to the industrialised countries, which are generally in more temperate climate zones at higher latitude and can potentially benefit from higher temperatures in sectors such as agriculture. Impacts of climate change on global food supply and hunger have also been evaluated, and show a higher risk of hunger, particularly in Africa, where subsistence farming remains a major source of nutrition (IPCC, 2007a; Parry et al., 2005). This is exacerbated by the result that the expected effects of a fertilising effect for crops due to the higher CO_2 concentrations in the atmosphere, which would partly compensates for the negative climatic consequences (Mendelsohn et al., 2006; Parry et al., 2005, and references therein) are probably overestimated in current assessments and is absent in several essential crops (Long et al., 2005).

Indeed, climate change seems to increase the gap between rich and poor countries (Mendelsohn et al., 2006). The IPCC (2007b) indicates that negative health impacts of climate change are enhanced for problems typically most severe in developing countries, such as malnutrition, malaria, and extreme weather events. For water stress, similar patterns apply. Even in the case of sea level rise, the vulnerability is greater in developing countries, as Figure 2.5 shows.

Figure 2.5 Relative vulnerability of coastal deltas as indicated by estimates of the population potentially displaced by current sea-level trends to 2050 (extreme >1 million; high 1 million to 50,000; medium 50,000 to 5,000). Areas with high and extreme vulnerability are more likely to experience severe impacts from climate change. Most of these areas are in developing countries (IPCC, 2007b)

None of these studies attempt to estimate the non-market impacts of climate change, as they are hard to convert into economic losses or gains. However, these impacts are by no means insignificant. They include possibly millions of additional deaths through extreme climate events over the coming decades, as well as impacts on health and ecosystems; Nicolas Stern (Stern, 2006) even compares climate change to the impact of the first World War. A large natural disaster has a considerable influence on the economic prosperity of a developing country, and a large hurricane, apart from the loss of life, can have detrimental economic consequences (Morris et al., 2002). All of these results fortify the hypothesis that most damage resulting from climate change will fall to developing countries, whereas some industrialized countries may even benefit from the consequences of climate change.

Whether the impacts justify the high costs of mitigation (see Section 2.2) is subject to debate. The uncertainties that are already present in the scientific assessments multiply once costs and other socio-economic factors come into play. Especially in the long-term context, there are different views on what kind of discount rate would have to be used. The first such analysis were done by Nordhaus (1973). The most famous attempt at a cost-benefit analysis for climate change policy was however done by Sir Nicholas Stern (2006), who concluded that the damage cost of climate change greatly outweigh the cost of mitigation. This has been criticised by e.g. Tol (2006), who argues that cost-benefit analysis over long timescales is inherently flawed. Others have argued that poverty reduction and economic development should get priority over climate change (Lomborg, 2007). The IPCC (2007c) did not accept the Stern conclusions to their full extent and was critical of the method used, but did support the general result that cost of inaction are greater than the cost of action.

2.2 Climate change mitigation

Addressing climate change through its root causes means stabilisation of the greenhouse gas concentration in the atmosphere at such a level that it limits global mean temperature rise to an acceptable level. The natural first step is hence to establish an acceptable temperature rise, associated with a minimal level of effects of climate change. There are different types of impacts that can be used as an indicator for unacceptable climate change, such as several-meter sea level rises over the long term or crop productivity losses. Figure 2.4 shows that impacts can already be seen at small temperature rises; it however is not possible to reverse those effects. Any “desirable” temperature rise needs to be seen as an arbitrary number.

The European Union has indicated its conviction that temperature rise should not exceed 2ºC relative to pre-industrial levels. Given that the temperature rise so far has been 0,7ºC already (IPCC, 2007d), in Figure 2.4 that would be consistent with the 1,3ºC level. This means that most corals would be bleached and some crop yields would decrease, especially in developing countries. However, species loss would be limited, the number of people affected by coastal flooding would be relatively low, and several meters sea level rise in the long term can be prevented. Scenario studies have subsequently shown that staying within such a temperature range would mean that greenhouse gas concentrations in the atmosphere would have to be stabilised at 400 to 450 ppmv (Meinshausen, 2006; IPCC, 2007c).

Reaching any stabilisation target means that the amount of greenhouse gases in the atmosphere has to be reduced, relative to the projected levels if emissions continue developing as they currently do. This can be done either through adding less greenhouse gases to the atmosphere, or through removing them from the atmosphere. The former means that emissions of greenhouse gases should be reduced, the latter that natural sinks, such as plants or oceans, should be enhanced.

Stabilisation of greenhouse gases should be achieved at a certain point in time. The end of the century is often mentioned as a target year. Because this is quite far in the future, the same stabilisation level can be achieved through very different emission profiles over time. One could think about immediate emission reductions to allow for a gradual settling of the rising concentrations, and there are various "overshoot" scenarios, that let concentrations rise above the anticipated stabilisation level but, through sudden deep emission reductions later on, still reach the stabilisation target in time (Elzen and Meinshausen, 2006; Elzen and Vuuren, 2007). Several emission scenarios that all lead to a 550 ppmv result are shown in Figure 2.6. Other studies on stabilisation at lower levels, show that this is a very difficult task at current emission levels (Vuuren et al., 2007; Anderson and Bows, 2008; see also the next section).

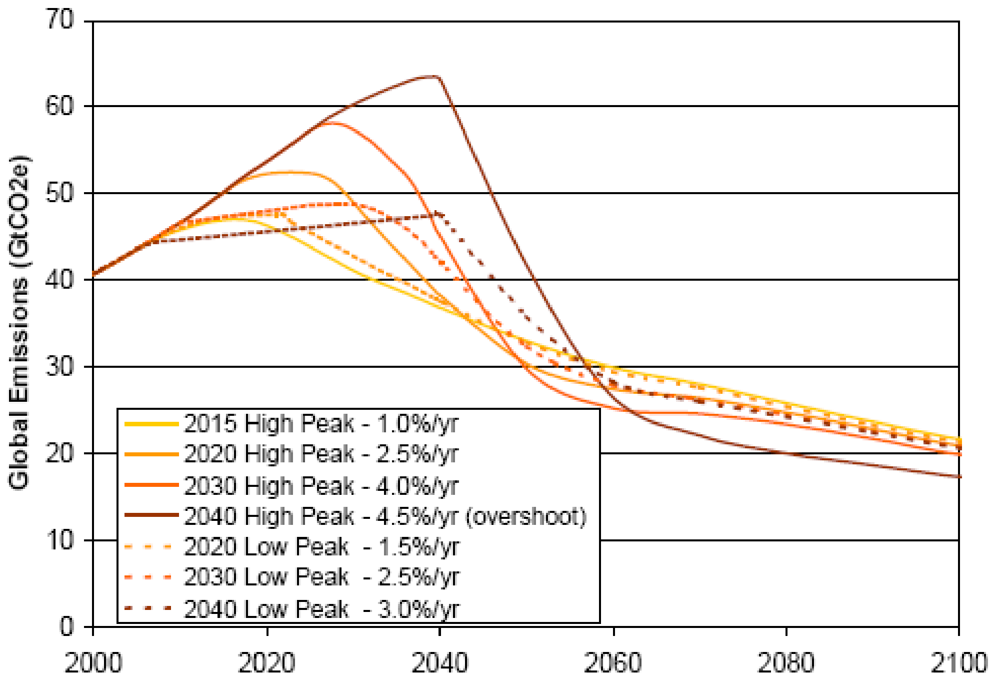

Figure 2.6 Different emission pathways to reach a 550 ppmv stabilisation level, including one overshoot scenario (Stern, 2006; based on Elzen and Meinshausen, 2006)

The global models that are used to compile all these variables into projections are very complex and it is often difficult to explain the outcome directly from the inputs. The uncertainties in emission scenarios and the way these uncertainties were communicated have led to controversies in popular media (Schenk and Lensink, 2007).

The challenge of climate change mitigation is often expressed in emission reductions. To determine the amount of emission reductions at a certain point in time and consistent with an acceptable stabilisation level, a baseline has to be assumed. Baseline scenarios are about as difficult to project as emission profiles, and have similarly large uncertainties. To avoid the baseline problem, emission reductions are therefore often given relative to a certain base year in the past, such as 1990 in the case of the 1997 Kyoto Protocol. National targets are often not expressed in emission reductions but in allowable emissions or an emission cap.

Global greenhouse gas emissions have risen by about 70% between 1970 and 2004, and most of the rise has been due to CO_2 in the energy supply and transport sectors (IPCC, 2007c). The current greenhouse gas emissions per sector are given in Figure 2.7, indicating clearly that not one sector is solely responsible for the problem, or is able to provide a solution. Much of the emissions in various sectors, particularly energy supply, transport, buildings and industry, however, are related to the use of fossil fuels for energy (IEA, 2007a). This is the reason why the energy sector is most often targeted in the climate negotiations and in studies on climate change mitigation.

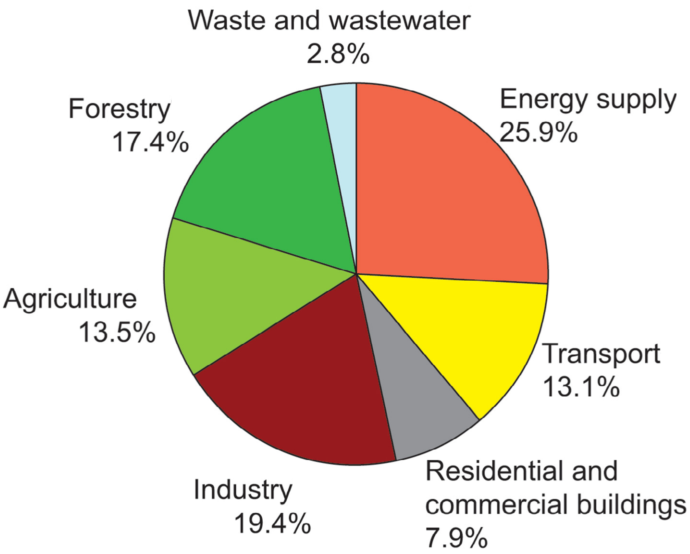

Figure 2.7 Sectoral distribution of global 2004 anthropogenic greenhouse gas emissions (IPCC, 2007c)

This thesis will focus on climate change mitigation through emission reductions, as opposed to carbon sinks. It will therefore mainly look at CO_2 emission reductions in the energy, transport, buildings and industrial sectors. The options to reduce emissions in these sectors are diverse, and include energy efficiency improvements, the use of non-fossil-fuel energy, the capture and storage of CO_2, industrial process improvements and behavioural changes. The "optimal path" of emission profiles over the course of this century, so up to 2100, and the optimal mix of mitigation options is mostly computed based on models that optimise on the overall cost of reducing emissions.

2.3 Economic models, climate mitigation and technology[4]

There are a wide variety of analytical models being used to consider and inform climate change policy at national, regional, and global levels. The IPCC (2007c) found over 750 emissions scenarios in the literature, and all of them consider different portfolios of technologies. The assumptions on success of technological innovation, learning curves, discount rates, and availability and adoption of technologies, as well as the assumptions on what would happen in a business-as-usual (or baseline) case, determine the outcome of such an analysis (IPCC, 2000b). The outputs, as well as the temporal and spatial scope, sophistication, language, assumptions, system boundaries, and theoretical frameworks of these analytical tools vary dramatically across the different models. They generally require assumptions about the technical status, potential scale and rate of deployment, costs and future costs and social acceptability, within an assumed framework for decision making - typically cost minimisation.

The principal forums for comparing energy/climate/Integrated Assessment Modelling models include: the Energy Modelling Forum (Weyant, 2004b), the Innovation Modelling Comparison Project (Edenhofer et al., 2006), the US Climate Change Science Programme (Clarke et al., 2007), and IPCC (2007c)[5]. In all of these collaborations, marginal abatement cost curves on various levels of aggregation are used as an instrument to estimate abatement costs and potential on the national and global level (Elzen et al., 2007; Ellerman, 1998). Global technology-focused marginal abatement cost curves, such as those prepared by Vattenfall (2007), Bakker et al. (2007) and IEA (2008b) are useful in considering technology priorities and relative costs. However one global

[4] This section is based on section 2.2 in Bazilian et al. (2008).
[5] Other results showing various technology portfolios include: Strachan et al. (2007), Das et al. (2007), Boeters et al. (2007), IEA (2007a), Riahi et al. (2007), Vuuren (2007b), Weyant (2004b).

curve is not sufficient to inform a comprehensive approach. Energy efficiency (or aspects of it), for instance, often appears with negative marginal abatement costs in these exercises, illustrating that the complex nature of technology innovation and diffusion is not solely related to economic costs. Hence, as with any forecasting study, model outcomes are surrounded with huge uncertainties, and should not be taken at face value. Apart from basic uncertainties on population growth, economic activity and large societal developments, there are many other uncertainties related to technological feasibility and costs.

Vuuren (2007a) also provides a detailed technology analysis to meet the dramatic shift required to reach a 450 ppmv stabilisation target over a longer time horizon (to 2100). His work has formed the basis of the 'lower range' of stabilisation targets, which rarely go below 450 ppmv (IPCC, 2007c). Vuuren et al. (2007a) impacted policy thinking on deep stabilisation levels and technology, for instance by demonstrating that such stabilisation levels require the application of 'negative' CO_2 energy production from bio-energy with CCS (Obersteiner and Azar, 2002). William Nordhaus (2007) developed the DICE model to consider a number of post-2012 policy options ranging from no action to moving into geo-engineering. The IEA Energy Technology Perspectives report (IEA, 2008b) shows more detail on technology's contribution to emissions reduction targets to 2050, and also shed light on total additional investment required to meet the scenario of 50% reductions in CO_2 emissions by 2050 relative to 2005 (Figure 2.8). The issue of timing, or capital stock turnover, is essential in considering the role of technology; creating an impetus for short-term action. This is considered in detail in IEA (2007a).

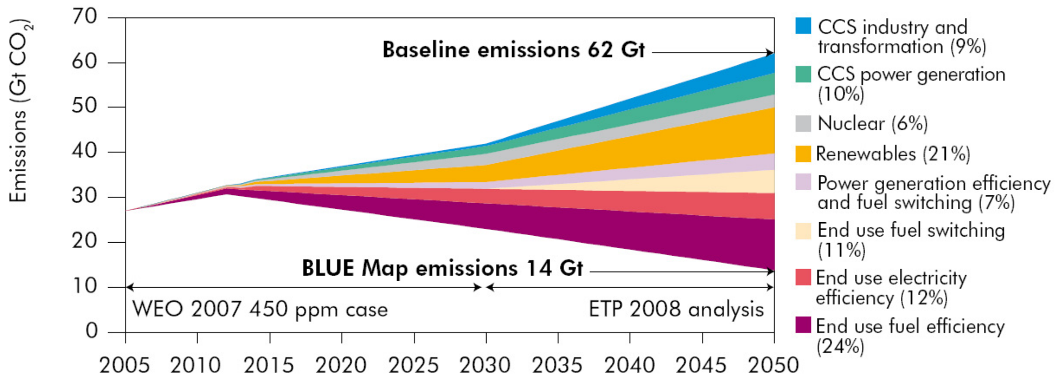

Figure 2.8 IEA technology portfolio for a scenario demanding 50% emission reductions relative to 2005 (IEA, 2008b)

It is a recent trend that cost-optimisation modelling are accompanied by technology action plans or "roadmaps". The IEA, for instance, in its Energy Technology Perspectives (2008b) considers roadmaps outlining a development and implementation pathway of the seventeen technologies included in the analysis. Likewise, the Japanese Cool Earth (METI, 2008) programme identified twenty-one technology pathways, and the European Commission also considered 'technology maps' for 14 technologies (EC, 2007a). The IEA modelling exercises and pathways are widespread: rather than making their own scenarios, the UNFCCC used the IEA numbers for its own reports identifying the finance and investment needs (UNFCCC, 2008a).

Obersteiner and Azar (2002), noting the vast uncertainties in technology investment and deployment, utilises real-options theory to consider technological possibilities, as do Yang and Blyth (2007). In such cost optimisation studies, uncertainties are addressed through a probabilistic approach. Another way of reflecting uncertainties is by including them explicitly in the model assumptions. Organisations less interested in cost optimisation have published energy scenarios based on an effective technology response to climate change via the technical feasibility of meeting growing global energy demand using sustainable energy technologies (e.g, WWF, 2008; Bellona, 2008). This approach is explicitly technology-specific. It does not assume technology costs or a carbon price - the costs of dangerous climate change are assumed to far exceed the costs of avoiding it. Instead, it focuses on key questions of the physical resources, the capacity of the technologies themselves and the rate of industrial transitions. The results of the approaches are roughly consistent: they suggest that there is a reasonable chance of success, however, physical and engineering constraints, regardless of a carbon price or other policy measures, limit the rate at which emissions can be bought down and that some overshoot of emissions may be inevitable (IPCC, 2007c).

2.4 What is technology, and what is its role in climate change mitigation?

Perspectives on technology have changed throughout the centuries due to changing culture, new insights and new roles for technology. Some regard technology as a panacea to all problems that face humanity, others see it as a human-created monster that is out of control (Hughes, 2004). The relation between technology and climate change is correspondingly tense: on the one hand, technology is the cause of the problem, on the other it is a large part of the solution and has greatly improved quality of life for many people. Although non-technological mitigation options such as behavioural changes should also play a role (IPCC, 2007c), all studies on mitigation (e.g., IPCC, 2007c; IEA, 2007a; Stern, 2006) foresee the largest role in mitigation of climate change for environmentally sound technology. Technology, however, is complex, means many things to many people, and therefore needs a specific definition in the context of this thesis.

Arguably, the broadest (and undoubtedly shortest) definition of technology has been given in social science literature: "configurations that work" (Rip and Kemp, 1998). It is used to place technology in a system context: the technological system, including the infrastructure and hardware, as well as the social system, including institutions, together comprise the level of adoption and the innovative capacity. Although this definition may be useful when studying dynamics of adoption of technology in social systems, it is less applicable to the context of international institutions, the topic of this thesis – although it should be said that exploring the role international institutions could play in enhancing the uptake of technology in a social system would be worthwhile.

Another literature that has had to come to terms with the role of technology innovation is economics. Schumpeter's model, which first addressed the relation between technology and economic growth in the 1910s (translated to English in 1934), was hardly challenged for about half a century, until Rosenberg (1973; 1976) and Nelson and Winter (1977) revitalised it to explain historical differences between countries. Rosenberg (1973) defines technology as "the relationship between inputs and outputs in the economy" and technological progress occurs when the outputs increase relative to the inputs. A natural question that arises is why certain economies develop in a different direction than others, perform better or worse than others, and hence what the role of innovation or technological change is. Rosenberg (1973), through a historical comparison of the US and British economies, arrived at the conclusion that the local resource endowments play an important role in the direction of technological change. In this context, resources can be natural resources, such as the availability of wood, but also resources such as skilled labour. Technology, in this view, thus pertains to much more than just physical structures; it also relates to general education and skills level of a country's population. Recent publications have not challenged this view (Arthur, 2006; Nelson, 2008).

A most applicable definition of technology is given in IPCC reports. In its Special Report on Methodological and Technological Issues in Technology Transfer (IPCC, 2000a): "A piece of equipment, technique, practical knowledge or skills for performing a particular activity". In its Fourth Assessment Report, the definition was expanded to "the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts)" (IPCC, 2007c). This marks the viewing of "technology as an object" to "technology as an application", and it notably does not take the economic, more firm-based approach to technology and innovation. On earlier occasions, Dosi (1982) posed "know-how, methods, procedures, experience of successes and failures, physical devices and equipment". This thesis will adopt the latter definition, as the international agreements that would further technology focus on its application and the processes involving that, rather than the hardware alone.

The rising greenhouse gas emissions are largely due to technology innovation and diffusion, such as more and larger household appliances, and in some cases the high greenhouse gas intensity of technology, such as the trend to heavier cars (IPCC, 2007c). Achieving the emission reductions required for stabilising greenhouse gas concentrations requires the development and diffusion of environmentally sound technologies. Environmentally sound technologies are technologies that lead to substantial emission reductions compared to the baseline. Baselines differ per situation, notably per country. Where, for instance, in the US corn-based bio-ethanol can be a significant improvement relative to a planned switch to transport fuel from coal-to-liquids operations, in Brazil this would worsen the greenhouse gas balance because of the availability of sugar-cane based ethanol, which has much lower greenhouse gas emissions. The appropriateness of technology will also depend on the eventual targets over the lifetime of the installation. For instance, although combined heat and power applications (CHP) reduce emissions significantly compared to the baseline of not using CHP, if the eventual target is to bring back emissions by over 50% within the lifetime of the CHP installation, the technology might be better than the baseline but not good enough for the policy goal.

It is clear, and various literature sources have confirmed this, that technology is essential for achieving climate mitigation targets. What is less known, however, is the level of innovation required for these targets. Although research and development, leading to technological innovation and new technological solutions, would improve cost-effectiveness, the required emission reductions can be fully achieved through deployment of existing technologies (IPCC, 2001d; 2007c). The IEA (2008b) has developed 450 ppm-scenarios based on currently available technologies. Pacala and Socolow (2004) have comprehensively explained through a number of technology wedges that seven times 1 GtC (3.67 $GtCO_2$) worth of deployment of technology leads to the same global emissions in 2050 as now; supposedly consistent with a 550 ppmv scenario. Their estimate is based on technologies known today, such as wind energy, hybrid cars, and nuclear energy. What kind of investment is needed depends on the stage of technological development – it is not of much use to do fundamental research on a technology that is near commercialisation. Diffusion of available technologies that currently are more costly than conventional ones would bring costs down further than large investments in research and development, which are unable to overcome the commercialisation barriers. The rate of diffusion also matters for making best use of learning effects.

The policy conclusion from the findings of climate change mitigation and technology forecasters is that climate policy that reduces greenhouse gases and implements technology is required on a rather short term to bring down emissions in time for the lower stabilisation levels. A policy based on technological innovation push role alone is insufficient to address the problem.

2.5 The political playing field

The international politics of climate change started with the inception of the Intergovernmental Panel on Climate Change (IPCC) in 1988. Although the IPCC is essentially a science-based organisation, its principles and procedures include a significant government role. The IPCC Plenary establishes the IPCC's strategic plans, determine which reports will be compiled, and approve the Assessment and Special Reports. The IPCC Principles and Procedures prescribe that every IPCC report should be accompanied by a Summary for Policymakers (SPM), which needs to be approved line by line by IPCC's 180 governments in a process that is essentially a full-fledged text negotiation. The scientific integrity is guaranteed by not allowing the SPM to contradict or paraphrase the body report text in any way. In the IPCC, the scientists have the last word.

The IPCC already in its First Assessment Report, published in 1990, concluded that climate change is occurring and that addressing it requires international collaborative action. This is reflected in the objective that parties to the UNFCCC agreed to in 1992 during the Earth Summit in Rio de Janeiro. Specifically, 191 of the world's nations have now ratified the UNFCCC, which explicitly states as its goal the "stabilisation of GHG concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system [...] within a timeframe sufficient to allow ecosystems to adapt naturally [...], to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

The UNFCCC is a pledge-and-review type of agreement and is binding to its participants. The phrasing of the commitments, however, leaves so much room for interpretation that it is in reality a soft-law treaty, with targets that make measurement of compliance impossible. This deliberate ambiguity has been reported to lead to only very limited action (Chayes and Chayes, 1993; Tompkins and Amundsen, 2008). In response to this, in 1997, the UNFCCC Parties met in Japan to negotiate the Kyoto Protocol, which is based on a clear and binding targets-and-timetables approach. The negotiation process in Kyoto was dominated by several major blocs of countries, united by their common interests. Each bloc was interested in a Protocol design that would minimise the domestic economic impact. Some countries, especially the United States and its allies at the time (Japan, Canada, Australia, and New Zealand), argued for the inclusion of market mechanisms within the Protocol. In contrast, the European Union (EU) argued for strong targets and against the inclusion of market-based policy mechanisms, as they would allow countries to avoid domestic emission reductions. The Economies in Transition, mainly Eastern Europe and Russia, were characterised by economic transformation since 1990, and strongly reduced emissions. The developing countries, including China and united in the G-77, were chiefly aiming at preventing emission reduction targets for developing countries and argued for industrialised countries to, in line with the UNFCCC, take action first and provide sufficient funding for technology transfer and adaptation.

The resulting Kyoto Protocol, to which all UNFCCC Parties agreed in 1997, contained quantitative emission targets for Annex-I countries, an emissions trading provision, the possibility of using the Clean Development Mechanism (CDM) to on the one hand allow non-Annex I countries to pursue sustainable development and provide them with incentives to reduce emissions, and on the other allow Annex-I countries to achieve their Kyoto targets in a more cost-effective way. The Kyoto Protocol entered into force in February 2005, after Russia decided to ratify. Currently, all Annex-I countries have ratified it, including most recently Australia. The only Annex-I country that rejected the Kyoto Protocol, at the same time the largest contributor to global greenhouse gas emissions, the United States, gave two reasons for its rejection: that the economic consequences would be too severe, and that developing countries, particularly China, which was not subjected to emission targets.

The Kyoto Protocol is generally designed as a market-based instrument. Market-based approaches are often only thought of as national or regional policy instruments. The Kyoto Protocol, however, shows that also international policy instruments can use a combination of the market and economic incentives to reach a policy goal. The Kyoto Protocol is notably not a regulatory (sometimes also named command-and-control) approach, as the EU initially favoured. UK delegates at the time constructed a list of "policies and measures" that would qualify for compliance with the future Protocol (UNFCCC, 1997). The list was eventually never used; the EU has since embraced market mechanisms and has gone on to establish its own internal emissions trading system.

The Kyoto Protocol has not gone without criticism from scholarly circles. There is a large body of literature covering the merits and drawbacks of the Kyoto Protocol (e.g., Cooper, 1998; Ott, 2001; Victor, 2001). The literature seems to converge on a number of main points on which a new climate agreement should be improved:

- Participation should increase to include the United States. For this, an agreement would have to be designed that takes away its concerns. Also, the large emerging economies would need to be involved in curbing emissions (Victor, 2001).
- Compliance and particularly enforcement mechanisms need to be strengthened, preferably by designing a treaty that is self-enforcing (Barrett, 1998; Victor, 2001).
- Environmental effectiveness, both in terms of reduction of greenhouse gas emissions and inducing technological change, should be greater than is currently the case. The reason is that the measures resulting from the Kyoto Protocol obligations are insufficient to solve the climate problem – the period over which the emission reductions are needed does not incentivise technological change. (Ott, 2001; Cooper, 1998).
- Technology transfer to developing countries should be enhanced. Technology transfer is mentioned in the UNFCCC and the Kyoto Protocol but is not tied up with concrete targets or obligations (Sathaye et al., 2006).
- Net economic impacts of the agreement should be predictable and as low as possible. The reason for this improvement relates to the earlier point of participation of the United States and other countries (Victor, 2001; Cooper, 1998).

Before the ink was dry on the Kyoto treaty, it was clear that the negotiators from several parties had stepped out ahead of their own domestic politics. In the United States, for example, the Senate voted preceding the Kyoto negotiations to repudiate the agreements in the Berlin Mandate (US Senate, 1997), an agreement made at the first Conference of Parties in 1995 that helped establish Kyoto. In 2001, the Bush Administration formally exited the Kyoto Protocol.

As the largest emitter of greenhouse gases, and therefore a major player, however, the United States had to do something. It decided to make technological research and development the central pillar of its climate policy, and has since 2001 invested heavily in research and development of greenhouse gas reducing technologies. Internationally, it has set up institutions that also aim to further technologies, particularly through knowledge sharing and coordination (Coninck et al., 2008a). The most well-known examples are the Asia-Pacific Partnership on Clean Development and Climate (APP) and the CO_2 capture and storage-specific Carbon Sequestration Leadership Forum (CSLF).

Views of these political initiatives of the United States are mixed. Some see them, and particularly the APP, as a step in the right direction and argue that one cannot pass judgment until it has been given a chance, and that technological innovation is also important. Others regard it as a purposeful and deliberate distraction of the real issue, and a poor replacement for dropping out of Kyoto (Asselt, 2007). So far, it seems that the latter are closest to the truth – it is unlikely that the APP will deliver anything close to the Kyoto emission reductions, or make much of a difference in the future.

The commitment period of the Kyoto Protocol extends from 2008 until 2012, and it will have to prove whether it is effective, and whether its Parties will comply to its conditions – notably a 6-8 % reduction of greenhouse gas emissions compared to 1990. Broad ratification of Kyoto, of 175 countries and its entry into force thanks to Russia's ratification, are among its successes. Prospects for compliance of the EU, Australia and Russia look good, for Japan slightly less well, and for Canada dim. The developing countries only participate through the voluntary, project-based market mechanism the Clean Development Mechanism (CDM), which has taken off quickly and is currently the largest CO_2 trading mechanism worldwide (World Bank, 2006a). Over 1100 projects are registered with the UNFCCC, and almost 4000 are in the pipeline (UNEP/Risoe, 2008).

Negotiations on what will happen after Kyoto, including types of commitments, developing country involvement, and the role of technology, have started officially with the adoption of the Bali Action Plan in December 2007. This plan sets a deadline for finalising the negotiations of COP15, in Copenhagen in December 2009, and mentions five fields of agreement: a shared vision on climate change, mitigation, adaptation, technology and finance. At the time of writing, it was still unclear what type of proposals would be considered under these tracks, although submissions have been made by various countries and negotiating blocks (UNFCCC, 2008b). The technology track and the possibilities it offers for a broadly acceptable and effective climate agreement are the topic of this thesis.

Chapter 3 Technology in the climate change regime[6]

Abstract
This paper explores how including technology in a climate treaty design can augment the institutional solutions offered by current political theory. It does so in three steps. First, the paper describes features of climate change that are relevant to rational actors and expands current thinking in international relations and rational design of institutions based on those features, to confirm the economic conclusion that an emission target-based regime is not a rational design. Subsequently, it looks at technology as a possibility to provide reciprocity and prevent free-riding in the institutional design of a climate change treaty. Climate-friendly technology is required to achieve emission reductions, it was introduced in the Bali Action Plan agreed in 2007, and might, as this paper argues, make a treaty more self-enforcing. Lastly, technology-oriented agreements, as an institutional form to include technology in the climate regime, are explored. Technology-oriented agreements are defined as agreements aimed at advancing technologies to address climate change. They have advantages such as better prospects on self-enforceability and better cost predictability, but also issues such as reduced cost-effectiveness and flexibility compared to emission-reduction agreements. Regardless of whether technology-oriented agreements would replace or complement a cap-and-trade agreement, embedding in the current climate regime needs to be coordinated to prevent fragmentation of the environmental effectiveness.

3.1 Introduction

The aim of this paper is to provide, founded on international relations theory, an explanation of the current climate negotiations situation, and explore the role of technology in a future treaty design. To that aim, it combines insights from the rational institutional design literature with recent climate change science, mitigation, and technology insights. It also explores views on technology-oriented agreements along with their advantages and drawbacks.

In the field of institutional design, over the past decades, approaches founded on economically rational behavior theory (Coase, 1986) and expanded with methods and insights from international relations have led to the recognition that the design of international institutions matters to the effectiveness of international governance (Keohane, 1984). Institutional design has emerged as a subfield of international relations theory and is still under development, with notable additions in the field of international law (see e.g. Raustiala, 2005), rational design of institutions (Koremenos et al. (2001) and networks (Slaughter, 2004). In terms of classical coordination games with a relatively symmetrical distribution of costs and benefits (e.g., Martin, 1992; Mitchell and Keilbach, 2001), or with obvious reciprocal elements or peer pressure (Simmons, 2000), the outcomes of international treaties seem predictable. For problems with asymmetrical interests and for issues that require deep cooperation to be solved, it has been argued that in the case of "strong victims" and even "weak victims", positive exchange or negative coercion may be employed to reduce the externalities, i.e., rewarding compliance or sanctioning defection, respectively (Mitchell and Keilbach, 2001; Sell, 1996). However, no obvious answer from the institutional design community has risen as of yet for the case of not only weak, but also poor victims, incapable of providing rewards to perpetrators or coercing them into agreement and compliance (Sell, 1996). This paper will clarify that climate change can be classified as exactly such a case, that the current deadlock is due to this very nature of climate change, and that the difficulty to act is consequential of this inherent situation structure. Technology as a rational design feature has not been discussed in the international relations literature, and this paper aims to fill part of that gap.

6 This chapter was submitted to International Environmental Agreements.

The anthropogenic emissions of greenhouse gases are thought to cause global temperatures to rise and an array of adverse effects to happen (IPCC, 2007d). This issue of climate change has received increasing recognition as a global environmental problem since the early 1990s. In response, the international community set up the United Nations Framework Convention on Climate Change (UNFCCC), which aims at "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 1992). In the Kyoto Protocol, which was agreed three years after the UNFCCC entered into force, specific greenhouse gas reduction targets for industrialized countries were agreed (UNFCCC, 1997a). On the basis of "common but differentiated responsibilities" (UNFCCC, 1992), developing countries were exempted from commitments but the Kyoto Protocol did enable voluntary participation via the Clean Development Mechanism (CDM).

After the Kyoto Protocol was agreed and while it was implemented, numerous papers were published in the field of political science, subjecting the protocol to general rules of institutional design (for a review, see Böhringer, 2003). The Kyoto Protocol was criticized for not taking account of requirements of participation, flexibility and compliance (Barrett, 1998; Victor, 2001). Indeed, the protocol had mixed results. Part of the criticism was proven right, as the United States, the largest greenhouse gas emitter, dropped out, and other developed countries may not comply. At the same time, however, in those countries where the protocol was seriously pursued, a carbon market now flourishes and most of the alleged design flaws have proven unproblematic. In addition to assessment, there is no lack of proposals for improved designs of a post-2012 climate regime for after the Kyoto period ends, in 2012 (Bodansky, 2004). Most of it builds on Kyoto by proposing economic instruments such as the emissions trading scheme that Kyoto has introduced (Höhne, 2005). Subsequent assessments of post-2012 proposals have attempted to overcome the criticism, but could never quite reach a workable treaty with a functional design (Aldy et al., 2003).

Since the 11th Conference of Parties (COP) to the UNFCCC, the discussion of post-2012 regimes has an official place both under the UNFCCC and among the parties of the Kyoto Protocol. After years of dialogue, the 13th COP in Bali resulted in a much welcomed Action Plan. The Bali Action Plan calls for a shared vision on long-term commitments and outlines four additional negotiation tracks: mitigation, adaptation, finance and technology (UNFCCC, 2007). The plan does not include a reference to commitments, but indicates that agreement should be reached by COP15 in Copenhagen, in December 2009.

Although the results of Bali point at some progress relative to the failed negotiations at earlier COPs, they are by no means a guarantee that the deadlock in the climate negotiations is now resolved. The negotiations in Bali were difficult and long, and consensus could only be reached by significantly watering down the ambitious text that appeared in earlier drafts. Statements of the Executive Secretary of the UNFCCC itself reveal some pessimism about the chances for a meaningful agreement in 2009, and recent meetings in 2008 have made little progress on the various agenda items. Views on how mitigation and adaptation should be addressed diverge between developed and developing countries negotiation blocs, as well as within these blocs, including the emerging economies whose involvement is essential for a credible Kyoto follow-up. Particularly the fields of finance and technology are relatively new in the negotiations and there are hopes that these issues will yield concrete results.

This paper looks at technology, and focuses on one of the possible forms to incorporate technology in the climate negotiations: technology-oriented agreements. Elsewhere, technology-oriented agreements are defined as “all agreements that are aimed at advancing research, development, demonstration, and/or deployment of technologies” (Coninck et al., 2008a). There is some mention of technology in reviews of potential post-2012 climate regimes, and some proposals have been made, although their role is small compared to economic instruments. Most proposals for post-2012 climate policy have a technology component, although almost always focusing on R&D and excluding deployment, so without prospects for significant reduction of greenhouse gas emissions through the technology component (Bodansky, 2004). Some agreements aim more directly at technology, but provide little incentives for deployment (e.g., Barrett, 1998; 2003). Such proposals have thus been dismissed as unacceptable from the climate point of view (Berk and Elzen, 2001; Höhne, 2005). A notable exception is a proposal by Edmonds and Wise (1998), who propose a global CCS mandate but present it exclusively as a “backstop” option. Recently, a review paper of existing and future technology-oriented agreements in different environmental fields analyzed how effective they have been in the past, and what their role may be in the climate change regime (Coninck et al., 2008a). The most significant technology-oriented agreement in climate change is the Asia-Pacific Partnership on Clean Development and Climate (APP), which aims at facilitating investments in climate-friendly technologies. The APP was initiated by the United States, with Australia, China, India, Japan, and South Korea, in 2005, and joined later by Canada, but has not resulted in significant deployment of technology (Asselt, 2007).

Technology-oriented agreements bear some resemblance to the policies and measures (or actions) approach advocated by the European Union in the pre-Kyoto climate negotiations (UNFCCC, 1997b; Ott, 1998), which was at that time rejected, amongst others on instigation of the United States, in favor of a cap-and-trade agreement. At the time, an agreement that leaves flexibility for the market to find the most cost-effective solution was preferred. Whether technology-oriented agreements are old wine in new bottles remains to be seen, and might also depend on new circumstances. For instance, the possibility that a new technology like CO_2 capture and storage might generate relatively affordable CO_2 reductions without the need to shift away from cheap coal increases the faith of the private sector as well as fossil fuel-reliant countries that pursuing the deployment of such technologies generates the momentum needed for deep reductions in emissions, without immediate major disruptions in the energy sector (IPCC, 2005).

It should be noted upfront that technology-oriented agreements could be pursued both parallel to and in place of an emission target-based approach (Sugiyama and Sinton, 2005; Coninck et al., 2008a). This paper oscillates between technology-oriented agreements being an addition to and a replacement for an emission target-regime, but this does not affect the outcome of this analysis. A single technology-oriented agreement would normally never operate in an institutional vacuum, as it by definition addresses one technology, and there is not one technology that can address climate change by itself. There will thus always be interactions with other agreements relevant to climate change, regardless of whether they are other technology-oriented agreements or emission reduction agreements. The question whether a technology-oriented agreement replaces or complements an emission-target aimed agreement, therefore matters under every each scenario. As a starting point, this paper will describe and evaluate a technology-oriented agreement on a stand-alone basis. The focus is on the question what dynamic technology and technology-oriented agreements would introduce in the climate negotiations. In various places in the paper, technology-oriented agreements are related to the situation around the current Kyoto Protocol and its most commonly proposed follow-ups – an international cap-and-trade agreement.

The paper is structured as follows. First, some relevant features of climate change are described in Section 3.2. Next, in Section 3.3, rational-actor outcomes of agreeing on an emission target-based climate regime are analyzed and the theoretical model is expanded. Technology-oriented agreements are introduced in Section 3.4, and their prospects are discussed in Section 3.5. Finally, a way forward is suggested in Section 3.6.

3.2 The difficulty of rationally designing a climate change regime: redistribution and depth of cooperation

If one conclusion can be drawn from the history of international climate change negotiations, it is that it is very difficult to reach agreement on mitigating climate change. Making suggestions for improvement requires understanding of the issues behind the sole goal of greenhouse gas emission reduction. A deeper look into the causes of the difficulties can facilitate reaching agreement in the negotiations. This section sets out with two major issues that inhibit an outcome on climate change mitigation: the redistributional character of climate change, and the issue of depth of cooperation.

Climate change has a number of characteristics that qualify it as a "redistribution issue", which for this paper is defined as "an issue that requires a more proportional distribution of commodities in order to be solved in a just manner". In the context of climate change, the perception of what is "just" pertains both to who bears the burden of preserving the collective good of a stable climate (i.e. who reduces greenhouse gas emissions), and who would suffer the most from impacts of climate change. Developed states generally emit more greenhouse gases and are in a better position to cope with the impacts of climate change, while developing countries are more vulnerable and bear a smaller responsibility for the problem. This characteristic feature intertwines the climate change problem closely development questions. For designing international institutions for climate change, it is important to understand the diversity in players in the culprits for the problem, the ones who will bear the cost of solving it, and those who will bear the costs of collective inaction.

In order to prevent climate change, the concentration of all greenhouse gases in the atmosphere, including CO_2, will need to stabilize. CO_2 concentrations before the industrial revolution (around 1850) were about 280 parts per million (ppm);. Current concentrations of CO_2 are over 380 ppm, and concentrations of the whole basket of greenhouse gases are already well over 400 ppm CO_2-eq (IPCC, 2007a). Early models indicate that a concentration of 550 ppm CO_2-eq (or double the pre-industrial level) would be low enough to stay below a global mean temperature rise of 2°C (IPCC, 2001a), but the current consensus is that stabilization at 450 ppm or even lower would be necessary to prevent the severest of effects (Elzen and Meinshausen, 2006; Hansen et al., 2008; Anderson and Bows, 2008). The emission reductions associated with such a stabilization level are daunting, require emission reductions in both industrialized countries and major developing country emitters, and would have profound impacts on the way energy is used and produced. The availability of reliable and affordable energy is an important precondition for virtually all economic activities. In 2003, 80% of all primary energy used in the world originated from fossil fuels. This share is lower than the 85% of fossil energy in 1973, but the use of energy has also increased by about 75% (and counting), so the absolute use of fossil fuels is still on the rise (Raupach et al., 2007). Most energy scenarios project doubling of CO_2 emissions by 2050 relative to 2000, due to increasing energy use and persistent share of fossil fuels in the energy mix (IEA, 2007a). However, in order to stabilize concentrations at low levels, global emissions will need to peak before 2015 and decline thereafter. It has been argued that it is technically feasible to achieve such goals with the current portfolio of technologies (IPCC, 2007c), and options to reach such levels have been outlined in several comprehensive approaches (IPCC, 2007c; 2001a; Pacala and Socolow, 2004).

Currently, CO_2 emissions in the industrialized countries are about half of the global emissions, while these countries constitute only about 20% of the world's population (IEA, 2007a). The lion's share of the greenhouse gases that have cumulatively been emitted over the past 150 years originates from the industrialized countries. These countries are also in the best position, both having the required economic means, institutional maturity, and level of technological development, to invest in addressing climate change. These factors have led to the political consensus that the actions to reduce CO_2 emissions would be taken (or at least paid for) in industrialized countries first, as reflected in the earlier mentioned UNFCCC[7]. On the other hand, however, it can be argued as well that the industrialized countries have been conditioned more than developing countries towards a fossil-fuel-based, high energy-using society. It makes deep emission reductions for those countries that have chosen an energy-intensive path in the past, unknowing of the consequences in the future, more disruptive and costly, as well as more difficult to achieve as it involves a more profound breach with prevailing practices. In addition, the situation is changing: large industrializing countries are responsible for an increasing share of global greenhouse gas emissions, making them an indispensable part of the solution.

The main incentive to prevent climate change is the aversion of harmful impacts that result from the rise in global mean temperature (IPCC, 2007b). Supported by initially patchy empirical and modelling evidence, from the beginning of the emergence of the climate change problem, it was assumed that developing countries, and particularly the poor in those countries, would bear the gravest consequences of climate change (Schelling, 1992). Recently, more evidence emerged that confirms this conclusion (IPCC, 2007b). Modelling of impacts of climate change on global food supply show a higher risk of hunger, particularly in Africa, where subsistence farming remains a major source of nutrition (Parry et al., 2005). Indeed, climate change seems to increase the gap between rich and poor countries (Mendelsohn et al., 2006), even excluding non-market impacts of climate change, such as premature deaths. To make things worse, the assumed positive effects of the higher CO_2 concentrations in the atmosphere on CO_2 fertilizing of crops are probably overestimated in current assessments and absent for several essential crops (Long et al., 2005). All of these results fortify the hypothesis that most damage resulting from climate change will fall to developing countries, whereas some industrialized countries may even benefit from the consequences of climate change.

There is another redistribution issue that is less discussed in literature, and that touches upon the Brundtland definition of sustainable development: the issue of intergenerational redistribution. If climate change is not prevented, later generations will bear the burden of the present generation's free-riding. If climate change is prevented, most of the benefits will be reaped by the later generations, while the costs are borne by the present generation. This simple way of putting it leads to the conclusion that a rational, self-interested present generation will not act on preventing climate change, which further complicates the incentive structure for mitigating climate change. Although the literature informs us that redistribution issues can be addressed in various ways (see Section 3.3), a solution to generational redistribution issues (or even a consistent framework to describe them) has not yet been proposed (Barrett, 2007). This paper will therefore focus on the material redistribution issues around climate change, and leave the intergenerational issues outside of its scope.

The second complicating factor is that the "depth of cooperation" required to address climate change is unprecedented in environmental issues, and perhaps even in all international governance. Depth of cooperation is defined as that extent to which an international treaty diverts behaviour from the national baseline (Downs et al., 1996). Given the intrusiveness of measures to reduce greenhouse gases into every single aspect of our economic activities, the depth of cooperation for any environmentally effective climate change treaty can be considered large.

Related to that, and adding complexity, is the breadth of actors that needs to be involved, convinced, stimulated or coerced into action. Reducing greenhouse gas emissions involves lifestyle aspects, industrial practices, energy production, mobility, buildings and agriculture. The actors are therefore multilayer: apart from governments, they include individual consumers, appliance users,

7 See e.g., the EU Climate Package, 2008, the Bali outcomes, and various speeches at the Major Economies Meeting, April 17-18, 2008, Paris, France.

vehicle drivers, businesses, manufacturers, real estate developers, urban planners, the metal and cement industry, the electricity sector, the fossil-fuel industry, airlines and farmers.

Given the demand for profound societal changes, it has been argued that the technologies that need to be implemented and the measures that need to be taken require more than just bringing down a number of barriers to making technologies ripe for the market; they require a change in the "socio-technical system" (Shove, 1998; Hofman, 2005). There is a significant body of literature on sociological aspects of technology and technology system dynamics, part of which will be discussed in Section 3.5. Globalization of innovation plays into this, which has been noted (Archibugi and Michie, 1995) but is generally not reflected in discussions of an international agreement. Already complex in the national context, including the aim of technological change in international policies is likely to be very challenging.

Although there are other reasons to pursue a more sustainable energy system, to increase energy efficiency and to use non-fossil sources of energy (such as security of energy supply or air quality) reduction of CO_2 emissions is the only compelling reason to make those changes as immediately and profoundly as a 450-ppmv or even a 650-ppmv scenario would require. As costs are high (IPCC, 2007c), the required depth of cooperation and associated compliance problems are very real.

The above shows that situation structure of climate change is characterized by three complicating components. Firstly, by reducing their own greenhouse gas emissions and letting developing countries increase theirs, industrialized countries would redistribute the right to use fossil-fuel-based, cheap energy to developing countries, in order to provide them with the opportunity to develop. Secondly, the industrialized countries have to make profound changes in their energy system in order to prevent the negative consequences that will primarily take place in developing countries. Any climate treaty would therefore need to result in an unprecedented depth of cooperation. And thirdly, future generations benefit from preventing climate change, while present generations bear the costs.

3.3 Rational design of international institutions, and climate change

Rational actors make self-interested decisions. If a rational-actor framework is consistently applied to public good provisions, the self-interested decision is to free-ride, and the public good will be underprovided (Olson, 1965). Applying this to climate change, the public good of a stable climate will be underprovided as the self-interested action will be free-riding (Buchner et al., 2002). This behavior is expected in all international environmental agreements, which lack enforcement mechanisms (Barrett, 1994) and thus a credible way to punish defectors. International agreements, especially if they feature a degree of depth of cooperation, should therefore be designed in such a way that they are self-enforcing, i.e., “attractive for countries to want to sign, and want to carry out the terms of agreement” (Barrett, 1994).

This section will show that the current deadlock in the climate negotiations – a Kyoto Protocol that some countries comply with and some will not, others refused to join, and shaky progress towards a follow-up – can be reproduced in a “rational design” framework. For this, I incorporate the features of the situation structure of climate change as described in the previous section, in the theoretical framework for rational design of institutions by Mitchell and Keilbach (2001). They apply a number of dependent and independent variables from Koremenos et al. (2001) in a rational-choice-based approach of institution-making to international environmental agreements. They thus create a model that can be used to predict and explain the outcome of international environmental agreements.

Mitchell and Keilbach evaluate the compliance and enforcement structure of a number of environmental treaties. As a result, they argue that in cases of symmetric externalities, where several states cause an externality and all of them also experience damage, the international institution can rely on narrow issue-specific reciprocity and is merely a coordination game. Conversely, when asymmetric externalities are in play, the situation becomes more complex and other means than just coordination are necessary to formulate an international response to the problem. The victim state could refer to a "negative linkage" in the form of coercion or other means of sanctioning, or it could use a "positive linkage" and reward the state that complies with the international agreement. Apart from the question whether the situation structure involves symmetric or asymmetric externalities, Mitchell and Keilbach consider the political strength of the victim. They arrive at a scheme of choices as depicted in Table 3.1.

Table 3.1 Outcomes of institutional design as a consequence of situation structure (after table 2 in Mitchell and Keilbach, 2001)

Political strength:	Strong victim	Weak victim	Examples
Symmetric externality	Issue-specific reciprocity		Whaling among whaling nations Ozone depletion among ozone depleting nations
Asymmetric externality	Coercion (negative linkage) OR Exchange (positive linkage)	Exchange (positive linkage)	Ozone depletion between industrialized (strong victims) and developing nations Whaling between whaling and non-whaling states (strong victims) Rhine river chloride between France/Germany/Switzerland and the Netherlands (weak victim)

Where Mitchell and Keilbach halt their analysis at the notion of weak versus strong victims, where they define "strong" victims as able to exert coercion over the perpetrating states, one could take another step and consider the economic abilities of both the victim and the perpetrator. This is relevant if countries want to choose between coercion and exchange, as poor states cannot reward, rich states are less sensitive to rewards than poor states, and weak states cannot coerce strong states. If, for the examples in Mitchell and Keilbach, one would classify the victims and beneficiaries as "rich" and "poor" besides being only strong or weak, additional insights arise (Figure 3.1).

Consider the case of a strong and rich victim, such as the United States in the "whaling between whaling and non-whaling states" and a rich and weak perpetrator, Iceland in this case. Iceland would like to continue whaling and is thus the perpetrator, while the United States was committed to halting whaling, and was the "victim" in the context of the international agreement. Although the interest of the whaling states of re-introducing commercial whaling may be partially economic, partially also cultural and social issues are at stake. In Iceland, whaling is a cultural heritage as much as a profession; the country identifies itself with whaling. Leaving the whalers unemployed therefore has a social cost far beyond economic costs. If the United States would offer rewards for complying with the International Convention for the Regulation of Whaling (ICRW), it would unlikely be sufficient as the cost is not the dominant consideration for complying with the ICRW. Negative linkage is therefore the only option for the United States to make Iceland comply.

In Mitchell and Keilbach's terms, the creation of the Financial Mechanism under the Montreal Protocol has the same background of a strong victim (the developed world in general). However, the analysis does not acknowledge that the perpetrators in the case of the Financial Mechanism of the Montreal Protocol are the developing countries, which often do not prioritize environmental issues, especially if they are costly to implement and if the problem is not harming them[8]. In this case, where the perpetrators lack the resources to address the environmental issue, positive exchange works; in this case the developed countries reward the developing countries for complying with commitments in the Montreal Protocol.

Next, in the Rhine river chloride case, the Netherlands is both a weak and a rich victim. The Netherlands paid considerable rewards to the perpetrators, primarily France, to reduce chloride dumping; a positive exchange helped in this case. But what would have happened had the Netherlands not been a rich country, able to devote significant resources to reward France and Germany for cleaning up? The options would have been very limited, and it is likely that the Dutch would have had to cope with the environmental problem. The inclusion of the rich/poor victim cases leads to the expansion of Table 3.1 as shown in Figure 3.1. It shows that in case of asymmetric externalities, it shows that the institutional design depends on 1) in the case of a strong victim (whether the perpetrator and victim are relatively affluent.

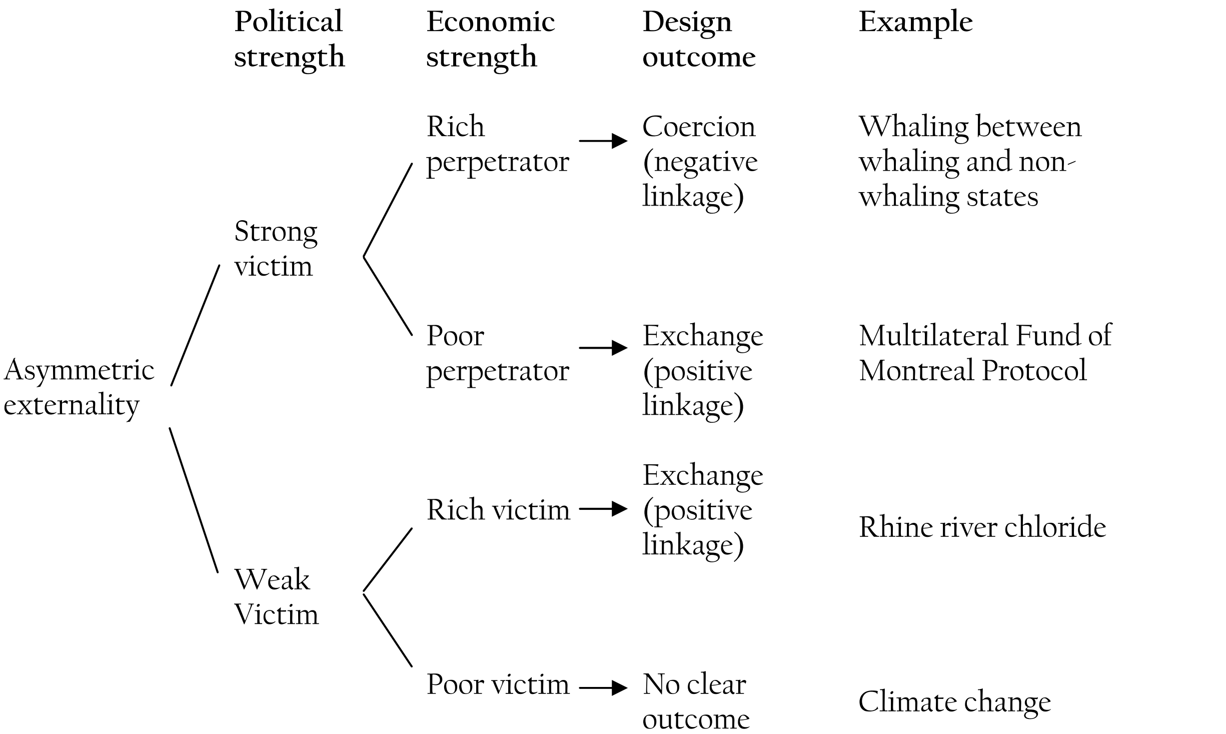

Figure 3.1 Expansion of Mitchell and Keilbach's analysis of design of international environmental institutions. In the case of climate change, the main perpetrators are the rich, strong developed nations, while the victims are the poor, weak developing nations.

For climate change, the main perpetrators are the rich, strong developed nations, while the victims are the poor, weak developing nations. It should be noted that this approximation is highly stylised and simplified. The reality of climate change is more complex than Figure 3.1 suggests. For example, the position of countries is changing. Increasingly, developing countries are perpetrators as well as victims, although it will be a several decades before China's cumulative or per-capita greenhouse gas emissions will equal those of the United States. At the same time, China and India are making renewable energy targets law. For a complete picture, more and mutually dependent issues need to be taken into account. In addition, the estimates and interpretations of interests of

[8] The damage of stratospheric ozone depletion is mainly done in high latitude, where the ozone layer is already thin and low temperatures that are needed to generate the catalytic reaction surface needed for rapid ozone depletion. Most industrialized countries are situated at those high latitudes, whereas most developing countries are in lower latitudes. At the time of the negotiation on the Financial Mechanism, most industrialized countries already had national policies to phase out CFCs.

states reflected in this paper reflect their positions in the climate negotiations around the Kyoto Protocol. In the United States, notably, the efforts on the state and municipal level have grown considerably, and more recently also on the national level. However, even given the simplifications in the model above, it explains that climate change ranks in the category where the victims are both unable to sanction and unable to reward. Because the most affected victims of climate change will primarily be located in developing countries, the demand for a regime addressing the problem is projected to be low, and the current difficulties in arriving at a post-2012 climate agreement make sense.

In the light of the above, to what extent are the UNFCCC and its Kyoto Protocol designed rationally? Although an international regime on climate change to address the issue has been established in the UNFCCC, in that sense confirming the ability of the international community to respond to such a problem, the depth of cooperation in the UNFCCC is by no means sufficient to begin solving the problem. Acknowledging this, the Parties to the UNFCCC agreed on the more substantive Kyoto Protocol five years after the Framework Convention was agreed. In the Kyoto Protocol, the industrialized countries agreed to quantitative targets for greenhouse gas emissions of (for the major players the United States, Japan and the European Union) 6 to 8% below their 1990 emissions. These emission reductions have to be achieved in the period 2008 to 2012. Trading in emission allowances is possible between industrialized countries. Developing countries have no obligation under the Kyoto Protocol to reduce emissions. However, the Kyoto Protocol rewards voluntary emission reductions in developing countries through the CDM. The emission reductions generated by CDM projects in developing countries can be sold in the international greenhouse gas allowances market and can be purchased by industrialized countries to achieve their Kyoto emission reduction targets.

Given the situation structure and the redistribution issues involved, from a rational-actor viewpoint, it is surprising that the Kyoto Protocol was agreed in the first place. Constructivists were enthusiastic, but rationalists expressed doubts whether the terms would ever be implemented. They were partly proven right – the United States did withdraw. Whether the history of the Kyoto Protocol proves the rational design framework right or wrong is an open question. Rational-actor theory predicted US defection, but not the (likely) EU compliance. Looking forward, although uncertainties have been reduced and awareness of the consequences of climate change has increased, the situation structure as explained in the previous section in relation to redistribution and depth of cooperation has not drastically changed between 1992 and the present.

The result of the analysis above is that the "rational design" framework can explain the outcomes of the current international climate regime. In this situation, issue linkage to another area than the single issue addressed in the treaty is the rationally proposed recipe (Koremenos et al., 2001). The candidate for issue linkage in this paper is technology. Game theorists have already looked into this possibility by evaluating the environmental outcome using applied game theory analysis. This analysis demonstrates that the greenhouse gas emission reduction based on technological cooperation rather than cooperation to achieve emission targets will not have comparable substance (Buchner et al., 2002; Buchner and Carraro, 2005). Although an insightful way to formalize the situation structure, this analysis assumes perfect information with the actors and no reciprocal means, both of which does not fully resemble reality. The predictive capacity of such games is therefore limited. Also given the outcome of COP13 at Bali, which defined a technology track, it is useful to view technology-oriented agreements in the framework of rational design of an international institution for climate change.

3.4 On technology-oriented agreements

Technology-oriented agreements are "all agreements that are aimed at advancing research, development, demonstration, and/or deployment of technologies. With respect to technology-oriented agreements to address global climate change, these technologies would be aimed specifically at reducing GHG emissions" (Coninck et al., 2008a). This section builds on existing literature to explain what technology-oriented agreements are, how they are viewed, what they might look like and how they could be embedded in the existing international regime for climate change.

3.4.1 Categories of technology-oriented agreements

Coninck et al. (2008a) identify four different categories of technology-oriented agreements: 1) knowledge sharing and coordination; 2) research, development and demonstration; 3) technology transfer; and 4) technology mandate, standards and incentives. They evaluate existing examples of all these types of agreements in different environmental fields, and arrive at the conclusion that all technology-oriented agreements types can make a valuable contribution to the climate change regime, as they can address market failures and reduce transaction costs. Moreover, they conclude that Type-4 agreements can be environmentally effective on their own, i.e., Type-4 agreements reduce emissions, so enough of them could achieve the same environmental outcome as an emission reduction agreement. This is a notable conclusion, as the role of technology-oriented agreements is thought to be limited to the reduction of market failures and transaction costs in a cap-based climate agreement – for cap-and-trade provides the most cost-effective outcome. Technology-oriented agreements are hence viewed mostly as complements to an emission targets-based approach to climate change mitigation. However, examples of successful Type-4 agreements exist, and technology-oriented agreements hence could theoretically form the backbone of an environmentally effective international agreement on climate change.

The conclusion on Type-4 technology-oriented agreements touches upon the most fundamental dichotomy in the discussion on climate regimes is the choice between effect and effort-based regimes[9] in the post-2012 context. Proposals for new treaty designs vary widely, both in aims and in architecture. All of them aim to address one or more of the main perceived problems of the Kyoto Protocol: the rejection by the US, the low involvement of large developing countries, the costs, the limited emission reduction, lack of incentives for long-term technological innovation, and the compliance arrangements (Aldy et al., 2003). All proposals for post-2012 regimes, including sectoral or technology-oriented proposals, can be characterized as either "effort-based" or "effect-based" treaties, while at the same time, they can be weaker or stronger in the commitment they ask.

"Effort-based" treaties fix a maximum effort of the signatories to the treaty and therefore incur an uncertainty on the effect of the treaty. For example, if a tax on CO_2 emissions would be installed by every country (as proposed by Cooper, 1998), it is clear how much the cost per ton of CO_2 is, and therefore how much measures to avoid emissions of CO_2 will cost in the worst case. It is however uncertain what will be the effect in terms of the actual reductions of CO_2, as this depends on price elasticities of a number of relevant sectors and products. "Effect-based" treaties work exactly the other way around; they fix an outcome of the treaty but allow uncertainty on the effort required to achieve that outcome. In the climate change world, the best-known effect-based treaty is the Kyoto Protocol, where the environmental outcome in terms of emission reductions is central, but the uncertainties around economic impact was one of the reasons why the United States rejected it.

9 The economic literature on this fundamental issue spans over several decades. One of the first papers is Weitzman (1974).

There are also hybrid proposals, which combine elements of effect-based and effort-based treaties. Ultimately, however, the treaty will have to prioritize between the two; when a treaty features deeper cooperation, one of the two elements will eventually be dominant. An example of a hybrid proposal is the "safety valve" approach (Victor, 2001), where an effect-based cap-and-trade system puts a maximum on the price paid for the credits, and is therefore in essence an effort-based system, as the costs in this case are capped, and not the emissions. A more genuine form of hybrid systems would be a staged approach, where one group of countries adopts an effect-based and another an effort-based approach and the basic treaty design differs for different countries.

Table 3.2 characterizes different examples of existing technology-oriented and emission reduction agreements or proposals for post-2012 regimes on whether they are dominantly effect- or effort-based, and whether they are weak or strong in terms of commitments. The distinction in depth of cooperation is an interpretation of the author. The IR literature has established that the perception of the cost of the concession in an agreement is in the eye of the beholder (Larson, 1988), and thus so is the depth of cooperation. The categorization as “strong” or “weak” in Table 3.2 is a combination of the cost to the actor, and the contribution it is likely to make to solving the problem.

Table 3.2 Attribution of existing proposals to effect- or effort-based, and emission-target or technology-based agreements. The literature citations provide reference to where the agreements are assessed.

General design	Cooperation depth	Examples of emission-based proposals	Examples of technology-oriented agreements and proposals
Effect-based	Strong	Multi-stage approach (Berk and Elzen, 2001), Brazilian proposal[a], Kyoto Protocol	EU Renewable Energy Directive, MARPOL treaty (Coninck et al., 2008a) or the Backstop Protocol (Edmonds and Wise, 1998)
	Weak	Intensity targets, weak sector-based emission targets (Baron, 2006)	Moderate technology deployment agreements, moderate technology standards (Barrett, 2003)
Effort-based	Strong	Carbon tax (Cooper, 2000), emissions trading with safety valve (Victor, 2001)	Asia-Pacific Partnership for Clean Development and Climate (Coninck et al., 2008a)
	Weak	Voluntary intensity targets	Carbon Sequestration Leadership Forum (Coninck et al., 2008a)

[a] See http://unfccc.int/resource/docs/1997/agbm/misc01a03.pdf.

Table 3.2 has two main messages. Firstly, in both categories of emission-based and technology-oriented agreements, there is a genuine breadth of options for treaties that all address climate change in one or the other way. This means that at the climate change negotiation table, there is an actual choice of directions, or there may even be potential for parallel agreements for groups of countries that favour the one or the other policy. Secondly, technology-oriented agreements can be effect-based, i.e. drafted in such a way that they have environmental effectiveness as their prime goal, and can show a significant depth of cooperation.

3.4.2 What technology-oriented agreements could look like in practice

At this point, a discussion of the concrete design of technology-oriented agreements is challenging as thinking on it has only recently begun. Many assumptions are premature and the positions of major stakeholders remain to be shaped. Still, in the interest of the understanding of the role of such agreements, it is important to clarify how they may work in practice and which proposals are currently floating around.

Technology-oriented agreements are often mentioned as a subcategory of a wider and as of late much-discussed type of agreements: sectoral agreements (Baron, 2006; Bodansky, 2007). Factors that would make sectors susceptible for sectoral agreements have been identified in a comprehensive paper by Bradley et al. (2007), and include the share of total world greenhouse gas emissions, exposure to international trade issues, the number and concentration of actors, uniformity of products or processes, whether the government has a role in the sector, and whether data availability and reliability are issues. The reasons for these factors can be readily explained. Trade-sensitive sectors are potentially disproportionally affected by emission target approaches, as they cannot charge the costs of carbon abatement on their customers in a competitive global market where other countries do not have emission targets. If the emission reduction potential is small, and the number of actors is large, making an international agreement might be cumbersome and complicated for only a limited result. Homogenous processes or products and availability of high-quality data make monitoring and enforcement of the agreement much easier. As sectoral agreements are often thought of as an agreement between governments with consent of the private sector, it seems better for the outcome of such an agreement when the government already is engaged in the sector.

Several studies have identified hypothetical sectoral or technology-oriented agreements. They include:

- Backstop Technology Protocol: the industrialized countries commit to capture and storage CO_2 from all new power stations and synthetic fuel plants from 2020 onwards. Developing countries commit to do the same as soon as their per capita GDP exceeds a certain amount (Edmonds and Wise, 1998);
- Iron and steel benchmarks: developing countries comply with an expert-judged benchmark for energy (or carbon) efficiency in iron and steel plants. Industrialized countries provide incentives for beyond-benchmark improvements through a Technology Finance and Assistance Package (Schmidt et al., 2006);
- Cement Sustainability Initiative (CSI): the World Business Council on Sustainable Development initiated CSI, which aims to establish country baselines and carbon intensity targets for the cement sector. Developing country participants would work with a no-lose baseline, whereby they would be rewarded when they reduce emissions below the baseline, but not punished when they exceed it (Baron and Reinaud, 2007);
- Sugarcane-based bioethanol: The EU, Brazil and a number of suitable countries in Sub-Saharan Africa agree to develop a large-scale sugarcane-based bioethanol industry in Africa. The EU finances the technology transfer by Brazil to Africa, and provides a guaranteed market for bioethanol (Coninck et al., 2007).

Technology-oriented agreements would come about by negotiation, taking into account specific technological and geographical circumstances, and in a bottom-up manner. It is not the premise of this paper to provide the most viable design of a technology-oriented agreement, although the examples above give an idea on what such agreements may look like in practice. The process of negotiating a number of technology-oriented or sectoral agreements in parallel might be challenging from a negotiation management point of view. The next section therefore discusses how technology-oriented agreements might be embedded in the current international climate policy context of the UNFCCC.

3.4.3 Institutional embedding of technology-oriented agreements

The UNFCCC, as well as other international organizations, are no strangers to technology. They have set up mechanisms aimed at technology, with varying degrees of success (Coninck et al., 2008a). The UNFCCC's main achievements with regard to its specific aim of promoting technology transfer to developing countries (UNFCCC, 1992: Article 4.5) are the establishment of an Expert Group on Technology Transfer (EGTT), and the formulation of a number of "technology need assessments" of various developing countries. The term of this work program ended recently. Negotiations on a follow-up have maintained the EGTT and extended its mandate to the technology track of post-2012 climate policy. Discussions around technology transfer in the UNFCCC have so far proven difficult because of diverging positions of industrialized and developing countries on acknowledgment of earlier accomplishments and the level of future financing and engagement.

The UNFCCC's financial mechanism is the Global Environment Facility (GEF), which is a fund, effective in implementing projects using new and cleaner technologies in developing countries, but its funding is limited, and therewith scope of impact. Technology is also indirectly included in the CDM. This mechanism has seen a boost in project implementation, greatly exceeding the effects of the GEF, and involving notable technology transfer in various sectors (Haites et al., 2006). For some technologies, the CDM has proven an effective incentive mechanism, but for other technologies that would be useful from the perspective of sustainable development (e.g., PV for rural electrification and end-use efficiency), it has so far hardly made a difference. This again indicates that a market-based instrument does not necessarily lead to the preferred technological change. In addition, the post-2012 demand for certified emission reductions of the CDM depends on the emission reduction targets agreed as part of the eventual follow-up of the Kyoto Protocol, which are uncertain as of yet. Although in principle a successful mechanism, the future of the CDM is in the hands of the negotiators of a post-2012 agreement based on emission trading.

Various ways exist in which technology-oriented agreements could be embedded in the UNFCCC context, through ongoing negotiations that provide a policy window to incorporate new insights. They include the abovementioned discussions on technology transfer in the UNFCCC under Article 4.5, but recently notably the technology track under the Bali Action Plan and the EGTT mandate. The Bali Action Plan and the EGTT mandate have opened the possibility to agree on technology under the UNFCCC umbrella. There is now speak of an "Enhanced Technology Framework" which could have technology-oriented agreements as one of its components.

Another possibility is to set up a separate agreement outside of the UNFCCC context, such as the United States have done in the case of the Asia-Pacific Partnership on Clean Development and Climate (APP) in 2005. The APP is essentially a technology-oriented agreement but its commitments are limited to knowledge sharing and possibly some technology demonstrations. Considering the issues around agreeing on mitigation efforts, a limited number of players is often suggested to streamline agreement, and the group of seven countries that are part of the APP form a significant group in terms of world population, GDP, energy use and CO_2 emissions. However, the formation of the APP has caused unrest with the Kyoto Parties, and the APP participants have been accused of undermining rather than fortifying climate change mitigation efforts in the existing institutions. So far, the APP has not proven effective in bringing down emissions or advancing technology (UNFCCC, 2008c; Asselt, 2007). An alternative agreement outside of the UNFCCC would only be worthwhile if it would lead to significant addition action compared to the UNFCCC.

3.5 Views on technology in the international climate regime

The Bali consensus reflects the expectation that technology will play a major role in the reduction of greenhouse gas emissions. From past experiences in technological development, theories on rational design of international institutions, and the specific characteristics of the climate change challenge, some leads can be given on how an international regime for climate change can be designed in such a way that it is environmentally effective by being effect-based and to some extent self-enforcing, as well as instrumental in bringing about the required technological change. Whether involving technology would aid or frustrate climate change mitigation is subject to debate. Some of the views are reviewed and analyzed here.

3.5.1 Views and considerations on the dynamic of technology-oriented agreements

It has been convincingly argued that environmental externalities and technological market failures reduce the effectiveness of cap-and-trade policies (Jaffe et al., 2005), and modelling suggests that a combination of technology-oriented R&D and sector-based emission targets, taking into account the imperfect market incentives for technological development and the differences between sectors, leads to a more economically efficient outcome (Otto et al., 2006). But even this enlightened economic view fails to account for the specifics of technologies, such as the different stages of development of technologies, the processes underlying adoption of technologies by users, infrastructure needs, desired or undesired lock-ins and path dependencies, and the different turnover times for various technologies, resulting in varying natural moments of technology replacement (see Grübler and Nakicenovic, 2002). Another weak point of the narrow emission-reduction approach is that it does not take co-benefits of the measures into account, leaving these positive externalities invisible for the negotiating parties. Consequently, emission reduction agreements are less conducive to specific reciprocity to increase chances of agreement and compliance.

The question then arises whether technology-oriented agreements might improve on emission target-based agreements. Firstly, for a self-enforcing, effect-based treaty, Parties should have an interest in its implementation. Upon agreeing on a technology-oriented agreement, countries that have or expect a strong market position for their industry in the field of the technologies that will be implemented as a result of the agreement are likely to be supporters and enthusiastic implementers of the agreement (Steiner Brandt and Tinggaard Svensen, 2006). They are unlikely to free-ride. Even if more countries boast industries in the same sector (e.g., several European and Asian countries have wind turbine producers), a far-reaching agreement on that sector would signify growth in all those countries. They are likely to view technology-oriented agreements as an opportunity rather than a cost.

This issue relates strongly to first-mover advantages, and the question is whether these advantages can actually be realized. First-mover advantages are much debated in economic and management literature, mostly at the firm level. Liebermann and Montgomery (1987) define it as "the ability of pioneering firms to earn positive economic profits". The most important source of first-mover advantages for climate-mitigation technologies, which are characterized by high capital costs and low turnover rates, is which firm can supply the technology first against an affordable cost[10]. Countries tend to be optimistic about their industry's ability to provide such leadership, and thus perceive first-mover advantages. Such perceived first-mover advantages could give confidence that a technology-oriented agreement leads to benefits for a country and its industry. A treaty that aligns with (vested) interests of parties otherwise not interested in emissions reductions would therefore more likely be self-enforcing.

Lastly, the level of technological development, or the maturity of a technology, determines what is the most effective way of designing a technology-specific international or domestic policy (Sandén and Azar, 2005). Near-commercial technologies, i.e. technologies that are advanced but that still face cost barriers inhibiting market entry, will most likely benefit from market-based instruments to enhance diffusion, such as subsidies or tax benefits; instruments that contribute to the "learning by doing" factor of the learning curve. Such efforts, however, are misplaced for technologies in the research or demonstration phase. Those technologies should be supported by targeted research and development support, or specific support for demonstration projects; on the "learning by searching" part of the learning curve (Smekens, 2005). Notably the demonstration step, which is

[10] A related issue is Intellectual Property Rights (IPR), which exist to provide incentives for innovation. For energy technologies, IPR is generally regarded as an issue that can be resolved through payments of royalties (see, e.g., Barton, 2007), which is a very small part of overall investment

the essential bridge between the research and the mature-market phase, is often neglected in policymaking, as it is both costly and risky.

3.5.2 Advantages of technology-oriented agreements

A number of advantages of technology-oriented agreements relative to emission-based approaches can be identified: 1) ease of implementation, particularly for developing countries; 2) political feasibility; 3) cost predictability; 4) compliance; and 5) compatibility with innovation trajectories.

First, the ease of implementation, or administrative feasibility, would be better compared to a cap-and-trade system, as the policy instrument is more straightforward. Although emissions trading, according to economic theory, is the economically optimal way of providing incentives for greenhouse gas reductions, it is institutionally quite challenging: emissions trading is a relatively complex instrument, it needs a functioning legal system both in the states and on the international level, and it may not work optimally due to "friction" factors in markets, hedging behaviour of countries and firms, and because of imperfect or asymmetric information (Akerlof, 1970). A relatively developed governance system as the European Union already has difficulties implementing a domestic emissions trading scheme (Egenhofer et al., 2006), and it can be expected that the difficulties in developing countries will be even larger (Greenspan Bell, 2006).[11] Technology-oriented agreements can be made less complex, may provide more of a basis to include developing countries and may increase the likelihood that they actually comply. On the other side, one would need several technology-oriented agreements, which would add to the institutional complexity and increases the risk of fragmentation. This is discussed in the next section.

Second, it was argued in Section 3.3 that the positions of negotiating states in the UNFCCC give little hope for an agreement on emission reductions, although the recent developments around Bali have shown some convergence. The United States, at this point, is unlikely to participate in an international regime that requires mandatory emission reductions (although it may implement a cap domestically) (Ueno, 2007). The large developing countries, who have recently experienced rapid economic growth and rising CO_2 emissions, are likely to resist obligations for non-Annex I Parties. The reason for their concerns partly relates to competitiveness of their industries. Technology-oriented (or sectoral) agreements can be designed in such a way that they affect only part of the economy, can be perceived as relatively harmless, and could also take competitiveness concerns away as all global sectoral players would make comparable efforts. In addition, the "perceived first-mover advantages", introduced in the former section, may play a role. The potential for a meaningful agreement in technology-oriented agreements appears to be larger than for emission targets as it matches better with the interests of several important players.

Third, cost of an agreement on technology are more predictable. More than with generic national emission reduction targets, it is clearer what the costs of a technology-oriented agreement will be, because the treaty would specify into some detail which measures are to be implemented in which sectors. In this respect, a technology-oriented agreement, and even a group of them covering many sectors in an economy, compares favourably to an economy-wide cap on emissions or even a carbon tax. The flipside of this advantage is the lack of flexibility, which is discussed in the next section.

A fourth advantage relates to compliance. International institutions, notably those addressing environmental problems, often lack the legal mandate to sanction defecting states. Enforcement is hence one of the fundamental problems in the design of international environmental institutions.

[11] This institutional complexity may explain why early environmental law is largely based on straightforward command and control measures rather than market-based approaches. In case of weak institutions and unfamiliarity with more sophisticated market-based instruments, regulation might be the better choice.

There is a continuing literature discussion whether the lack of enforcement actually reduces chances of compliance and affects the depth of cooperation (Chayes and Chayes, 1993; Downs et al., 1996; Simmons, 2000; Raustiala, 2005). The discussion is around the question if compliance with international agreements is usually good because of peer pressure and effectiveness of the agreements changing behaviour, or because countries are reluctant to agree on agreements that they are unlikely to comply with. In the case of the Kyoto Protocol, this is convincingly shown. Showing its commitment to taking on a costly and stringent target for greenhouse gas emissions, Canada ratified the Kyoto Protocol in December 2002. Internally, however, not much had happened in terms of domestic measures, and Canada's greenhouse gas emissions rose by nearly 27% between 1990 and 2004, which left Canada almost 35% above their Kyoto target of -6% (Environment Canada, 2006). The rise in emissions was mainly due to the carbon-intensive tar sand exploitation industry, a sector that started flourishing in the 1990s. It remains to be seen whether Canada will comply with the Kyoto Protocol by buying emissions allowances on the global CO_2 market, or whether it will decide to not comply. In Canada's case, the initially lukewarm domestic commitment to the Kyoto Protocol might turn into defection. Broadening the issue of climate change towards technological development might increase support for a climate change agreement. One could for instance imagine that Alberta's oil and gas sector could use its favourable position to develop cleaner technologies that could later be exported to the United States and other fossil-fuel-producing countries, and which would increase their support for an international agreement as it provides for reciprocity. If such situations could be foreseen and anticipated by states, technology-oriented agreements could increase chances of general compliance.[12]

There have been proposals for increasing compliance for post-2012 regimes, for instance by making the cost of the treaty more predictable by the earlier mentioned "safety valve" or by making a technology-oriented R&D agreement self-enforceable via an encouraging signing-up scheme (Barrett, 2003). The latter has been evaluated on environmental outcome in the above-mentioned study by Buchner and Carraro (2005), who use applied game theory analysis to demonstrate that the greenhouse gas emission reduction based on technological cooperation rather than cooperation to achieve emission targets will not have comparable substance. However, in their analysis, they do not take into account the potential self-enforceability of technology-oriented agreements that further the technological interests of countries, nor the favourable attitude of business for certain technologies, both of which are indeed hard to approximate in any model, even qualitative ones.

A last advantage is more theoretical, and although not central to the analysis in this paper, it might be worth mentioning. Emission reduction agreements, particularly cap-and-trade, are technology-blind, which leaves economic flexibility but is not necessarily most environmentally effective. A technology goal has a wholly different dynamic than an emissions target. Including the concept of technology in an agreement therefore raises a host of questions of different nature than the questions for emission target-based approaches. How do technologies and policy interact? What is effective and efficient technology policy? How is technology perceived and implemented in society? Technological change takes more than merely the change of technology; it often requires a change of the context in which the technology operates as well. Consequently, technologies are introduced at a certain pace, which is not only determined by economic factors such as incentives, but also by user preferences and habits, technological maturity, and technology-specific turnover factors. A useful framework may be the "co-evolutionary, multi-level perspective" that has been introduced by Frank Geels (2005), based on a decades-long debate in the sociology of technology. In this framework, the starting point is the present socio-technical system. Although the system is stable and firmly locked in by a multiplicity of social, economic, technological, and cultural factors, it is still dynamic. Innovation takes place, but is strictly "incremental" - it will not spontaneously

[12] On another note, the “windfall emission reductions” that the UK and Germany have experienced since 1990 might have to be considered too.

lead to the overturning of the whole system, but establishes the system even more firmly, and enhances the stability of the system through the "path dependency lock-in" (see also Arthur, 1989).

System innovations will hence not come about unless modifications in the multiple dimensions are introduced simultaneously. In the case of climate change, hydrocarbon regime, responsible for much of the emission of CO_2 to the atmosphere, is a the socio-technical regime. In order to provoke technological change in that regime, the landscape should create favourable windows of opportunity that give novelties the chance to step in, but this will not happen unless the novelties have been given the chance to develop and give themselves a place in the multi-dimensional reality. The change of a socio-technical regime, therefore, requires alignment of landscape developments, including appropriate timing (Zundel et al., 2005), and the maturing of the new technologies in a socio-technological context.

Although the notions of technological dynamics appear to slowly trickle through at the national level, they are not commonly incorporated in international policy-making. The Kyoto Protocol is one of the examples of international treaties where the notion of accumulating niches or technological co-evolution are not addressed. Specific attention to the processes that lead to technological change may help the feasibility of an agreement, through improving on applicability, appropriateness and types of incentives given.

3.5.3 Disadvantages of technology-oriented agreements

The disadvantages of sectoral or technology-oriented agreements relate very much to the advantages that are generally attributed to emission-target-based approaches: environmental effectiveness, cost effectiveness, and flexibility. In addition, particularly for technology-oriented agreements, there is a risk of governments playing an important role in "picking technology winners" – something that can be better left to the market.

One of the clear advantages of an emission target was explained in Section 3.4: it is an effect-based agreement, which fixes the environmental outcome and therefore (assuming full compliance) guarantees the environmental effectiveness of the agreement (Aldy et al., 2003; Bodansky, 2007). Although in principle technology-oriented agreements can also be designed in an effect-based way, adding up to the same result as an emission-target agreement, there is a complication that distorts the environmental effectiveness, which relates to the transparency of the agreement as a whole. A range of sectoral and technology-oriented agreements could lead to fragmentation of the climate regime, with potentially negative consequences for goal attainment (Koskenniemi and Leino, 2002; Raustiala and Victor, 2004). Administrating all technology and sectoral agreements under one umbrella, most likely the UNFCCC, would help, but knows many challenges. The Bali consensus has put the UNFCCC in a position to make progress in the technology field, but the inclusion of technology (and finance) to the discussions will add to the complexity of the negotiations (even though, as argued above, the individual technology-oriented agreements are likely to be easier to implement).

Another often-mentioned problem with agreeing on technology by governments is that governments lack the expertise and the information to make the right choices of technology winners (see e.g., Nelson and Langlois, 1983). In some technology-oriented agreements, this can be avoided. In the "Backstop Protocol" (see Section 3.4) for instance, the technology favoured is CO_2 capture and storage (CCS), but it is phrased in a way that fossil-fuel-fired electricity production without CCS is phased out. Power producers therefore have the option to not use fossil fuels but renewables for electricity production, and the agreement would be technology-prescriptive in a limited way. But generally, especially among economists, the contention is that governments should leave the technology choice to the market. The role of the government would have to be to shape that market rather than to micro-manage technology, while technology-oriented agreements clearly attribute a bigger role.

Perhaps the largest disadvantage to technology-oriented and sectoral agreements is on cost effectiveness and flexibility. In Bodansky's (2007) words: "An economy-wide approach gives countries maximum flexibility to reduce emissions in whatever sector is cheapest, and discourages emission leakage from regulated to unregulated sectors. By contrast, focusing on particular sectors restricts options and thereby raises costs". This summarizes well that the cost-effectiveness and flexibility of a carbon tax or an emissions trading scheme is unmatched, and from an economic viewpoint is clearly preferred over a sectoral or technology-oriented approach. However, if indeed cost effectiveness was the only compelling criterion for countries to join and comply with an international agreement, the Kyoto Protocol and the follow-up negotiations would have been less problematic. History has taught us that this is not the case. Although cost effectiveness is important and should be maximized as much as possible, the necessity of having an overall framework that meets approval of the most important countries and credibly addresses climate change appears to be larger.

3.6 Conclusion: a way forward for technology in the climate regime?

This paper argues that agreement on deep emission reductions is not necessarily in line with rational interests of important actors in the climate change arena. Treaties that are designed to strictly pursue a single policy goal, such as greenhouse gas emission reduction, have many benefits: they are effect-based, and, in the case of a worldwide, multi-gas, cap-and-trade system, they allow for much flexibility in achieving the targets in different countries, sectors, and by reducing a range of greenhouse gases. The cost-effectiveness, in theory, is therefore optimal.

However, such emission-based agreements have disadvantages that technology-oriented agreements may solve. The current state of negotiations demonstrates that participation and compliance are difficult. The consensus reached in Bali includes a mitigation track, but also a technology track. This paper argues that some of the arguments against technology-oriented agreements can be refuted. Firstly, technology-oriented agreements can be designed in an environmentally effective way; they can be effect-based just as well as emission-based agreements, and potentially at greater cost certainty. Secondly, technology-oriented agreements can make use of Parties' perceived first-mover advantages of technological leadership. Thirdly, they allow for more flexibility of alignment with strong vested interests in important sectors, notably the fossil-fuel industry. This would increase the scope of agreement, and would make the treaty more self-enforcing. Lastly, technological maturity and dynamics of the socio-technical system can be taken into account, which could lead to greater ease of implementation and lower costs relative to an agreement that does not take these factors into account. In addition, technology-oriented agreements can be institutionally embedded in existing agreements, particularly the UNFCCC, potentially by creating subgroups of countries signing up to various technology-oriented agreements.

Technology-oriented agreements, however, are no panacea. Compliance is by no means a certainty, they are less cost-effective than emission reduction agreements, and fragmentation and poor design might pose a threat to environmental effectiveness. A number of recommendations can be made to address the disadvantages of taking technology-oriented agreements further:

- To ensure environmental effectiveness, focus on implementation (effect-based) where this is technologically appropriate;
- Be technology-specific where necessary but allow for as much technological flexibility as possible to allow the market to pick the technological winners;
- To prevent potential fragmentation, use the UNFCCC as an umbrella convention, and allow time and resources for managing more complex negotiations;

- To increase acceptability and compliance for self-enforceability of the agreement, make use of perceived first-mover advantages and vested interests.

This paper has argued the difficulty in reaching agreement on a post-2012 international climate regime reflects the perceived self-interests of the players, and that a possible way forward for an international agreement on climate change mitigation is to link the climate change issue to technology. There are reasons to believe that technology-oriented agreements can create leverage for those countries otherwise unwilling to reduce emissions. It was argued earlier that a compilation of technology-oriented agreements can provide an environmentally effective replacement of an emissions-trading-based agreement. However, focussing exclusively on technology-oriented agreements would lose much of the benefit, particularly in cost-effectiveness and market pull, of emission targets, for instance in a cap-and-trade regime context. A well-designed, complementary combination of technology-oriented agreements and emission target-based approaches could shift vested interests, could make an overall treaty more self-enforcing, and could make preventing climate change more feasible.

Chapter 4 Widening the scope of policies to address climate change: directions for mainstreaming[13]

Abstract
Both mitigation of and adaptation to climate change require actions to be taken in many sectors of society, but so far this is hardly happening. This paper suggests possibilities for widening climate change policy by strengthening inter-linkages between climate policies and various relevant policy areas to mainstream climate change concerns. It argues that, if these inter-linkages can be strengthened and policy coherence is improved, the effectiveness of climate policy can be enhanced while also supporting these other policy areas. The contention in this paper is that improved policy coherence and mainstreaming requires climate policies to go beyond the UNFCCC framework to realise its full potential and to better deal with possible trade-offs. The potential benefits in the policy domains of poverty reduction, rural development and agriculture, disaster management, energy security, air quality and trade, and finance are examined, and the institutional and organisations linkages highlighted. Finally, opportunities for mainstreaming are identified to make better use of possible synergies between climate and related policy areas.

4.1 Introduction

There is ample evidence now that anthropogenic climate change poses serious threats to development (IPCC, 2007b). Despite international agreement, laid down in the United Nations Framework Convention on Climate Change (UNFCCC, 1992) that dangerous human interference with the climate system should be prevented, climate policy faces many challenges (see amongst others Barrett, 1998; Victor, 2001). One of them is that many climate-relevant decisions continue to be taken in different policy areas with little or no regard to climate change. Both mitigation of and adaptation to climate change require actions in many sectors of society, but climate change concerns are so far hardly integrated in the decision-making in those sectors. Most analyses of post-2012 climate policy so far have focussed on the design and stringency of the post-2012 agreements within the UNFCCC or alternatives to the UNFCCC and its Kyoto Protocol (see e.g. Aldy et al., 2003; Höhne, 2005). This paper aims to assess the inter-linkages between climate change policy and a number of other policy domains and the opportunities and challenges for mainstreaming climate change therein (Huq et al., 2004; Huq and Reid, 2004). The policy domains of poverty reduction, rural development and agriculture, disaster management, energy security, air quality and trade and finance are examined for such inter-linkages.

The contention in this paper is that the effectiveness of climate change policies can be enhanced by mainstreaming climate change in other policy areas. Establishing appropriate linkages between functionally linked issues enhances the opportunities for problem solving and can increase the efficiency and effectiveness of policy making. Realisation of this potential, this paper argues, requires climate policy makers to widen their scope and go beyond the UNFCCC framework. This paper, hence, explores the possibilities to widen climate change policy by providing possible directions for mainstreaming and establishing institutional and organizational inter-linkages between climate change policy and a number of relevant policy areas (Asselt et al., 2005; Bouwer et al., 2006). The paper in this way contributes to the discussions on a post-2012 climate regime.

[13] This paper was published in Environmental Science and Policy (Kok and Coninck, 2008). It is to a large extent based on the report "Beyond Climate. Options for broadening climate policy" (Kok and Coninck, 2004). It has also benefited from the outcomes of the Development and Climate programme (Kok et al., 2006). This research was originally supported by the Netherlands Research Programme on Climate Change, Scientific Assessment and Policy Analysis. The complete report, on which the article is largely based is "Beyond Climate: Options for broadening climate policy" and is available via www.mnp.nl. We thank Harro van Asselt, Stefan Bakker, Cees van Beers, Frank Biermann, Laurens Bouwer, Joyeeta Gupta, Jan van Heemst, Bert Metz, Jan Verhagen and three anonymous reviewers for helpful comments on earlier drafts of the paper.

The aim of a mainstreaming strategy, as part of climate policies, is to capture the potential in other policy areas and sectors for implementing climate-friendly and climate-safe development pathways (Munasinghe et al., 2002). It would help to enhance the climate change regime by increasing policy coherence, minimising duplications and contradictory policies, dealing with trade offs and capturing the opportunities for synergistic results in terms of increased adaptive capacity and lower emissions. It may also help to make climate change policies more acceptable to both industrialised and developing countries (Davidson et al., 2003; Gupta 1998; Gupta and Hisschemöller, 1997). The importance that countries for example attach to health and air quality can result in addressing climate change indirectly, but only if these policy activities are well aligned.

It is however also clear that a mainstreaming strategy comes with challenges of its own. We identify four main problems. Firstly, during recent decades, the number of international (environmental) treaties and the institutional density on the international level increased dramatically. This has taken up a large part of the political manoeuvring space. Given the existence of different regimes, with their own rules, dynamics, culture and ambitions, improving policy coherence and mainstreaming climate change into them may lead to friction. Climate change is often only one of many issues that need to be addressed and a risk of mainstreaming overload arises. Secondly, existing international policy frameworks are usually not designed to promote mainstreaming and the organisational structures with their vested interests complicate this further. This often results in a lack of cooperation, coordination and joint decision-making on different levels, hindering any mainstreaming strategy. Thirdly, there is the issue of communication and understanding. Different communities operate on different spatial and time scales, have different priorities and speak different languages. This is especially the case for climate change: a long-term problem characterised by intrinsic uncertainties. And fourthly, it needs to be acknowledged that climate change is not always synergetic with other policy areas. Between climate change and energy security of supply for example, clear trade-offs can be identified for coal-producing countries. Improving on institutional inter-linkages help dealing with these trade-offs (OECD, 2005a; Kok et al., 2006).

This paper aims to strike a balance between the opportunities and limitations that a mainstreaming strategy has on offer for future climate policies. In the analysis, a distinction is made between climate change adaptation (Section 4.3) and mitigation (Section 4.4), as the interactions are notably different for both elements of climate policy. In these sections, the following issues are subsequently addressed. It starts with an analysis of what the potential synergies and trade-offs between climate change and other policy areas are. Although in some areas, modelling exercises are available to arrive at quantitative estimates of synergies (particularly in the field of air quality and climate change mitigation) in most there is insufficient quantitative information to pursue the same level of precision. Subsequently, we identify policy options for mainstreaming. Although we recommend directions for mainstreaming, to go deeply into this for every policy area is beyond the scope of this paper. This has two main reasons. The paper would become overly expansive and the general message, that there is a considerable underused cost-effective potential for climate change mitigation and adaptation that can be exploited through mainstreaming, would be lost in detail. Furthermore, in mitigation but particularly in adaptation, it is highly context dependent, whether a particular recommendation can be carried out and would be effective. To conclude, this paper suggests ways forward on the institutional level to make better use of the possible synergies between climate change and the other areas (Section 4.5), and ends with a discussion of the conclusions (Section 4.6).

4.2 Approach

The approach in this paper is to start from development and societal priorities of countries and sectors to identify opportunities for widening the scope of climate change policy. So, this paper looks for opportunities realising such primary objectives as poverty alleviation, improving health, food and energy security, while also realising climate benefits. By aligning development and climate objectives, mainstreaming climate change adaptation and/or mitigation can help to "make development more sustainable" (Davidson et al., 2003). From a climate change perspective, this means development that reduces vulnerability to climate change impacts (adaptation) and/or development with lower greenhouse gas emissions (mitigation). Earlier analysis has reviewed the existing literature on the potential for this in a number of policy areas (Kok and Coninck, 2004). This paper summarises the main findings and brings them together in a coherent framework to discuss the potential of a mainstreaming strategy as part of the effort to combat climate change.

As a first step this paper explores the potential for mainstreaming climate in other policy areas, by looking at the *material (or factual) inter-linkages*. Material inter-linkages are inherent physical connections between policy domains. Analysing material inter-linkages helps to identify the potential of enhancing collaboration between different issues because of the way they interconnect. Material inter-linkages between air quality and climate change are for instance, that ozone is both an air pollutant and a greenhouse gas or that certain air pollutants can be chemical precursors for greenhouse gases. In the second step *possible measures* are identified that either are synergetic or result in trade offs between different policy goals. A possible measure may, for example, be to increase the use of domestic coal, without applying carbon dioxide capture and storage. In that case, the energy security situation of a country may be improved, but the climate change problem is worsened. In the third step possible *policy options* for mainstreaming climate adaptation and mitigation in these other policy areas are analysed.

Table 4.1 provides an overview of the policy areas for which this paper explores the possibilities for mainstreaming climate change adaptation and mitigation. This selection is not meant to be exhaustive for all areas that interact with climate change, but provides an overview of some the most relevant policy areas to look at. Other possible policy areas to look at would include water (see for example Cooperative Programme on Water and Climate (2006) and forestry (see for example Trines et al. (2006)).

Table 4.1 Policy areas for which this paper examines the possibilities for mainstreaming climate change adaptation and mitigation

Adaptation	Mitigation
Poverty reduction Rural development and agriculture Disaster management	Energy security of supply Air quality and health Trade and finance

The last part of this paper considers the *institutional and organisational inter-linkages* that are necessary to capture the potential identified. These are connections between different institutions that rule a specific policy domain and/or the organisations that are active in that domain. By looking at this, it is possible to examine whether different institutions and organisations are compatible, synergetic, incompatible or contradictory. This helps to identify ways in which the combined impacts of institutions and organisations can be enhanced (Asselt et al., 2005). The assumption is that also on the institutional and organisational level changes need to take place before the policy options for mainstreaming can be implemented effectively. Although this needs to start within countries, this paper will focus on the level of international institutions that have to provide the conditions that enhance national implementation.

4.3 Widening climate change adaptation efforts

Adaptation to climate change comprises all efforts to reduce vulnerability to the impacts of climate change (IPCC, 2001a). Vulnerability is a function of exposure, sensitivity to impacts and the inability to cope or to adapt. This section discusses the material inter-linkages, possible measures and policy options for mainstreaming climate adaptation in poverty reduction, rural development and agriculture, and disaster management.

4.3.1 Material inter-linkages with climate change adaptation

Strong material linkages exist between climate change adaptation and poverty reduction, rural development and agriculture, and disaster management. These linkages come about through the following characteristics of impacts of climate change, that: a) will likely be highest in developing countries; b) would be severest for sectors that are highly climate-dependent, notably agriculture; and c) are likely to hit the poorest part of the populations most as they are less able to cope or to adapt.

Poverty reduction and the fight against hunger and malnutrition are the highest priorities on the (international) development agenda. In many developing regions, natural resources are especially relevant as a means to lift the rural poor above the poverty line, focusing attention on rural development (Millennium Ecosystem Assessment, 2005). In 2000, all 191 UN States agreed to halve poverty and hunger by 2015 in the Millennium Development Goals (MDGs) (Millennium Declaration, 2000). In 2000, about 1.1 billion people (or 23% of the total population of developing countries) lived on less than US$1 a day (UNDP, 2004). It is, however, increasingly recognised that meeting development goals, including the MDGs, will become more difficult as a result of climate-change impacts (DFID, 2002, UN Millennium Project, 2005). Climate change will for example reduce economic growth, threaten investments and lower food production and these impacts will be felt most strongly by the poor.

FAO's latest estimates (1997-99) indicate a total of 815 million undernourished people in the world of which 777 million in the developing countries. For the developing countries, the latest figure represents a decrease of 39 million since 1990-92 (the benchmark period used at the World Food Summit in 1996 (FAO, 2005)). Climate change is starting to become an additional stress factor for **agricultural production**, having a negative impact on the productivity of the land, especially in low-latitude countries (Mendelsohn et al., 2006). In developing countries, many people are directly dependent on the natural resource base for food production and other services, either for subsistence or for income through selling of agricultural products. Agriculture has always been one of the most climate-sensitive economic sectors. Some 40% of the world's land area is located in environments which are prone to water scarcity (Kabat and Schaik, 2003), most of them in developing countries. The major characteristic of these land areas, often denoted as "drylands", is the extreme spatial and temporal variability of precipitation.

Societies evolving in these environments have, over the centuries, developed a broad range of mechanisms to cope with climate variability (Falkenmark and Rockström, 1993, Leisinger et al., 1995; Dietz et al., 2004). These mechanisms are increasingly challenged as traditional weather patterns are changing and the number of reported climate-related **disasters** is rising rapidly. Although currently the cause for this trend cannot be attributed to climate change, and much of the rise is probably due to population growth, particularly in coastal areas, and improvements in reporting, it is likely that climate change will reinforce the trend towards more frequent, more severe and more costly climatic disasters (IPCC, 2001c; Aalst, 2006).

4.3.2 Possible measures

Offering economically viable opportunities for the sustainable management of natural resources needs to be at the core of any rural development planning. Economic development of the poor is necessary to provide income to decrease their vulnerability and to empower them to cope with the impacts of climate change. It is at the same time also clear that natural resources alone often do not provide sufficient income and employment opportunities in rural areas to support sustainable forms of development to all (Heemst and Bayangos, 2004; Verhagen et al., 2004). The measures identified can be grouped in resource management for sustainable land-use, specific activities aimed at rural and agricultural development and specific measures for climate proofing agricultural practice, also taking into account a future increase in climate related disasters. Implementation of these measures can be stimulated through policies taken in the three areas addressed in the previous section.

Over the last decades food production has more than kept pace with global population growth. This has mainly been achieved through agricultural intensification. In order to increase production per hectare (Evans, 1998), the global irrigated area has increased and the use of purchased inputs (e.g. fertilisers) and new technologies has grown. The expansion of agricultural land has slowed down over the last few decades. Changing consumption patterns and diets have caused the increase in cereal production to slow down, but the quantity of livestock products to rise (Delgado et al., 1999).

In general, increased food production has come at a cost. Natural resources, in particular soil and water, are overexploited. This undermines the very base of these production systems via erosion and soil fertility loss, and reductions in water quality and quantity. Sustainable land use depends on maintaining environmental functions such as water supply, biodiversity and carbon stocks. It is possible to increase food production in an environmentally sustainable way while at the same time avoiding overexploitation and vulnerability to climate change. Good management of the natural resource bases (including agricultural production) takes into account the different social, economic and environmental concerns that are important from a sustainable development perspective. This requires an integrated and synergistic resource management approach that embraces locally appropriate combinations of livelihood strategies for farm households (Dixon et al., 2001). The exact measures will differ per area and crop, and it goes beyond the scope of this paper to detail them further (see Verhagen et al., 2004).

Activities crucial to boosting development in rural areas include increased agricultural production, small-scale industrial enterprises and tourism. Non-food crops with added value such as energy and raw materials are also interesting options. Depending on local resources and price levels, this could open up new opportunities for rural development. The production of non-food crops, for example, for industrial processes and as bio-fuels, would create new options for farmers as long as this fits in sustainable land use and, notably, does not occur at the expense of pristine areas. The substitution of fossil fuels would also lead to reduced emissions of greenhouse gases and positive linkages with mitigation (see Section 4.4). It is interesting to note that economic development, reducing vulnerability, and climate change mitigation can come together this way, provided that small-scale farmers will benefit from these new opportunities (ENDA et al., 2006). If the world moves towards a bio-based economy, the area cultivated with non-food crops can increase dramatically. As with other cash crops, competition for land with food crops will be a concern for food-insecure areas.

Measures for sustainable resource management and rural development can make a contribution to disaster risk management. Risk prevention is highly synergetic with climate adaptation measures (Sperling and Szekely, 2005). Often, in early-warning, rural planning, and other information systems, the present climate variability is taken as the benchmark. Incorporating possible future climate changes will be increasingly possible as regional and local projections for climate change patterns improve and contribute to better preparedness.

Addressing the trade-offs between climate change impacts and the other policy areas to avoid maladaptation could be defined as a “minimal approach”. Such an approach would screen measures on their climate resilience, and only allow those that are minimally vulnerable to a changing climate, and to minimise future negative impacts of climate change by climate proofing agriculture. A “maximal approach” would expand on the minimal approach by trying to achieve multiple dividends and potential synergies in the field of poverty reduction, agricultural production and disaster reduction and climate change. This would yield a basket of measures, including resource management for sustainable land-use, specific activities aimed at rural and agricultural development, and non-food use of biomass.

4.3.3 Policy options for mainstreaming

The previous section has identified measures that make livelihoods more sustainable, while also reducing the vulnerability to climate change impacts. This section provides an overview of polices for international organisations that offer opportunities for mainstreaming adaptation to climate change in these policy areas.

The need for mainstreaming climate change adaptation in development planning and cooperation is increasingly recognised. This is for example illustrated by the declaration of development and environment ministers of OECD countries (OECD, 2006), that states that OECD-countries will work to better integrate climate change adaptation in development planning and assistance. The 2007 EU Green paper on options for EU action identifies integration of adaptation into EU external relations as an important pillar of its work (EC, 2007b). As a significant part of development assistance is directed at activities that are potentially affected by climate change (OECD, 2005a). There is a whole suite of policy frameworks for development planning and development cooperation that currently hardly pay any attention to climate change risks (OECD, 2005a) and in which climate change adaptation can be mainstreamed at the project, national or sectoral level. An example is the process leading to Poverty Reduction Strategies Papers (PRSPs).

The PRSP process is relatively new and still evolving. Various reviews have noted the opportunity to influence the process leading to a PRSP, emphasise them as mechanisms for mainstreaming climate change policies and strategies as well as the need to go beyond the national level and integrate climate adaptation into local-level planning and implementation (VARG, 2003; Eriksen and Naess, 2003; Agrawala and Berg, 2002), following the extensive decentralisation processes that are taking place in many developing countries. Reviews of the integration of environmental concerns in PRSPs conclude however that many PRSPs pay little to very little attention to basic issues of environmental health, natural resource degradation and vulnerability to environmental hazards (Bojo and Reddy, 2004). This is consistent with a review of country-level progress on the implementation of the seventh MDG, on ensuring environmental sustainability, that shows that environmental issues do not receive much attention outside of MDG 7 (Lee and Ghamine, 2005). Yet, reviews also state that positive examples exist. There are several examples of PRSPs providing promising links, for example in the case of Tanzania (Mwandosya, 2006). These examples clearly deserve a following and could be put forward as “best practices” to enhance up-scaling of these experiences.

For vulnerable areas and groups, additional efforts will be necessary to adapt to changes in climatic conditions. Relevant agricultural decisions are taken mainly at the local and national level, but international policies also influence these choices. Organisations like the Food and Agriculture Organisation (FAO) and the Consultative Group on International Agricultural Research (CGIAR) can guide local and national decisions by showing best practices and by helping to improve (sub-)national policy frameworks.

Increasingly, the links between vulnerability for disasters and climate change adaptation are acknowledged in the development and international aid communities, and some governments have even formulated policy objectives to integrate disaster reduction in poverty reduction policies (DFID, 2006; Schipper and Pelling, 2006). Development policies would provide the framework that can bring disaster reduction and climate change adaptation together and strengthen both (Sperling and Szekely, 2005). Measures may be most effective if they are structurally applied in "natural disaster hotspots" (Dilley et al., 2005). Examples of policies that can be undertaken by donors to support countries to mainstream disaster reduction and adaptation in development planning include: a) support for improving government response capacity as part of sustainable development policies; b) support for provision of information and capacity to the most disaster-prone regions and communities to leave them more prepared (especially those recovering from earlier shocks); c) support for making disaster preparedness part of the national development planning; d) support for early warning systems and capacity in responding to disasters; and e) encouraging affected governments to take a more systematic approach to disaster preparedness.

The importance of structural conditions that determine the vulnerability of farmers, although not directly linked to climate change adaptation policies, is illustrated by the fact that farmers and countries that depend on commodity exports could benefit from changes in agricultural subsidy policies. Subsidy-reform would allow farmers to strengthen their position in the market and invest in development of the sector, thus reducing farmers' vulnerability.

Based on the above, Table 4.2 provides an overview of policy options for mainstreaming climate change adaptation. These policy actions are not very specifically elaborated as adaptation efforts are intrinsically local in nature and implementation is context dependent.

Table 4.2 Policy options for mainstreaming climate change adaptation in poverty reduction, agriculture and land use and disaster reduction.

Issue	Area of interaction	Policy options for mainstreaming climate change adaptation
Poverty reduction	Synergy: biodiversity and conservation of natural resources with prevention of land degradation and climate change adaptation	Payment of the poor for ecosystem services if these lead to climate change-proof environmental management.
	Synergy: sustainable livelihoods as an approach to reducing poverty and dealing with climate change	Three strategic entry points for adaptation: (1) reduction of vulnerability of livelihoods, e.g. livelihood diversification; (2) strengthening local capacity and reducing sensitivity; (3) risk management and early warning
	Synergy: Poverty Reduction Strategy Papers and National Strategies for Sustainable Development	Mainstreaming adaptation measures in policy frameworks and programmes for poverty reduction and sustainable development mechanisms, using documented "best practices"
Agriculture	Synergy: drought resistance	Increased water use efficiency, improved soil crop management, insurance
	Synergy: more efficient use of inputs (nutrients and water)	Precision agriculture, improved soil and crop management
	Synergy: more resistance against pests and diseases	Climate change resilient crops, insurance
	Synergy: dealing with climate variability	Early warning systems, also helpful in dealing with climate change

Issue	Area of interaction	Policy options for mainstreaming climate change adaptation
Soils and sinks	Synergy: combating land degradation, overexploitation	Intensification of agriculture, freeing land for carbon management. Extensification: enhancing carbon management, zero tillage
Disaster reduction	Synergy: effects of flooding in degraded and deforested areas	Arrange landscape planning to minimise the effects of flash floods
	Synergy: drought prevention	Early warning systems aimed at land managers
	Synergy: natural disaster risk reduction; increasing resilience to floods and droughts	Landscape planning and (micro-) insurance
Subsidies	Trade-off: current agricultural subsidy regime is not enhancing resilience or sustainable land use	Moving subsidies moving towards rewarding farmers for sustainable land use (reduces their vulnerability)

4.4 Widening climate change mitigation efforts

Mitigation of climate change includes all anthropogenic efforts that reduce greenhouse gas emissions or enhance their sinks (IPCC, 2001b). Greenhouse gas emissions arise from almost every thinkable economic activity through the use of fossil fuel-based energy or changes in land use. This section will discuss the material inter-linkages, possible measures and policy options for mainstreaming climate change mitigation in security of energy supply, air pollution and health, and trade and finance.

4.4.1 Material inter-linkages with climate change mitigation

Security of energy supply is an important priority for energy import-dependent countries. In most countries, the reliance on imported energy is expected to increase over the next decades (IEA, 2005); for the European Union, for instance, the self-sufficiency is expected to decrease from around 55% in 2000 to 30% in 2030 (EC, 2006). The principal aim of energy security policies is to ensure the reliable supply of affordable energy. Currently, the most used and cheapest energy source is fossil fuels, and because of rising oil and gas prices, particularly coal is on the rise. The main material linkage between security of energy supply and climate change relates to the greenhouse gas emissions resulting from the dominant use of fossil fuels in our energy system. IEA (2007b) distinguishes four areas of energy insecurity, of which "concentration of fossil fuel resources" is the one most pertaining to climate change, as means to address it "include moving away from fossil fuels". Tension between the rising energy demand and the limited number of countries that control the available resources on the one hand, and the need to reduce CO_2 emissions on the other, is growing. While reducing dependence on imported energy is a key objective in most countries and clear synergies with climate change mitigation are possible, the benefits of increased use of domestic energy carriers is rarely accounted for (Egging and Oostvoorn, 2004).

Air pollution is a severe cause of health problems in both developing and industrialised countries, and in all countries alike, policies are developed to address it. Research on **air pollution and health** shows that there is a large potential for synergies between air pollution and climate change policy, especially in the technological measures taken to abate both (Alcamo et al., 2003; Syri et al., 2001). The material inter-linkages between air quality and climate change are diverse. Firstly, air pollution and greenhouse gases share the same atmosphere, which enables physical interaction and therefore creates strong material linkages. There are health-affecting air pollutants, notably ozone and soot that are also contributors to climate change. Reduction of atmospheric concentrations of these substances automatically has a double effect as it reduces air pollution and mitigates climate change. In addition, there are indirect effects of air pollutants on climate change and vice versa. For instance, emissions of sulphur oxides, which lead to *inter alia* acid rain, also enhance formation of sulphate aerosols, which have a short-term cooling effect. It has been emphasised that the reductions in sulphur emissions for the sake of air pollution control may lead to enhanced climate change (e.g., Stanhill and Cohen, 2001; Wild et al., 2005), and even that sulphur can be deliberately emitted to mitigate climate change (Wigley, 2006; Crutzen, 2006). Secondly, air pollution is often caused by activities that also produce greenhouse gas emissions, such as industrial production, electricity generation and transport (Sliggers, 2004).

The interactions between **trade and finance** and climate change mitigation take place in different ways. Trade liberalisation policies usually increase economic activity, and hence greenhouse gas emissions. On the other hand, climate policy may have an impact on trade flows by affecting the competitiveness of countries, or may lead to innovation and diffusion of new technologies, in turn opening greenhouse gas abatement opportunities (Charnovitz, 2003). Direct and indirect subsidies on fossil fuels are important policy disturbances that artificially reduce prices of fossil fuelled energy and affect climate change in two ways. In the first place, artificially lowered prices lead to more consumption and hence greenhouse gas-intensive trade and production. Secondly, these subsidies also artificially increase the relative prices of alternative energy options, such as renewable energy (Beers, 2004).

4.4.2 Possible measures

Measures that meet the objectives of energy security policies as well as mitigation of climate change are ample (Holdren and Smith, 2000). For example, energy efficiency measures can be implemented against low cost, but are difficult to implement because of a variety of social and system limitations (Shove et al., 1998). Renewable energy use in the transport sector – because of its almost-exclusive oil dependence the sector most susceptible to security of supply problems – is an area where many opportunities have been identified, but costs are often higher than the costs of conventional oil, and the large-scale cultivation of bio-energy crops may lead to deforestation and food security problems. In the heating and electricity sector, synergetic measures can be identified, as well as trade-offs. The use of renewable fuels or nuclear can lead to lower energy imports and reduce greenhouse gas emissions, but switching to coal to reduce dependence on oil or gas will increase CO_2 emissions, provided CO_2 capture and storage is not applied.

Air quality improvements and climate change can be synergetic when the use of fossil fuels is addressed (Rabl and Dreicer, 2002). This means that either the use of fossil fuel is made more energy-efficient or is avoided through the switch to renewable and nuclear energy. This can be done in the energy sector, in industry, households and in transport. In addition, to address air quality alone, end-of-pipe technologies can be used. However, these have a negative effect on climate change, as they tend to decrease plant efficiency and increase its carbon intensity. The use of sustainably grown biomass, which is good for climate change, may be bad for air quality if the flue gases are left untreated (Bakker et al., 2004).

Table 4.3 gives an overview of the main interactions of the measures identified. Many measures are related to the energy sector and address the fuel mix in particular. The most promising options are those with synergies in climate change, air quality and security of energy supply. A "+" indicates a synergy between the measure and the policy field of climate change, air quality or security of energy supply; a "-" indicates a trade-off. "0" indicates that no interaction in particular can be discerned. A "+/-" indicates that the effect can be positive in some regions and negative in others, depending on the circumstances. The options that have a "+" in one of the columns, and a "-" in one of the others may signal trade-offs that need to be addressed.

Table 4.3 Inter-linkages between measures dealing with air pollution, security of energy supply and climate change mitigation

Sector	Measures		Air quality	Security of energy supply	Climate change mitigation
Electricity production	Conversion of efficiency improvement		+	+	+
	Renewable electricity	Photovoltaic	+	+/-	+
		Wind energy	+	+/-	+
		Biomass	0/-	+	+
	Hydro		+	+/-	+
	Nuclear		+	+	+
	Fuel switch for coal → gas		+	-	+/-
	More use of coal		-	+	-
	More use of coal, but combined with CO_2 capture and storage		+/0	+	+
Transport	Hybrid electric cars		+	+	+
	Fuel cell technology		+	+	+
	Fuel efficiency		+	+	+
	Fuel switch for petrol -> diesel		-	0	+
	Coal to liquids		-	+	-
Industry	Energy efficiency		+	+	+
	Material efficiency		+	+	+
	Air pollutant scrubbers		+	0/-	-
Household	Fuel switch for local heating and cooking		+	-	+
	Efficient cook stoves		+	+	+
	Solar home systems for lighting		+	+	+

Table 4.3 shows that synergies between the three issue areas can be realised by using the right technologies. Examples of potentially promising options are improving energy efficiency and low-carbon energy sources (which both address climate change and air pollution), along with ensuring energy supply security by: 1) focusing on domestically available resources and making domestic reserves or 2) focussing on supply of fuels that have a wide geographical spread in countries that are not or less susceptible to political turmoil. More low-carbon energy sources can be achieved by shifting from oil to gas, bio-fuels or hydrogen in the transport sector and deployment of renewable and nuclear energy.

Addressing the trade-offs between climate change mitigation and the other policy areas could be defined as a “minimal approach”. Such an approach would be aimed at minimising the negative impacts of non-climate policy developments on climate change. The mix of policies and measures comes into play on a global level or in countries crucial to climate negotiations, and involve four crucial components: “greening” of investments in the energy sector; phase-out of subsidies on fossil fuels; addressing the vested interests in fossil fuels; and using clean coal technologies to meet the growth in large developing countries through technological cooperation or mandatory international technology-oriented agreements (Coninck et al., 2008a).

A "maximal approach" would achieve the above goals, extended with policies and measures that can be undertaken in the field of climate change mitigation, reduction of air pollution, and security of energy supply, yielding a basket of measures that have a "triple dividend" and use the potential synergies. These measures include energy conservation; a fuel switch to hydrogen in the case of transport; hydrogen generated by coal gasification with CO_2 capture and storage; and mass transit systems and vehicle maintenance programmes.

4.4.3 Policy options for mainstreaming

The previous section has identified measures that are synergetic for energy security, air quality and climate change mitigation. This section provides an overview of policies that offer opportunities to mainstream climate into these policy areas.

Regional circumstances affect the available and possible options for integrated security of energy supply and climate change mitigation policies. Many regions can currently not do without fossil fuels to meet their energy demand, so it will be necessary to at least reduce the negative impacts of their use. In addition, several countries are economically dependent on the export of fossil fuels. As indicated above, using technologies that do not compromise the interests of the fossil-fuel exporting countries, such as CO_2 capture and storage combined with hydrogen production (allowing for the continued use of gas and coal, and possibly also oil) could prove beneficial for those economies, for energy security of supply and for reducing greenhouse gas emissions. These measures are, however, difficult to realise on an international level in an international agreement, as the security of energy supply is not commonly regarded as a collective action problem but as a field where countries simply compete based on price. There is limited cooperation though in alliances such as the European Union or via such organisations as the International Energy Agency. Fossil-fuel exporting countries and industrialised fossil-fuel importing countries could make an agreement on transfer of climate-friendly technologies in exchange for fossil fuels supply. Large oil and gas companies could be vehicles for such international technology initiatives, either via principles of corporate social responsibility and voluntary agreements, or enforced by legislative measures on energy efficiency and environment.

Trade policies offer a limited number of opportunities for enhancing climate policy so far. Environmental policies aimed at incorporating the negative environmental external effects of production processes could affect trade flows towards more sustainable production. In terms of financing of projects, mainstreaming mitigation concerns in different financing areas is a considerable opportunity in making investments more sustainable. A significant share of global foreign direct investment is done via multilateral banks, and for example the World Bank is working towards a low-carbon investment framework (World Bank, 2006b). In addition to financing, Beers (2004) has identified the area of energy subsidy reform as being crucial for using trade and finance regimes to address climate change mitigation. For example, in the second half of the 1990s, energy subsidy rates of 40% for coal in China were reported. The subsidy rate of all energy sources taken together is 11%, with both industrialised and developing countries boasting significant subsidy regimes (IEA, 1999). If OECD countries would remove fossil fuel subsidies and assist non-OECD countries in their energy subsidy reform through financial and technology transfers, they could require that non-Annex-I countries accept greenhouse gas obligations as part of the bargain (Beers and Moor, 2001).

International treaties aimed at reducing air pollution are mainly regional, although it is increasingly recognised that air quality is also a global problem (Holloway et al., 2003; Sliggers, 2004). This recognition may generate possibilities for harmonising air pollution measures with climate agreements, in the case that full integration of the policy areas is not feasible. Energy security of supply, conversely, is mainly a national issue, with only some room for bilateral cooperation or co-operation in the context of, for example, the European Union. Policy harmonisation both ways (energy security in climate policy as well as vice versa) would be difficult here because of the different policymaking levels. Mainstreaming with respect to policy options and measures would therefore be relevant here.

Table 4.4 gives a number of policy options to create synergies between security of supply policies, air quality and health, and climate mitigation. The table points out the countries for which the interactions are most relevant, and further provides information on how climate policy concerns can best be integrated in other policy areas.

Table 4.4 Policy options, and relevant countries and regions, for integrating climate change mitigation concerns in security of energy supply, air quality and health, and trade and finance

Issue	Area of interaction	Relevant countries or regions	Policy options for mainstreaming climate change mitigation
Security of energy supply	Synergy: more efficient use of energy	Global	Energy-saving policies to reduce demand
	Trade-off: use of coal to meet increasing energy demand	India & China, in particular	Policy package for more efficient and cleaner fossil fuel use and incentives for development of new low-CO_2 coal technologies
	Synergy: reduced use of fossil fuels through use of renewable and nuclear energy and other fuels	Energy-dependent countries with much potential for renewable energy	There are many interests that can be served by applying renewable energy sources. E.g., for transport, fuel switch to gas and in the longer term to hydrogen is an option, or more use of biomass. Countries and parties could be encouraged by helping them to see the interests
	Trade-off: conviction enhancing renewables means an economic threat to energy-exporting regions in the world.	OPEC, gas-exporting countries, United States	Technological cooperation in climate-friendly fossil fuel applications: fossil based hydrogen, CO_2 capture and storage & clean fossil fuel technologies
Air pollution/Health	Synergy: urban air pollution caused by the same activities as greenhouse gas emissions	Global	Energy conservation in supply and demand For transport, fuel switch to gas and, in the longer term, to hydrogen, mass transit systems and vehicle maintenance programmes Decentralised renewable energy for electricity, cooking and lighting
	Synergy: access to modern energy services in rural areas reduces indoor air pollution and GHG.	Developing countries	Modern energy provision with renewable energy, more efficient heating and cooking techniques and clean fossil fuel use
	Synergy: both ozone and soot are significant air pollutants; both contribute to climate change.	Global	Include ozone and soot in climate negotiations
Trade and finance	Trade-off: energy subsidies favour greenhouse-gas emitting activities	Global	Reduction or elimination of subsidies for fossil fuels, more subsidies for climate-friendly energy supply as part of electricity reform and liberalisation
	Trade-off: huge investments still targeted at fossil fuels	Global	Reducing energy consumption so less investment is needed Introducing GHG taxes or border tax adjustment to favour climate-friendly investments, goods and services

4.5 Institutional and organisational inter-linkages

This section examines the *institutional and organisational inter-linkages* to identify ways in which the impacts of international institutions and organisations can be enhanced. International organisations have to satisfy the demand for coordination in areas where the actions of individual countries do not lead to the best outcome for everyone. In trans-boundary environmental issues, international treaties have mushroomed over the past decades (Raustiala and Victor, 2004). The institutional landscape has therefore become increasingly dense and complex, and overlaps are bound to occur. Overlap, in the meaning that an outcome of one treaty has an impact on the outcome of another, can reduce the effectiveness of treaties, but can also be used to mainstream other interests and mobilise synergies. The institutional inter-linkages are discussed simultaneously here for climate change adaptation and mitigation.

There is a long list of relevant institutional and organisational arrangements that could be applied in the different policy areas from the previous two sections. An overview is provided in Table 4.5. Each of these treaties, organisations or platforms offers opportunities to mainstream climate change adaptation and mitigation. Table 4.5 also outlines the "windows of opportunity", clearly indicating that work on mainstreaming climate change adaptation and mitigation can start immediately.

The importance of mainstreaming climate is also increasingly recognised amongst the Rio Conventions, as there is a clear convergence of objectives on land use and climate change from the three Rio Conventions, the United Nations Convention to Combat Desertification (UNCCD), the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC), along with the Ramsar Convention and the UN Forum on Forests. The Rio Conventions have set up a Joint Liaison Group to enhance coordination between them. At the individual country level, implementation of the various environmental agreements needs to converge to a greater extent (UNCCD, 2004), as many synergies exist between the different options implemented under the different conventions (CBD, 2003). The Scientific and Technical Advisory Panel (STAP) to the Global Environment Facility (GEF) has designed a tool to improve the inter-linkages in GEF funded projects (STAP, 2004). Moreover, there is a need for parties to focus on an environmental governance framework that links environment with the broader development agenda.

Table 4.5 Windows of opportunity in institutional and organisational inter-linkages from the perspective of climate change

Issue linked with climate	Institutional and/or organisational linkages	Window of opportunity
Poverty	Global Environment Facility (GEF)	Funding of adaptation-related activities
	United Nations: Millennium Development Goals (MDGs), bi- and multilateral donors (World Bank, UNDP, donor countries)	Show importance of climate change adaptation for realising MDGs
		Official Development Assistance
Environment and biodiversity	Ramsar Convention on Wetlands	Multilateral Environmental Agreement (MEA) co-ordination UNEP
	UN Convention on the Combat of Desertification (UNCCD)	Joint Liaison Group Rio-Conventions, MEA co-ordination UNEP
	Convention on Biodiversity (CBD)	Joint Liaison Group Rio Conventions, MEA co-ordination UNEP
	International water agreements	MEA co-ordination UNEP

Issue linked with climate	Institutional and/or organisational linkages	Window of opportunity
Rural development and agriculture	Food and Agriculture Organisation (FAO) / Consultative Group on International Agricultural Research (CGIAR)	Intensification of existing co-operation, use of extension services
	World Trade Organisation (WTO)	Agricultural subsidy reforms under debate
	UNCCD and CBD	Use environmental services as base for improved co-ordination
	United Nations Forum on Forests	Relevant for sinks and avoided deforestation
	Commission on sustainable Development – Agriculture and land use, 2008-2009	Agriculture, rural development, land, drought, desertification, and Africa
Disaster reduction	Hyogo Framework for Action 2005-2015	Risk reduction frameworks for disaster reduction and adaptation that can be combined Inter-agency taskforce on climate change and disaster reduction
Trade and finance	World Trade Organisation (WTO)	Greening of decisions Special focus on subsidies counterproductive to climate change mitigation
	Regional trade and investment agreements	Greening of regional trade and investment agreements
	International Monetary Fund, World Bank, Regional Development banks, Organisation for Economic Cooperation and Development (OECD)	Greening of the decisions Greening of finance / investments
Air quality and health	UNFCCC	Tropospheric ozone and soot in international climate agreements
	Convention on Long-Range Transboundary Air Pollution (CLRTAP)	Inclusion of CO_2
	Montreal Protocol (MP)[a]	Exclusion of greenhouse gases as CFC substitutes; aligning financial mechanisms MP and UNFCCC
	World Health Organisation	Intensification of existing cooperation
Security of energy supply (including sources of energy for development)[b]	OPEC, Gas Exporting Countries Forum, International Economic Forum, International Energy Agency (IAEA)	High oil prices increase the potential of combining this agenda with climate change
	Commission on Sustainable Development – Energy and climate, 2006/2007	Follow up the 2006/2007 CSD cycle Use public-private partnerships set up after World Summit on Sustainable Development
	Millennium Development Goals (MDGs)	Energy for development more prominent within MDGs

[a] It should be noted that the Montreal Protocol, which targets stratospheric ozone, it not relevant for the tropospheric ozone air pollution referred to in the text of this paper.
[b] Security of energy supply is among other things composed of access to affordable energy. For developing countries, especially large, rapidly growing economies, this has a large interaction with climate change as their growth in energy use is contributing significantly to the increase in greenhouse gas emissions. This is the reason why in the list of institutional linkages, the Commission on Sustainable Development and the Millennium Development Goals (UN, 2000) are recognised as such. It should be emphasised, however, that due to the scale of providing energy to the poor, electrification is not expected contribute much to climate change, even if this energy is provided through fossil fuels.

In terms of adaptation, establishing links to risk-management practices in national sectors as well as development assistance by bi- and multilateral donor institutions would be among the first on the priority list for mainstreaming climate change adaptation. Although adaptation is essentially a local process, international policies are influencing these local processes and can hence enhance mainstreaming adaptation at the national and local level. The incorporation of climate change risks in the reduction of weather-related natural disasters is already gaining attention (Burton and Aalst 2004; Aalst and Helmer 2004). Capacity-building of integrated climate risk management can be improved through conventional development assistance and programmes, such as those operated by the UNDP, the International Red Cross, World Bank and bilateral donors. Specific attention has to be paid to mainstreaming climate change in risk management approaches such as Integrated Water Resource Management and Integrated Coastal Zone Management, either financed from domestic budgets and/or donor sources. Associated national and multilateral institutions, such as the UN International Strategy for Disaster Reduction, development agencies and NGOs, can already start supporting these linkages.

In the field of mitigation of climate change, efforts are underway to establish links between the WTO and climate change mitigation. These have so far not led to very concrete results. As mentioned, World Bank has developed an investment framework, both to make projects more climate-proof, but also to reduce the greenhouse gas emissions associated with World Bank activities (World Bank, 2006b). This could be replicated and institutionalised in other relevant financing institutions, such as the regional development banks. The links with air quality could be addressed through the successful Convention on Long-Range Transboundary Air Pollution (CLRTAP), which in recent meetings has discussed climate change and is looking into the possibility of mainstreaming climate change in its activities, or even including CO_2 in its basket of gases. Continuation and deepening of these efforts would be particularly useful as it provides best practices for countries not included in the CLRTAP but interested in reducing air pollution and how to best combine this with climate change mitigation. Institutional linkages between development, climate change and energy security of supply have been firmly established and extensively discussed during the CSD-14 (CSD, 2006). These different agenda's are converging. The follow-up policy-oriented discussions during CSD-15 have however not led to an agreement on how to operationalise the linkages between development, energy security and climate change further. The potential of the CSD to contribute to these issues therefore remains uncertain. A new opportunity arises with the focus of CSD 2008/2009 on agriculture, rural development and land use.

4.6 Discussion and conclusions

Currently, the potential of mainstreaming climate change adaptation and mitigation remains underexploited. This paper has identified and assessed potential directions to widen the climate regime by mainstreaming climate change adaptation and mitigation in a number of policy areas. Implementing this strategy could enhance the effectiveness and efficiency of the climate regime. As it is clearly going beyond what is currently discussed and agreed upon within the UNFCCC, a mainstreaming strategy would be additional to the climate convention, and should not be seen or pursued as a substitute.

The reasons for seeing mainstreaming as an additional strategy differ for adaptation and mitigation of climate change. With respect to adaptation, there is a risk that the issue gets buried in other agendas, with the result that the climate issue loses attention. Any next UNFCCC agreement therefore needs to be stronger on adaptation to climate change. With respect to mitigation, there is a concern that mainstreaming on its own is unlikely to be environmentally effective as it will not give certainty on achieving the emission reductions that are required to realise mitigation targets.

One of the advantages of a mainstreaming strategy is that it can be implemented immediately, without a formal connection to the UNFCCC process, and in this way help the climate regime forward at a time that international negotiations on both climate adaptation and mitigation are at a crucial stage. Although the opportunities for mainstreaming climate change are increasingly recognised by analysts, and (inter)national policies are starting to be formulated, implementation is still in its infancy.

With respect to the implementation of mainstreaming climate change adaptation, mainstreaming can be a key component of any national, sectoral or international development framework or project. At the very least, climate change adaptation needs to be mainstreamed in all relevant national and sector planning processes to avoid mal-adaptation that limits realising the specific national and sectoral development goals. Especially in developing countries, this will be of great importance for climate proofing of development planning and assistance.

The institutional embedding for mainstreaming climate change mitigation is likely to differ per related issue. In air quality, for instance, the organisational landscape is relatively clear and linking greenhouse gases with air pollutants seems possible to a certain degree. In energy security of supply, there is much less international coordination, which leads to the recommendation that trade-offs can be prevented by aiming at measures on the technological level, as well as recommending national policies. A minimal approach, addressing the trade-offs only, would already be useful, and is within the scope of what the international community can do.

It is also clear that a mainstreaming strategy has its challenges and this paper has addressed several reasons. Although policy integration is long recognised as a cornerstone for sustainable development, progress has been limited. There is no reason to assume this would be different for mainstreaming climate change adaptation and mitigation. The paper has shown that in different policy domains initiatives start to emerge, but that this still is really only the beginning of a process that needs to be fostered by the international community to become effective. Success will critically depend on further operationalisation at a practical level and up-scaling of these directions for mainstreaming in the specific contexts of each of the policy domains addressed in this paper. Mainstreaming can make an important contribution to addressing climate change, but, to realise any of its potential, requires strong political will and active follow up in implementation.

Chapter 5 International Technology-Oriented Agreements to address climate change[14]

5.1 Introduction

There is widespread agreement that achieving the dramatic reductions in greenhouse gas (GHG) emissions necessary to stabilize GHG concentrations at between 450 and 750 parts per million (ppm) would require innovation and large-scale adoption of GHG-reducing technologies throughout the global energy system (IPCC, 2001a). Alongside policies aimed directly at mandatory GHG emissions reductions—such as a GHG cap-and-trade system or tax—much discussion has therefore surrounded policies targeted instead at technology research and development (R&D) activities and technology-specific mandates and incentives. The associated debate is therefore not so much over the importance of new technology per se in solving the climate problem, but rather over what the most effective policies and institutions are for achieving the dramatic technological changes and associated emission reductions necessary for stabilization.

For example, one frequently cited study (Pacala and Socolow, 2004) found that stabilizing carbon dioxide (CO_2) concentrations at about 500 ppm would require a 50 percent reduction in global CO_2 emissions below baseline within the next 50 years and then a more significant decline over the following 50 years. Achieving this magnitude of reduction would require very substantial increases in the penetration of a wide range of energy-supply and end-use technologies, including: technologies that increase demand- and supply-side energy efficiency; renewable energy technologies (solar, wind, biomass, tidal, geothermal, wave); nuclear energy; and CO_2 capture and storage. Doing so at reasonable cost would require substantial cost-reducing innovations through research, development, and learning.

Existing agreements—such as in the Kyoto Protocol and the EU Emission Trading System (ETS) —have emphasized mandatory GHG reduction targets. However, the protocol's limitations with respect to participation and effectiveness have become apparent, as the United States and Australia have withdrawn and Canada largely has reneged. Meanwhile, an array of climate technology policies has emerged, at both national and international levels. Such policies include government funding for research, development, and demonstration of new technologies, subsidies and mandates for the production of alternative fuels and associated technologies (e.g., renewable portfolio, building, and biofuel standards), loan guarantees for investments, technology performance standards (e.g., for energy efficiency), and the provision of information to encourage improved decision making by equipment purchasers. There also are voluntary agreements of international scope, such as the Asian Pacific Partnership.

Following these developments, growing attention has turned to the possible role of international technology-oriented agreements (TOAs) as part of the architecture of international climate-change policy. This attention is due in part to the willingness of the United States and some of the more rapidly growing developing countries to initiate new and engage in existing TOAs, as well as a growing sense that emissions targets alone may be an insufficient response to the long-term global climate change problem. Another potentially attractive feature of policies targeted at the innovation and adoption of GHG-reducing technologies is that they might have higher co-benefits than GHG emissions-reduction policies alone. For example, renewable standards might help pro-

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mote energy security by diversifying fuel sources, and energy-efficient technologies can lower operating costs. Such ancillary benefits might help promote greater participation and stringency in an international climate agreement. Emissions policies also have ancillary benefits, but they cannot be managed as specifically as can technology mandates.

Furthermore, since markets for technology and technological change have their own problems, policies that address these problems directly generate their own benefits in addition to pure emissions reductions. Additional interest in technology strategies is generated by the fact that strict future targets cannot be set credibly today, so substantial progress and cost reductions could enable more effective (and credible) emissions policies in the future. For all these reasons, there is growing recognition that TOAs could play a substantial role in post-2012 international climate policy discussions.

It is less clear, however, what specific form future TOAs might take, how large a role TOAs might play within an international climate-policy framework, whether their role should be as complements to or substitutes for emissions-based agreements, or how effective they might be in advancing certain international climate-policy objectives. Such objectives include reducing GHG emissions, increasing technological advances, reducing costs, and increasing the participation and compliance incentives for various large countries.

This paper therefore explores the extent to which TOAs can play a constructive role in addressing the unprecedented problem of climate change. In Section 5.2, we identify four main types of TOAs, describe several motivations for considering TOAs, and lay out key criteria for evaluating these agreements. Section 5.3 evaluates both current examples and recent proposals for different types of agreements, as well as a potential portfolio of TOAs. Then in Section 5.4, we consider how TOAs might be embedded within a complementary framework along with other climate-mitigation strategies, and what linkage with other international issues may occur, such as with international trade and development. We conclude in Section 5.5.

5.2 Technology-Oriented Agreements

5.2.1 Types of TOAs

We define the scope of technology-oriented agreements as including those international agreements that are aimed at advancing research, development, demonstration, and/or deployment of technologies. With respect to TOAs to address global climate change, these technologies would be aimed specifically at reducing GHG emissions. This is in contrast with agreements framed primarily in terms of emissions targets, such as the Kyoto Protocol, or emissions-intensity targets. While both types of agreements may have GHG reductions as their ultimate aim, commitments to actions under TOAs are framed in terms of technological development activities or technology-specific mandates and incentives, rather than in terms of emissions. Within this group of agreements, there are four broad types of TOAs: (1) knowledge sharing and coordination; (2) research, development and demonstration (RD&D); (3) technology transfer; and (4) technology deployment mandates, standards, and incentives.

Activities undertaken under knowledge sharing and coordination agreements include meeting, planning, exchange of information (e.g., the Carbon Sequestration Leadership Forum or the task-sharing within International Energy Agency Implementing Agreements), and possibly the coordination and harmonization of research agenda and measurement standards. RD&D agreements include jointly agreed RD&D activities and funding commitments (e.g., the ITER fusion project) or mutual agreements to expand or enhance domestic RD&D programs. Technology-transfer agreements include commitments for technology and project financing (e.g., the Global Environment

Facility), particularly flowing from developed to developing countries, as well as potentially facilitating international licensing and patent protection. A fourth class of TOAs is comprised of international agreements encouraging technology deployment by establishing deployment mandates for a specific technology or group of technologies (e.g., renewable portfolio standards), international technology performance standards (e.g., automobile fuel economy or appliance efficiency), or technology deployment incentives (e.g., renewable subsidies).

Thus, efforts under TOAs may involve efforts to "push" technologies by subsidizing or otherwise fostering RD&D or efforts that "pull" technologies into the market by providing incentives for or mandating their use. In the latter case, however, those incentives are targeted toward promoting technologies and not more broadly at emissions reductions. Our discussion of TOAs therefore goes beyond, and does not address, several "bottom-up" efforts to develop emissions targets and climate policies whereby sector-level targets, performance standards, and technological options are used to allocate overall emissions-reduction obligations based on technical possibilities (e.g., Höhne, 2005; Groenenberg, 2002; Sijm et al., 2001). Our objective, in contrast, is focused on agreements that directly target technology. We, like Blok et al. (2005), also consider a broader scope for TOAs than studies restricting TOAs to voluntary R&D agreements, which lack certainty regarding reductions of GHG emissions (Berk et al., 2002; Höhne, 2005).

The flexibility exists to design agreements according to technological needs so that they take into account the level of development of each technology. Some technologies, such as organic solar cells, require fundamental research in order to develop into a technology that will eventually be ready for use. Other technologies, such as a number of clean coal technologies, may not benefit considerably from more fundamental research and development but may instead benefit from more operational experience in demonstration. Energy-efficient technologies may require only greater financial incentives or mandates to increase their penetration; TOAs could be tailored toward those specific ends. Whether TOAs are designed for the short term or long term also may be regarded in a technology-specific manner. However, the further one looks ahead, the less clear it is which technologies will be relevant and preferable from a technical or economic perspective.

5.2.2 Motivations for Technology-Oriented Agreements

With the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol entered into force and ratified by a large number of the countries around the world, an international climate regime is already in place. An important question, however, is to what extent the transaction costs of modifying the current international policy direction could justify the benefits of a possibly better regime with broader participation. The Kyoto Protocol establishes emissions targets and timetables for the industrialized countries that have ratified it and allows for flexibility across those countries and across sectors in achieving those targets. The ensuing price that these reduction targets place on GHG emissions in those countries (e.g., through the ETS) provides an incentive for the near-term adoption of GHG-reducing technologies. It also allows for flexibility between industrialized and developing countries in achieving reductions through the Clean Development Mechanism (CDM), which is designed to lead to the adoption of GHG-reducing technology in developing countries. The Kyoto Protocol is intended to provide a complete, short-term answer to the need for GHG emissions reductions, with the intention to continue with further reductions after the first commitment period ends in 2012.

Given this broad-based support, it is reasonable to ask why one would need to consider agreements specifically aimed at technologies. The added value of TOAs should be evaluated in the context of the complex interplay of near-term supply and demand for technology, longer-term market incentives for technology innovation, and international trade. Climate change policy has benefited from research across many other disciplines, including economics, science and engineering, political science, law, and sociology. In this context, the economic perspective is especially relevant, as it pays particular attention to the operation of markets and the relative costs and benefits of different policy strategies. Nonetheless, each perspective has considered the role of technology in climate policy in different ways and each provides alternative motivations to look at TOAs in detail. Although we may oversimplify these perspectives below, the discussion illustrates the richness and variety of arguments for enlarging the degree of technological specificity in international climate-change agreements.

An economics perspective

Economics brings two related perspectives to policy in general and to climate policy in particular. One perspective is cost-effectiveness, which takes as given the goals set out by policymakers and seeks out the least-cost means of attaining those goals. Cost-effectiveness is a necessary, but not sufficient, condition for economic efficiency. Economic efficiency calls for setting policy goals based on a clear identification of "market failures"—deficiencies in private markets to properly allocate resources—and the potential implementation of policies that directly correct these deficiencies. Efficiency requires setting the stringency of policies to maximize net benefits by equating incremental benefits and costs. Both perspectives have a useful role in advising the policymaking process. Policymakers who decide not to pursue the economically efficient policy may still prefer cost-effective implementation.

In the economics of climate change, the most immediately relevant market failure is the environmental externality of global warming and related climate effects. Individuals, firms, and even countries, in the case of climate change, do not face the full social costs of their GHG emissions, leading to a level of GHG emissions that is too high from a societal perspective. The economist's policy prescription for environmental externalities is to "put a price" on the externality—for example through a GHG tax or cap-and-trade system—thereby forcing individuals and firms to internalize the cost that they are placing on everyone else when they emit GHGs.

When considered alongside policies that impose an emissions price, additional technology policies may not seem necessary or desirable. After all, this price places a financial value on GHG reductions and like other market prices (such as energy prices) induces households and firms to buy technologies with lower GHG emissions the next time they are in the market. This market-demand pull in turn encourages manufacturers to invest in R&D efforts to bring new lower-GHG innovations to market, just as they do for other products and processes. There are nonetheless several economic rationales for considering technology-oriented policies within a portfolio of climate policies (Jaffe et al., 2005; Newell, 2007).[15] These technology market problems are not as relevant for environmental problems addressed over the course of years as they are for climate policy developing over decades or centuries and requiring much more dramatic changes in technology.

First, the economics literature on R&D points to the difficulty firms have in capturing all the benefits from their investments in innovation, which tend to "spill over" to other technology producers and users. This market reality can lead to underinvestment in innovative efforts—even given intellectual property protection—potentially warranting policies that directly target R&D. In a related manner, the fact that knowledge can be relatively inexpensive to share, once it is produced, raises the possibility that research coordination can conserve on R&D resources by reducing duplicative efforts. This innovation underinvestment problem may be worsened in the case of GHG-reducing technology, in which the assets involved are often very long-lived, and the market for innovations resulting from R&D relies heavily on the stability of domestic and international public policy rather than natural market forces (see below).

[15] See Jaffe et al. (2003) for an overview of issues at the interface of environmental policy and technological change.

Second, adoption externalities may be relevant in the adoption and diffusion of new technology, including learning-by-using, learning-by-doing, or network externalities. For a number of reasons, the cost or value of a new technology to one user may depend on how many other users have adopted the technology. In general, users will be better off the more other people use the same technology, so there is a benefit associated with the overall scale of technology adoption. The supply-side counterpart, learning-by-doing, describes how production costs tend to fall as manufacturers gain production experience. If this learning spills over to benefit other manufacturers without compensation, it can represent an additional adoption externality. Finally, network externalities exist if a product becomes technologically more valuable to an individual user as other users adopt a compatible product (as with telephone and computer networks). These phenomena can be critical to understanding the existing technological system, forecasting how that system might evolve, and predicting the potential effect of some policy or event.

Third, market shortcomings arise through incomplete information. While all investment is characterized by uncertainty, the uncertainty associated with the returns to investment in innovation often is particularly large. Potential returns also are asymmetrically distributed and the developer of new technology typically is in a better position to assess its potential than others and may find investors sceptical about promised returns. In the context of environmental problems such as climate change, the huge uncertainties surrounding the future effects of climate change and the magnitude of the policy response and, thus, the likely returns to R&D investment, exacerbates this problem further. Another type of information problem relates to the inability of current policymakers to credibly commit to a long-term emissions path. As a result, it is possible that the feasible near-term emissions price and/or the expected long-term emissions price is lower than the socially desirable level, thus providing an insufficient market inducement for GHG technology R&D. In addition, incomplete information lies at the source of principal-agent problems, as when a builder or landlord chooses the level of investment in energy efficiency in a building but the energy bills are paid by a later purchaser or a tenant. In general, to the extent that consumers undervalue energy efficiency for any reason—information problems, limits to decision-making, or plain myopia—they will demand insufficient improvements and innovations in energy-using products.

In sum, the interplay of technology and the environment therefore involves the interaction of two analytically distinct but linked sets of market failures (Jaffe et al., 2005). The consequences of this interaction can be complex. The fact that markets underinvest in new technology strengthens the case for making sure that environmental policy is designed to foster, rather than inhibit, innovation. In cases where environmental externalities have not been fully internalized, it also is likely that the rate of investment in such technology is significantly below the socially desirable level. And it seems unlikely that environmental policy alone will create sufficient incentives.

It is a basic principle of economics that for sound policy you need at least as many policy instruments as there are market problems to be addressed (Tinbergen, 1956). Hence, the optimal set of climate policies also likely includes instruments explicitly designed to foster innovation, and possibly technology diffusion, in addition to GHG emissions policies that stimulate new technology as a side effect of internalizing the GHG externality. Likewise, long-term technology R&D alone is not sufficient because it provides no direct incentives for adoption of new technologies and because it focuses on the longer term, missing near-term opportunities for cost-effective emissions reductions (Philibert, 2003; Sandén and Azar, 2005; Fischer and Newell, 2007). Of course the value of any particular policy will depend on the actual benefits and costs of that policy given its specific design and the policy and market context in which it is applied.

An engineering perspective

The engineering perspective on climate policy typically has focused on estimates of the technical potential for emissions reductions from different technology strategies and the development paths of those technologies (see, for example, Pacala and Socolow, 2004). In related projections, future energy use and associated emissions are based on technical estimates of how large a role particular technologies could play in the future. The limiting factors tend to be the physical characteristics of a resource (e.g., land availability for bio-energy, solar radiation for photo-voltaic energy), the technical feasibility of certain options (e.g., conversion efficiency of coal-fired power plants or a wind turbine), and the learning rate of the technology (i.e., how much costs are assumed to decrease with increased cumulative production).

Based on a GHG-stabilization scenario, a business-as-usual scenario, and assumptions on present and future costs, studies estimate whether it is technically possible to achieve the required degree of emissions reductions. The message emanating from such exercises typically is that the magnitude of required changes in the energy system is daunting but also that currently available technologies are able to very substantially cut GHG emissions. The penetration of such technologies depends, however, on further cost reductions and the existence of policies that provide an incentive for or mandate their adoption.

An international relations perspective

The international relations literature typically views international politics as a consequence of rational choice by countries and relies on game-theoretic perspectives that see politics as strategic interactions of rational actors (Stein, 1990; Martin, 1992). The current political gridlock of the international climate regime also can be seen as a consequence of strategic choice. Because countries can benefit from mitigation efforts by other countries, they have incentive to free ride on others' efforts, leading to cooperation that is less successful than desirable from a global perspective. Furthermore, asymmetrical burdens and benefits of climate protection worsen the situation. The costs of mitigation fall primarily on the major energy producing and consuming countries, while the benefits of avoided climate damages arguably accrue primarily to the least developed countries that produce and consume less energy (Mendelsohn et al., 2006). Therefore, major emitters may have an inadequate incentive to reduce their emissions to an extent that would satisfy the needs of potential victims.

In addition, nations are supreme authorities and there is no international authority that can enforce international agreements. Therefore, even if nations agree to treaties, their compliance is not guaranteed. Even without enforcement authorities, however, nations would be motivated to comply with international commitments. For example, if states betraying commitments are punished by other states through countermeasures, they will be restrained from defection. This reciprocity mechanism may work for trade issues, such as tariff reduction and non-tariff barrier removal. However, it seems unlikely to work for climate-change mitigation, because weak victim states are unlikely to be able to punish non-complying nations through countermeasures. In the GHG-mitigation case, equivalent countermeasures are more emissions, which are not substantial threats to noncompliant nations.

Despite these difficulties, some researchers in the field of political economy speculate that TOAs could alter this dynamic. First, network externalities associated with technologies could change the calculation of national interests. According to Barrett (2003), once the aggregate scale of economies of joining a hypothetical technology diffusion agreement reaches a critical mass, targeted technologies could become standards. In that case, joining agreements and following standards would be a better strategy than non-participation. This speculation has been contested, however, because the existence of such a tipping point is a technology-specific matter and is very unlikely to exist for technologies (e.g., carbon capture and storage) that will always entail added costs relative to alternatives (see e.g., Philibert, 2004) Second, adding new components to agreements could expand the "zone of possible agreements" (Sebenius, 1983) and make international cooperation more likely by changing the strategic interactions between the Kyoto parties and the current non-parties. In addition to emissions reductions, accelerating technological progress is of continual concern to governments. However, some game theoretic modelling of the benefits from international cooperation on R&D and has shown there are few positive effects in terms of participation (Buchner and Carraro, 2005).

A sociological perspective
The sociological perspective typically focuses on the role of technologies and technological change in the context of a "sociotechnical system" (see e.g., Geels, 2004; Bijker et al., 1987). In this perspective, technologies are considered to be embedded in society and social institutionalization, whether it is formal or informal, is part of any technological change, whether the user society is the general public (e.g., for the use of more energy-efficient appliances) or operators and business managers of power plants (e.g., for the adoption of CO_2 capture technologies). From this perspective, the dynamics of technological change can only be understood in symbiosis with social changes.

Theories of energy transition and industrial transformation make a distinction between different levels of technological and social co-evolution: the landscape level, the regime level and the niche level. In terms of climate-change policies, the landscape level refers to geopolitical developments of an ideological and institutional nature that determine the character and direction of international negotiations and the nature of framework agreements about climate change. The regime level refers to the present configuration of the energy sector in terms of the balance between market forces and regulation and the role and power of prominent stakeholders. Finally, the niche level refers to specific types of technologies and installations that are on the verge of entering the market and possibly could lead to a new energy regime with a different balance of markets and regulations and a different set of key stakeholders. A transition starts with the establishment and accumulation of technological niches, eventually leading to change of the larger technological landscape (Geels, 2004), although the way of bringing about these changes is disputed (Berkhout et al., 2003). According to many studies, the pathways toward regime shifts are likely to be a nonlinear sequence of events, rather than continuous linear development (e.g., Sandén and Jonasson, 2005). Navigating such transitions by policies, therefore, is almost impossible. Nonetheless, policies can facilitate niche formation and accumulation and then a dominant technological regime can arise in an unexpected manner.

Profound changes in the energy system, such as those required for significant GHG reductions, involve not only individual technical changes but a technological regime shift. From a sociological perspective, this goal is fulfilled by the development of long-term technological pathways that facilitate a careful, but nonlinear transition. TOAs may be more capable of incorporating specific policy approaches, such as measures aimed at strategic niche management[16], than agreements based solely on emissions targets.

5.2.3 Criteria for assessing TOAs

As with any policy goal, a variety of criteria can be brought to bear upon the choice of policy instruments to achieve environmental protection (see e.g., Bohm and Russell, 1985). The literature evaluating post-2012 climate regimes has identified a wide variety of evaluation criteria specifically oriented toward the assessment of alternative international climate policy approaches (Philibert and Pershing, 2001; Aldy et al., 2003; Höhne, 2005; Elzen, 2002; Berk et al., 2002; Torvanger et al., 2004). Taking into account previously identified criteria as well as the particulars of TOAs, we consider five criteria in our assessment of the potential of TOAs to make a significant contribution

[16] Strategic niche management is based on the idea that in order to make new technologies flourish, it is necessary to create protected environments (technological niches) in which actors can experiment with technologies and rules that deviate from the dominant regime. Strategic niche management involves the deliberate creation of such protected environments for targeted technologies so that actors learn to improve the technology and societal embedding. Eventually, the technological niche can evolve into a market (Raven, 2005).

to the international climate policy framework: (1) environmental effectiveness; (2) technological effectiveness; (3) economic efficiency and cost-effectiveness; (4) incentives for participation and compliance; and (5) administrative feasibility.

Environmental effectiveness
In the global climate context, environmental effectiveness measures the degree to which an agreement would reduce GHG emissions and atmospheric GHG concentrations if the participating parties adhere to the agreement. A key issue that arises in this regard is the timing and degree of certainty associated with the GHG effects of TOAs, which will vary widely across different types of agreements. For example, basic research and development tend to be associated with environmental effects farther in the future than technology demonstration, transfer, or near-term deployment policies. As one moves from knowledge sharing and RD&D to technology transfer and standards, the degree of certainty surrounding GHG reductions increases. Another difficulty is related to establishing a counterfactual of what would likely happen in the absence of a policy, which can be particularly problematic with respect to the measurement of technological change and the effects of technology policies.

Technological effectiveness
Technological effectiveness refers to the specific contribution a TOA makes in advancing science and technology. Specific metrics of technological effectiveness will differ depending on the stage of the technological change process at which different TOAs are directed, such as effectiveness at stimulating new scientific and technological breakthroughs, bringing new innovations to market, or lowering the cost and increasing the penetration of existing technologies. These metrics should be applied as appropriate for the different types of TOAs, as the aims are different. For instance, fundamental and applied research is directed toward scientific achievements and innovation rather than technology adoption, whereas technology-transfer agreements are oriented toward encouraging technology diffusion rather than path breaking innovations.

Economic efficiency and cost-effectiveness
Cost-effectiveness seeks out the least-cost means of attaining a given goal, while economic efficiency additionally calls for setting the goal to maximize net benefits by equating incremental benefits and costs. With respect to the ultimate objective of reducing GHGs, cost-effectiveness means achieving GHG reductions in a manner that equalizes the cost of incremental reductions across all sectors and countries. With respect to furthering specific technological development goals, cost-effectiveness means achieving these technological goals at the lowest possible total cost. Efficiency would add to this condition the further requirement that the policy target, be it emissions-based or technology-based, is chosen so that the marginal costs of achieving it are equal to the marginal benefit. Given the difficulties associated with quantitatively valuing the costs and particularly the benefits of climate-change mitigation, the efficiency goal is somewhat elusive.

Given the need for substantial long-term technological developments to significantly reduce GHG emissions, cost-effectiveness across time—or dynamic cost-effectiveness—is a particularly important assessment criteria for GHG policies in general and TOAs specifically. Dynamic cost-effectiveness implies that investments in technological development (e.g., R&D) occur to a point where the incremental investment equals the expected incremental reduction in future GHG abatement costs (in present value terms). Note that the desired amount of near-term investment in technological advance will depend on the magnitude of anticipated future reductions. Likewise, the economically feasible extent of abatement in the future will depend on the magnitude and success of near-term investments in technological development. The extent to which an agreement allows for flexibility in the presence of new information also will influence its economic efficiency. Because new information that resolves various uncertainties related to the benefits and costs of GHG mitigation can be highly valuable, sequential decision making processes and flexible policies that adapt to this new information can have substantial advantages over more rigid approaches (Arrow et al., 1996).

Incentives for participation and compliance

In addition to the other criteria, which also would apply to policies implemented at national or sub-national levels, international agreements face the additional challenge of providing sufficient incentives for individual nations to participate in the agreement and comply with its terms. An absence of sufficiently coercive powers at the international level tends to imply that international agreements to which it is not in a nation's self-interest to abide by will suffer from a low level of participation or compliance. A substantial amount of thought has gone into consideration of how climate agreements might be structured to create the conditions in which enough countries agree to participate and comply so that the agreement is effective. A key element of any country's participation incentives will be the economic costs the agreement imposes relative to its perceived environmental, economic, and political benefits.

Administrative feasibility

Administrative feasibility pertains to whether the legal, institutional, and practical means exist to implement a TOA in an effective and cost-effective manner. This will depend on the range of existing experience and social structures associated with similar policies enacted at a domestic or international level or the practicability of building these structures. Administrative feasibility also relates to the practical ability to measure compliance and ensure enforcement. For example, the issue of measuring whether efforts are new or additional raises important questions for the design of specific TOAs.

5.3 Evaluation of TOAs

We now examine TOAs at the general level in the case of specific existing and proposed climate-related agreements as well as existing non-climate agreements. Table 5.1 shows an overview of the existing and prospective TOAs we examined according to the type of TOA. We include existing TOAs analyzed by Ueno (2006), as well as several other existing TOAs and prospective agreements as outlined by Bodansky (2004).

5.3.1 Knowledge sharing and coordination

The least demanding type of TOA we examine is knowledge sharing and coordination. Agreements of this type generally will not lead to high environmental effectiveness by themselves, and they are broadly seen as a useful addition to approaches that guarantee emissions reductions. Knowledge sharing and coordination TOAs can have several different forms, from labelling agreements to international research coordination. Knowledge-sharing and coordination agreements have relatively low costs, combined with a high level of exchange of information among stakeholders in countries and with raised awareness of the opportunities, pitfalls, and barriers of the targeted technologies. In cases where a technology is in an advanced stage of development and can be implemented at low cost but other barriers inhibit its diffusion, these agreements can be environmentally effective and contribute to diffusion. In the case of technologies that are in the RD&D phase, knowledge-sharing agreements can identify RD&D needs, but the practice in the agreements evaluated below shows that they tend not to lead to additional funding.

Table 5.1 Technology-Oriented Agreements Examined. All TOAs except those in the category "Prospective TOAs" are real-world examples

Knowledge sharing and coordination	Carbon Sequestration Leadership Forum (CSLF) and the International Partnership for the Hydrogen Economy (IPHE) Methane to Markets Partnership Task sharing in International Energy Agency Implementing Agreements (IEA-IA) Asia-Pacific Partnership on Clean Development and Climate (APP) Energy Star bilateral agreements
RD&D	European Organization for Nuclear Research (CERN) ITER fusion reactor Cost sharing in International Energy Agency Implementing Agreements (IEA-IA) The Solvent Refined Coal II Demonstration Project (SRC-II)
Technology transfer	Multilateral Fund under the Montreal Protocol Global Environment Facility (GEF)
Technology mandates and incentives	International Convention for the Prevention of Pollution from Ships (MARPOL) European Union Renewables Directive
Prospective TOAs	Carbon capture and storage technology mandate (Edmonds and Wise) proposal Zero-Emission Technology Treaty (ZETT) proposal Barrett and Benedick proposals for combined technology R&D and standards

The Carbon Sequestration Leadership Forum and the International Partnership for the Hydrogen Economy

The United States has developed several partnerships and forums for promoting specific technologies. The U.S. Climate Change Technology Program strategic plan provides a useful overview of the programs we discuss herein, as well as other programs with international components (US DOE, 2006). In 2003, the Carbon Sequestration Leadership Forum (CSLF) and the International Partnership for Hydrogen Economy (IPHE) were launched. The CSLF's objective is to "facilitate the development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage; to make these technologies broadly available internationally; and to identify and address wider issues relating to carbon capture and storage" (CSLF, 2003). The IPHE, similarly, aims to "serve as a mechanism to organize and implement effective, efficient and focused international research, development, demonstration and commercial utilization activities related to hydrogen and fuel cell technologies" and works as a forum for advancing policies and standards (IPHE, 2003).

Both forums aim at collecting and sharing scientific and technical research results and occasionally publish working papers to address a specific topic in the field of CO_2 capture and storage (CCS) or the hydrogen economy. The activities undertaken by CSLF and the IPHE have thus far consisted primarily of organizing meetings where knowledge and experiences are shared among the countries involved. Also, both forums have a procedure for recognizing existing projects.

These forums have provided an opportunity for discussion and interaction that can help build trust between parties without the pressure of negotiation. This relationship building tends to occur at an intermediate level among primarily energy ministry participants familiar with energy technology, while in contrast IEA Implementing Agreements foster interaction among researchers and climate negotiations tend to involve foreign ministry and environment ministry representatives from higher levels in governments. Such interactions may prove important to the longer term incentives for participation by countries, which have an array of internal specialties and interests.

Budgets for the organizations are nonetheless very limited and it is difficult to establish that the CSLF or the IPHE have had a discernable direct impact on the research and development of CCS or the hydrogen economy. These types of forums could nonetheless have an indirect effect by influencing domestic R&D funding priorities. The environmental effectiveness of these efforts is also difficult to evaluate, but is likely to be limited. Given the rising number of participants—the CSLF started with 13 countries and now has more than 20, including Saudi Arabia and China—the initiation by the United States, and the low entry conditions, the incentives for participation are significant. Compliance with the partnership's charter does not require significant diversion from business-as-usual other than attendance at twice-yearly meetings by national delegates. Due to the low complexity, administration is straightforward.

The Methane to Markets Partnership

The Methane to Markets Partnership was established in 2004. The partnership focuses on "the development of strategies and markets for the recovery and use of methane through technology development, demonstration, deployment and diffusion, implementation of effective policy frameworks, identification of ways and means to support investment, and removal of barriers to collaborative project development and implementation" (Methane to Markets, 2004). The partnership, initiated by the United States and based on a domestic, voluntary methane reduction program, asserts it could reduce GHG emissions by 180 $MtCO_2$-eq in 2015, although no specific target is set. The partnership relies on bringing together governments and the private sector to facilitate the identification of cost-effective opportunities. Indeed, reduction of methane emissions in the sectors defined— landfill gas, oil and gas sector, agriculture and coal mines)—is relatively inexpensive.

The environmental effectiveness of the partnership could be significant but the aspirations are optimistic, so the projections should be regarded with care. The assumed diffusion rate of methane-reducing projects, for instance, is very high. The partnership seems unlikely to develop new technologies, although it could encourage diffusion and modification of existing approaches. If the partnership lives up to its goals—which is uncertain—it could be cost-effective due to its focus on the relatively low-cost mitigation option of methane reduction and its emphasis on information provision and market development. Incentives for participation are high for both the private sector (which sees the partnership as an opportunity to enhance business) and for the host countries of the technology, who see both economic and environmental benefits. The administrative feasibility is high as it is not a complex organization and there is experience with something similar on the domestic level. The additionality of actions taken under the Methane to Markets Partnership is difficult to establish relative to CDM project activities that also involve methane emissions reduction.

Task-sharing within IEA Implementing Agreements

International Energy Agency Implementing Agreements (IEA-IA) use two primary mechanisms: task-sharing and cost-sharing. Cost-sharing is where one contractor performs a research task with funding from the collective of the countries participating in the IEA-IA. Task-sharing is where a joint program is pursued with the participating countries but where each country funds and implements its own contribution to the project. We categorize the task-sharing components of these agreements as knowledge-sharing TOAs because they tend not to involve any additional R&D funding beyond pre-existing domestic programs. In contrast, we categorize the cost-sharing components as RD&D TOAs.

There are 35 Implementing Agreements (IAs), all of which incorporate task-sharing and about half of which have cost-sharing. They cover the fields of technology information (four IAs), renewable energy and hydrogen (nine IAs), end-use energy efficiency (twelve IAs), fossil-fuel technologies (five IAs), and nuclear fusion energy (five IAs).

Most of the tasks have been funded through domestic R&D budgets. If the IAs have generated additional funds for energy R&D, the magnitude of the additional amount is difficult to estimate. The impact on technological change and ultimately the environment therefore comes in the form of better research coordination. The IAs have in some cases had a useful impact on technology standardization, such as in the case of the development of harmonized testing procedures for wind turbine performance (IEA, 2003). Given the limited cost and the opportunities to reduce costs and increase efficacy through information sharing and coordination, the cost-effectiveness probably is relatively high. Membership in IAs is not restricted to governments or to Organisation for Economic Co-operation and Development (OECD)-based actors, and a number of organizations from non-OECD countries are participating in the IEA-IAs. Incentives for participation, therefore, are relatively high. The organization is not complex and administration tends to be housed at a sponsoring domestic energy agency, keeping costs low.

Asia-Pacific Partnership on Clean Development and Climate
In 2005, the United States established the Asia Pacific Partnership on Clean Development and Climate (APP) with five other countries: Australia, China, India, Japan, and South Korea. The purpose of the APP is to "create a voluntary, non-legally binding framework for international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging and longer term cost-effective, cleaner, more efficient technologies and practices" in order to meet "increased energy needs and associated challenges, including those related to air pollution, energy security, and GHG intensities" (APP, 2006).

The participants established eight task forces for industrial sectors: cleaner fossil energy, renewable energy and distributed generation, power generation and transmission, steel, aluminium, cement, coal mining, and building and appliances. Each task force is to develop a detailed action plan on short- and medium-term actions and achieve specific outcomes in the short term.

It is difficult to predict how the APP will develop in the future. At this point, there are small budgets allocated to the APP by the participants and implementation plans are unclear. Combined with the voluntary nature and purpose of the partnership, this implies that it qualifies as a knowledge-sharing TOA in that its activities to date have been limited to road-mapping and planning.

At this time, the environmental effectiveness and the impact on technological change of the APP are likely to be limited. Economic cost-effectiveness cannot be evaluated at this point; costs are low but so are effects. The incentives for participation are high for the developing countries in the group, as they may get greater access to climate-friendly technologies. Administrative feasibility is enhanced by the restrictive membership and hence the streamlined process for achieving agreement.

Energy Star bilateral agreements
Energy Star is a voluntary label for energy-efficient appliances, and more recently, new homes. Rather than targeting knowledge transfer at the RD&D stage, Energy Star is focused on provision of energy efficiency information to end-users. It was originally developed by the U.S. Environmental Protection Agency for personal computers but has been expanded to many other products as well. Products with the Energy Star label have been diffused to other countries through international trade, and the Energy Star bilateral agreements have helped to harmonize the use of the label (and the associated testing procedures) in other countries. It has been adopted in Canada and Mexico for many of the same appliances used in the United States and in Japan and the European Union only in distinct categories, as these countries already had standards of their own (Meier, 2003).

The Energy Star agreements raised awareness about hidden energy consumption, such as stand-by power, and have diffused policy tools to reduce it (US EPA, 2003). Although it is uncertain how much electricity reduction can be attributed to the bilateral agreements (as labels could be adopted without the agreements), the energy-efficiency labelling policies for several countries have become more cost-effective. Incentives for participation exist when there is not yet a domestic energy efficiency standard or where harmonization is beneficial due to international trade. Administration is straightforward.

5.3.2 Research, development and demonstration agreements

TOAs that feature cooperative RD&D are varied and can take place in virtually all research fields. They appear to be most successful in research that is more fundamental and that has not yet accumulated commercial interests. Agreements to further RD&D can be effective in several respects: they increase international exchange of scientific and technical information and they increase the cost-effectiveness of research and developments through cost-sharing and reduced duplication of effort. Continuity of funding, however, has been problematic at times with existing efforts. The eventual contribution of RD&D to emissions reductions is uncertain without incentives for eventual technology adoption but that is not the primary goal of RD&D agreements. For technologies that are in the research or demonstration phase or for fundamental research, RD&D agreements can lead to more efficient development. We examine RD&D TOAs in the fields of particle physics, energy research, and coal liquefaction. We discuss proposals by Benedick (2001) and Barrett (2003) for a combination of technology R&D and standards in Section 5.3.5. Another option is internationally coordinated innovation inducement prizes for advances in GHG-reducing science and technology (Newell and Wilson, 2005).

The European Organization for Nuclear Research

The European Organization for Nuclear Research (CERN) was founded in 1954 by 12 European countries to share the cost burden of fundamental particle research and has been joined since by 8 other European countries and a number of observers from outside Europe. It focuses on fundamental physics. While not motivated by environmental concerns, CERN provides a useful case of international research collaboration. The institute operates a number of particle accelerators, which are used by research groups from all over the world for experiments in natural sciences and engineering. Currently, the largest fraction of the budget is being spent on the newest accelerator, the Large Hadron Collider (LHC), which straddles the French-Swiss border. The LHC will be the most powerful accelerator in the world and actually is a separate project outside the regular CERN agreement. Apart from cost sharing, the CERN joint venture also was one of the first steps in the direction of the unification of Europe, being established less than ten years after World War II.

The member states of CERN contribute to the CERN Institute in proportion to their GDP, with some small adjustments. CERN's expenditures in 2005 were almost US$ 1 billion, of which about 50 percent was on material costs for the LHC and 35 percent on personnel (CERN, 2006). The reliance on separate national contributions for the US$ 2 billion LHC project led to budget problems in 1996, when CERN settled on a tight budget for the LHC because of a lack of offers from participating nations. In addition, budget overflows fell to CERN's account, not that of the LHC consortium, which led to serious budget problems in 2001 (Nature News, 2001).

The purpose of CERN is to lower cost and cooperation barriers for particle physicists in Europe and the rest of the world and to achieve more technological progress. CERN appears to have succeeded in the purpose of advancing basic research, as it is one of the leading particle physics institutes in the world. The cost-effectiveness of particle physics seems to have been enhanced by the institute through cost-sharing of expensive particle accelerators. The incentives for participation are great and the provisions for contributions proportional to GDP seem to be acceptable to the parties, although separately negotiated project budgets, such as the LHC, may be subject to free rider problems. Administration has worked without any major problems, other than the budget contribution issue.

ITER fusion reactor
The ITER is an international fusion experiment designed to show the scientific and technological feasibility of a full-scale fusion power reactor. The ITER builds upon prior research devices but will be considerably larger. Fusion power offers the potential of essentially inexhaustible, zero-GHG electricity without the levels of radioactive waste associated with nuclear fusion—properties that have obvious appeal as world energy demand increases. However, this option is still in the research phase. While some indicate that fusion power might be commercially available by 2040, many others doubt whether this can be accomplished by the end of the century. The high uncertainty that this research will deliver results, its low near-term commercial value, and the very high costs of the demonstration facility make a cost-sharing arrangement worthwhile.

The ITER began in 1985 as a collaboration between the European Union, the United States, the Soviet Union, and Japan. Participation has varied over time, and currently there are seven parties participating in the ITER program: the European Union, the United States, Japan, Russia, India, China, and South Korea. Conceptual and engineering design phases led to a detailed design in 2001, supported by US$ 650 million worth of R&D by participating countries. The program is planned to last for 30 years—10 years for construction, and 20 years of operation—and cost approximately US$ 12 billion, making it the second most expensive international scientific project after the International Space Station. After many years of deliberation, and a contentious debate over locating the project in France versus Japan, the participants announced in 2005 that ITER will be built in Cadarache, France—Japan was promised 20 percent of the research staff on the French location of ITER as well as the head of the ITER administrative body. Also, a research facility for the project will be built in Japan, for which the European Union will contribute about 50 percent of the costs. Overall, the participating ITER members have agreed on a division of funding contributions where 5/11ths is contributed by the hosting member (the European Union) and 1/11th by each of the six non-hosting members (ITER, 2006).

Cost-sharing within IEA-IAs
In many cases where cost-sharing was included in IEA-IAs, money from the common funds was spent for covering central administration and information-sharing activities only and actual projects were implemented through task sharing. In a few cases, however, participants financed joint R&D or demonstration projects in a cost-shared scheme (Scott, 1995). One such case is a joint demonstration project of high-temperature, high-pressure filters necessary for pressurized, fluidized bed combustion and integrated gasification combined cycle plants. In this project, participants, including private companies, shared the cost (about $US 15 million) and pooled technical knowledge (IEA, 1996).

Other cost-sharing examples are the IEA Clean Coal Centre and the IEA GHG R&D Program, which do not perform much hard research but bring together research and development results in desk studies in the field of coal and CCS and organize international conferences in that field. IEA GHG also has contributed funds for conducting monitoring in CCS demonstration projects. Although the publications of these organizations are in the public domain, only paying members of these cost-shared implementing agreements (mostly industrial organizations in the member countries) have free access to the information. In another example, the Implementing Agreement on Bioenergy works partly through task-sharing and partly through cost-sharing and had a research budget of US$ 1.36 million in 2005, which was spent on country reports, information provision and conferences, and desk studies (IEA, 2006a).

The added value of most cost-shared IEA-IAs is in the bundling of research results and the provision of a platform for information exchange and learning. Although research is conducted in cost-sharing IEA-IAs, it typically concerns desk studies of technological progress, which indirectly contribute to technological development. Desk studies usefully bundle information but rarely do the technological research itself. The cost-effectiveness is likely to be good given the relatively low budgets and the informational impact of some programs. The IEA GHG Program, for instance, has played a very prominent role in the work on CCS, and the Bioenergy IA is instrumental in sharing scientific knowledge. Incentives for participation are high if the technology is at the centre of attention, especially in the case when only paying members can get access to the information (although this decreases knowledge spill-over benefits).

The Solvent Refined Coal II demonstration project

In response to the 1970s oil crisis, the U.S. Department of Energy (DOE) built several small-scale pilot plants to test various approaches to coal liquefaction. The rationale for developing the technology was to expand the alternatives to conventional oil as a hedge against oil price increases. After pilot plant tests, the DOE picked up promising liquefaction ideas and implemented large-scale demonstration projects between 1978 and 1982. Private companies shared the burden of the projects with the government (NAS, 2001). Solvent refined coal (SRC) was one of these ideas. At the pilot test stage, two plants were built to test two types of SRC and one of them was supposed to be chosen for a large-scale demonstration. Later, DOE decided to build two demonstration plants to test both ideas. To offset this cost increase, the DOE invited Japan and Germany to join SRC-II, and the three governments made an agreement for co-funding the project in July 1980. The total cost was approximately $US 1.5 billion (in 1981 dollars). The burden was to be shared 50 percent by the United States, 25 percent by Japan, and 25 percent by Germany.

However, SRC-II was cancelled due to budget cuts by the Reagan Administration. The project was perceived to be less urgent as oil prices stabilized and it became more difficult to justify coal liquefaction as a response to the oil price shocks. This case has been cited by the international scientific research community for particle science, fusion, and space, however, as an example of a country not respecting international joint-funding projects (OTA, 1995).

As this project was cancelled, the technological outcome was not favourable ex post. Incentives for participation and compliance with the agreement changed over time with political and economic circumstances and eventually led to the programme's demise. The SRC-II international agreement made clear that no agreement is carved in stone and that changing conditions can influence the continuity of any treaty.

5.3.3 Technology-transfer agreements

Specific mechanisms have been established to facilitate technology transfer in existing agreements related to climate change and other international environmental problems. Provisions for technology transfer are driven primarily by a need to help developing countries follow a less GHG-intensive development path by providing access to climate-friendly technologies and the funding to cover their additional cost. As such, technology-transfer TOAs can help to increase incentives for developing country participation in climate-mitigation agreements, while advancing overall technological and environmental effectiveness (IPCC, 2000a).

Technology-transfer agreements have to address typical impediments to technology adoption, such as information availability and technological maturity, but in addition must address financing barriers that are specific to developing countries. Appropriate financial incentives are therefore an essential part of an effective technology-transfer agreement. The environmental effectiveness of technology transfer can be high, provided sufficient funding is available. The degree of intellectual property right protection, rule of law, regulatory transparency, and market openness are also critical conditions and potential impediments bearing on technology transfer.

Multilateral Fund for Implementation of the Montreal Protocol

The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) was agreed to in 1987 as part of the 1985 Vienna Convention for the Protection of the Ozone Layer with the aim of phasing out the use of ozone-depleting substances (ODSs). It has commitments for all countries and was ratified quickly by the industrialized countries, but developing countries were unwilling to ratify it due to the costs of implementation. In order to provide incentives for developing countries to join the Montreal Protocol, and thereby curb the expected rise of ODSs in developing countries, the Multilateral Fund for Implementation of the Montreal Protocol was set up as part of the 1990 London Protocol (an amendment of the Montreal Protocol). Industrialized countries committed to donating funds to the Multilateral Fund on a three-year basis to "meet all incremental costs" for compliance of the developing countries, who in exchange committed to the slow phase-out of ODSs. The money is in the form of grants or loans for projects such as the conversion of existing manufacturing processes, training of personnel and setting up of national ozone offices, or paying royalties and patent rights on new technologies. Donor pledges amounted to US$ 2.1 billion over the period 1991 to 2005 and the current level of replenishments to the fund are around US$ 400 million for the three-year period of 2006–2008 (UNEP, 2005).

The environmental effectiveness of the Multilateral Fund has been substantial and contributed to the successful environmental outcome of the Montreal Protocol, as well as to technological diffusion in developing countries. The incentives for participation are high, as industrialized countries were willing to make contributions in order to prevent their efforts as part of the Montreal Protocol from being offset by a rise in ODSs in developing countries. Developing countries were willing to make the necessary adjustments to comply with the Montreal Protocol as long as incremental costs were kept to a minimum. Administration has been as could be expected as it was the first mechanism of its kind and was set up with virtually no experience. However, through the use of implementing agencies—the United Nations Development Programme (UNDP), United Nations Environmental Programme (UNEP), United Nations Industrial Development Organization, and the World Bank—that distributed tasks according to their competences, the operation of the Multilateral Fund is managed by a secretariat with about 20 staff.

The Montreal Protocol, including its Multilateral Fund, is rightly seen as a success story in environmental governance (DeSombre and Kauffman, 1996). It resulted in very substantial reductions in CFCs and effectively involved developing countries that were at first unwilling to commit to reductions. Because both stratospheric ozone depletion and climate change are global atmospheric problems, the institutional solution of the Montreal Protocol, with its considerable institutional difficulties, often is pointed to as a model for climate change (Victor, 2001). As many experts have pointed out, however, this comparison is not entirely appropriate given the substantial differences between the two problems. The scale of changes required to address climate change is much greater, the sources of GHGs much more widespread, and the likely costs much higher than for addressing the ozone problem. Low-cost substitutes for ODSs were available, while the same is not true for large-scale GHG reductions. A technology-transfer fund that attempted to cover the incremental costs of GHG reduction in developing countries would have to be orders of magnitude larger in scale and in reach than the Multilateral Fund under the Montreal Protocol.

Global Environment Facility

The Global Environment Facility (GEF) was established by the UNDP, UNEP, and the World Bank. The GEF provides grants to both small and large projects in developing countries that protect the global environment. Several categories are funded; climate change being the second most important (after biodiversity), claiming about 40 percent of the GEF's current yearly budget. Since its establishment in 1991, the GEF has invested almost US$ 2 billion in climate change, generating co-financing of over US$ 9 billion. About 90% of the funding has gone to energy efficiency, renewable energy, GHG reduction, or sustainable transportation. The UNFCCC also has entrusted its financial mechanism for developing country capacity building and technology transfer to GEF (GEF, 2005a).

A 2005 evaluation of GEF found that while there has been variation in the success of different sub-program elements, its climate change program has satisfactorily performed, exceeding its interim GHG reduction targets in an increasingly cost-effective manner (GEF, 2005b). While GEF's overall resources and role in GHG mitigation is small on a global scale, the organization has the potential to play an important catalytic role in influencing transformation in energy and related markets in developing countries so that over the long-term their economies are less carbon-intensive (GEF, 2005b). The incentive for developing countries to participate is to obtain new technology and project financing at low cost. For industrialized countries, the GEF is financed from Official Development Assistance (ODA) flows, and were the sums to become very large and additional to regular spending on ODA, the enthusiasm to contribute to such a fund may fade. Administration of GEF has worked, but the organization is relatively complex, with task distribution between UNDP, UNEP and the World Bank. Requirements for the design and evaluation of projects are substantial and therefore relatively costly for smaller projects.

5.3.4 Technology mandates and incentives

Technology mandates and incentives can be both technologically and environmentally effective treaties to the extent that they divert the signatories of the agreement significantly from business-as-usual. Cost effectiveness depends on the detailed provisions and domestic policies that are employed.

International Convention for the Prevention of Pollution from Ships

The International Convention for the Prevention of Pollution from Ships (MARPOL) Treaty was agreed in 1973 to halt marine oil pollution from oil tankers. Since the 1950s, attempts had been made to restrict oil emissions into the marine environment by means of the International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL). OILPOL required ships to record all ballasting, cleaning, and discharge operations. This reflected the two main sources of oil pollution: the emission of oil-polluted ballast water that was used for balance after ships returned from their journey and the cleaning of tanks with seawater and subsequent dumping of the oil-water mixture at sea. The implementation of the OILPOL treaty was problematic because the enforcement was supposed to be done by the states where the ships are registered (i.e., the "flag" states), which tended not to be those suffering from the pollution. In addition, there was considerable leakage of ships changing their flag state to states that were not enforcing OILPOL.[17]

MARPOL eventually was agreed to after unilateral threats from the United States to impose stringent domestic technology standards, which would have lead to the denial of access to U.S. ports for noncompliant ships. As a result, in 1978, countries agreed to strengthen international regulations on tankers, setting mandatory design requirements for installation of separate tanks for ballast and operating requirements for washing tanks with crude oil rather than sea water; 119 countries are party to MARPOL.

After entry into force of the MARPOL treaty and harmonization of standards by a large number of countries, international shipping had difficulties escaping the standards because all major ports required that ships meet MARPOL standards. Barrett (2003) calls this the tipping point: once the number of ratifying countries reached a certain threshold, the number of tankers equipped with specified technologies grew rapidly. Nonetheless, although much international shipping now is

[17] According to Murphy (2004), with regard to ships other than oil tankers, a classic "race to the bottom" can be observed: competition of deregulation and loose enforcement occurred among flag states.

regulated, according to Tan (2006) many substandard ships still are in operation in many parts of the world and pollution, therefore, has in part been relocated to more lenient countries.

The effectiveness of the MARPOL treaty in mandating the diffusion of environmentally beneficial technology has been high, as has been its environmental effectiveness given that it directly targets the most significant sources of marine oil pollution. However, the technological prescriptiveness of the treaty potentially could discourage innovation toward less-costly or less-polluting technologies in the shipping industry. There has been flexibility over time, however, with double-hull requirements eventually replacing the segregated ballast tank prescription. However, it often is pointed out that mandating segregated ballast tanks under MARPOL is a relatively costly way to achieve a given oil-reduction goal, compared to emissions standards (Mitchell, 1994). The incentives for participation and compliance are present for countries that suffer from oil pollution and are enhanced by strict domestic regulations in the United States for companies with U.S. trade destinations. Administration includes a detailed inspection mechanism.

EU Renewables Directive

Technically speaking, environmental agreements in the European Union should not be qualified as international environmental agreements, as the European Union has a degree of enforcement authority that does not exist across other national boundaries. We include the EU Renewables Directive nonetheless because it provides a relevant example of how an international technology mandate might be designed.

The goal of the 2001 EU Renewables Directive is to double the share of renewable primary energy in the European Union to 12 percent in 2010. An element of this target is for the share of renewable electricity to reach 21 percent in the European Union, up from around 14 percent in 1997. The implementation of the directive is left to the member states. Although the electricity targets in the Renewables Directive are indicative and not accompanied by penalties for non-compliance, the European Commission can make them mandatory if a country is unlikely to comply. The indicative targets for each member state depend on the share of renewables already in the electricity supply in that member state (Rowlands, 2005).

All EU Member States currently have a renewable energy policy in place to comply with the directive and most are aimed solely at electricity supply. Countries have chosen either a feed-in tariff system or an obligation system coupled with tradable green certificates (Linden et al., 2005; Lauber, 2004). However, not all are on track and the European Commission has estimated that the share of renewable energy sources in the EU15 is on course to reach 10 percent in 2010.Although this is an improvement relative to business-as-usual, it is less than the 12 percent target.

Even if progress has not been as fast as hoped, both the environmental and the technological effectiveness of the EU Renewables Directive are likely to be high given the ambitious targets and the magnitude of technology investments that will need to be made in many countries to achieve their targets. It is expected, for example, that the directive will boost the use and development of wind energy, which appears to have been the case in Germany (Michaelowa, 2004). The costs of the policies to achieve the targets have been significant in many countries and cost-effectiveness is enhanced in cases where tradable renewable energy certificates allow for flexibility.

The question of participation and compliance is less relevant on the EU level but is likely to be an issue would such an agreement be proposed on a global level. The efforts of a number of countries to establish something similar for renewable energy have shown limited success. These efforts were spearheaded by the German Government at both the 2002 World Summit for Sustainable Development in Johannesburg and at the Bonn International Conference on Renewable Energy in 2004. A Johannesburg Renewable Energy Coalition (JREC) was formed by some 60 countries. More than 200 renewable energy partnership projects have been reported (REN21, 2006). The difficulty is the additionality of the projects; it is unclear whether these are projects that already existed and were simply reported to the project secretariat or whether the projects are actually new and would not have taken place without the JREC. Administration of a global renewables agreement is feasible, assuming that the definitions of renewable energy are clear. In Europe, for instance, a debate is currently underway on whether the co-firing of palm oil from developing countries can be counted as renewable energy, as rainforests are often cleared to make room for palm oil plantations. On a global level, the complexity of such issues only would increase.

5.3.5 Prospective Technology-Oriented Agreement proposals for post-2012 climate policy

Although most of the post-2012 international climate policy proposals in the literature entail emissions reduction targets of various forms, a small number of proposals include technology-oriented elements.

Carbon Capture and Storage Technology Mandate
The only prospective TOA mandating a specific GHG mitigation technology is the Carbon Capture and Storage (CCS) scenario by Edmonds and Wise (1998). In a modelling study, they explore the costs and effects of an obligation of Annex I countries to implement CCS with all fossil fuel-based power plants and coal-based synthetic fuel facilities built in 2020 and beyond and demonstrate that such a measure would stabilize atmospheric GHG concentrations at 550 ppm, storing almost 350 $GtCO_2$ cumulatively between the start of the treaty and the end of the century. In this scenario, developing countries are obliged to take the same commitment if their GDP equals the average Annex I GDP.

The effectiveness of the simulated agreement in diffusing CCS technology and reducing emissions is significant, as given by their outcome of stabilization at 510 ppm. Cost-effectiveness is not high, according to the authors, but could be enhanced through some type of flexibility measures. The incentives for participation and compliance with this agreement alone are low for countries that rely heavily on coal, because they would face more restrictions than other countries. Administration would be comparable to traditional technology standards for air pollution assuming it takes place at the domestic level. Enforcement may be simplified by the targeted technological nature of the mandate on large stationary sources.

Zero-Emissions Technology Treaty
Sugiyama and Sinton (2005) propose an “Orchestra of Treaties” with four elements: emissions reductions, a Zero-Emissions Technology Treaty (ZETT), a climate-wise development treaty, and the UNFCCC forum. The ZETT is a technology-mandate TOA because of its commitment to zero-CO_2-emission technology for the energy sector as its ultimate goal. It is not proposed to be a binding emissions target, and the mechanism for compliance is “pledge and review.” The hypothetical treaty formulates flexible targets, such as technology cost reduction and deployment, for a number of technologies by coalitions of countries. It allows countries to contribute to the long-term development solely of their preferred technologies. A later version of the ZET treaty, proposed in Sugiyama et al. (2005), elaborated on the types of technologies and outlined how the treaty could develop given the current players. The potential environmental effectiveness of the ZETT depends on the strictness of its targets but could be high, especially if implemented alongside an emissions target approach, as in the Orchestra of Treaties proposal. The treaty proposal is designed to facilitate long-term technological development and adoption and, therefore, the potential impact on technological change could be high. The cost-effectiveness is unclear but is unlikely to be very high. Incentives for participation are increased by allowing countries to focus on their preferred technologies.

Combined Technology R&D and standards
Benedick (2001) proposes a number of parallel approaches. Emissions targets that can be renegotiated are in his portfolio, but in terms of technology, he proposes to have long-term international technology standards and a small global carbon tax to fund research and development of technologies. He does not argue for international cooperation in energy research but proposes to devote the revenues of a small domestic fuel tax to research funding. Similarly, Barrett (2003) proposes a protocol based on both technology push through collaborative R&D and technology pull through technology standards. Although both approaches have similarities, we focus on Barrett's proposal.

Barrett argues for an international approach to energy R&D, and takes "big science" collaborative research, such as the International Space Station and the LHC as examples. The essential incentive for participation is that the contribution of the countries to the R&D fund would depend on the other countries participating. If one country accedes, then all the other parties will increase their funding by a specified amount. Alternatively, if that country withdraws, the others will lower their funding. A cap on the total fund ensures that countries know their maximum costs. The incentives for participation and compliance are increased by the mutually enforcing participation clause, provided a credible sum can be agreed upon. However, the fund as proposed might suffer from the same problems as the LHC example in the CERN case.

Barrett models the technology standards part of his approach on the MARPOL treaty and his most important critique of the Kyoto Protocol—its non-enforceability—would be solved because it eventually would lead to a tipping point for climate-friendly technologies. Barrett's claim that climate-change technology is sensitive to a tipping point is essential to the argument for his proposal, particularly for participation and compliance incentives. His claim, however, is highly speculative. Most importantly, such measures would have to be implemented for such a broad number of products that there would be a significant degree of complexity and potential problems with the measurement of compliance.

The technological, and hence the environmental, effectiveness of the proposal depends in part on the total sum that the participating countries are willing to devote to the fund. This can go two ways. On the one hand, governments could indeed view energy research as a global public good and agree on a high level of funding, which the clever sign-in mechanism could assist in attaining. On the other hand, governments may want to keep a technology-leader role in their own hands and feel that they already have sufficient programs domestically. It also is questionable whether funding devoted to a newly established international fund would be additional to domestic funding for low-carbon energy research or whether it would crowd-out existing funding. The technology-mandate part of the proposal enhances the proposal's overall environmental effectiveness, assuming that the standards are stringent enough.

Cost-effectiveness of technology-based standards is likely to be relatively low, especially if no trading or offsets of any kind are allowed. Cost-effectiveness can be enhanced through the benefits of R&D cooperation and long-term cost reduction, and therefore the combination of standards with R&D allows for greater long-term technological effectiveness.

5.4 Embedding Technology-Oriented Agreements

5.4.1 Rationale for a technology and emissions policy portfolio

Addressing climate change likely will require a broad range of policies and measures given the long timeframe and the breadth of sectors, economic activities, and actors involved. TOAs include a variety of cooperative actions and no single action can address the environmental and technological challenges of the climate problem on their own. In combination with measures that directly ensure emissions reductions—which may include emissions targets, technology mandates, standards, or incentives-based treaties—TOAs aimed at knowledge sharing, RD&D, or technology transfer could play an important role in a portfolio of actions and commitments. The economic rationale for combining emissions targets or prices with TOAs is clear (see Section 5.2). Since the ultimate goal is to reduce GHG emissions, a policy directly targeting emissions is likely to be the most cost-effective single policy means for achieving this end. However, since private markets often provide insufficient incentives for RD&D, TOAs can be used to address these shortcomings by facilitating technological progress. RD&D policy by itself is a poor substitute for mitigation incentives for reducing emissions, however, since it postpones the vast majority of the effort until after costs are brought down, requiring large R&D investments and forgoing many cost-effective opportunities to reduce emissions (Fischer, 2004; Fischer and Newell, 2007; Jaffe et al., 2005).

Of the different types of TOAs, only technology mandates or significant adoption incentives have the possibility of acting as a substitute for emissions policy. Such TOAs may be sector-specific, as technologies often are used only in a single sector or sub-sector. Mandates may be particularly appropriate for sectors in which it is difficult to implement emissions trading or where informational or other market problems may be present, such as in the context of energy efficiency in building and/or transportation technologies.

Experience also shows that for reasons of administrative and political feasibility, technology standards and mandates frequently are proposed and applied in the electricity sector, which has a history of regulation for economic as well as environmental reasons. Examples include renewable energy portfolio standards in the European Union, Japan, and the United States and the CCS Technology Mandate agreement. Such applications of TOAs can be environmentally and technologically effective on their own, although the economic cost-effectiveness tends to be less than an emissions target-based approach due to inflexibility and technological specificity. TOAs also can complement one another. For example, an agreement on knowledge sharing could be made more effective if it goes hand-in-hand with joint RD&D efforts, and technology transfer could enable developing countries to participate in a technology standard regime. Complementarities also exist because technologies are developed through several stages, from R&D to demonstration, initial adoption and widespread diffusion (Sandén and Azar, 2005). A portfolio approach may be supported based on uncertainties involved in the innovation process, the risk of attempting to pick winners, and the variety of national circumstances.

Finally, it is worth mentioning that TOAs could be designed according to country interests. If, for instance, Brazil sees itself as a major player in the world market of dry biomass, it may have an interest in agreeing to an international agreement on bio-energy technologies. The same may apply to Indonesia or Malaysia, countries that dominate the international palm oil market. Saudi Arabia may be inclined to use its emptying oil fields for CO_2 storage of if there is an international agreement for its implementation and it has incentives to take the CO_2. Countries like Denmark, whose companies have dominated the world wind-turbine market, may be able to further their industrial interests with a TOA aimed at wind energy in energy-hungry countries such as China and India, which have significant potential for wind energy but a limited wind-energy industry of themselves. East Asian countries, the growing centre of world energy demand, may agree to a TOA dedicated to energy efficiency (Sugiyama and Ohshita, 2006). TOAs could be worldwide (with most countries involved) or could be made by groups of countries, even though that would lead to fragmentation of international regimes.

5.4.2 Institutional embedding of TOAs

The larger question then is how to structure various technology-specific components into a package with emissions-based policies and/or mandatory TOAs aimed at technology deployment. Many ways are conceivable. TOAs may be negotiated on their own terms, alongside or aside from other climate agreements, or they may be treated explicitly as part of a larger climate-policy package with emissions targets or other policies and measures. Depending on the structure, different forums are likely to be appropriate.

For example, we already see that knowledge-sharing and joint RD&D agreements are possible in bilateral, regional, and larger multilateral frameworks. Depending on their scale and ambition, they may not need distinct institutions and may be administrated by cooperating domestic agencies. Larger and deeper commitments are likely to need more centralized and better equipped multilateral institutions (Koremenos et al., 2001). The IEA may be an appropriate body for managing energy-related agreements among its members, mostly developed countries. Other organizations could facilitate efforts in other areas, such as the United Nations Food and Agricultural Organization for biological sequestration technologies and techniques. While considering these options, it also should be kept in mind that the fragmentation of agreements across country groups, technologies, and existing international agreements may lead to reduced transparency, compatibility, and accountability.

Technology transfer agreements similarly could follow different frameworks. They could be negotiated bilaterally between particular developed and developing countries. Developed countries could agree in a multilateral framework to engage in technology transfer through their own development agencies or they could agree to jointly fund climate-friendly technology transfer through international organizations, such as the multilateral development banks or the GEF. Efforts in a broader, multilateral context are likely to have more impact, but the lesser degree of domestic control may be a stumbling block for some countries[18].

Some of the technology mandates are more likely to require broader multilateral engagement due to the costs entailed by these commitments. In other cases, a small coalition of countries may agree on specific technology mandates that have expected ancillary benefits for their situation (e.g., improving security of supply, reduction of local air pollution, providing incentives for innovation in domestic industry). By design, they may be better able to foster participation. For example, sector-based technology standards may be able to provide better assurances of a level playing field for international trade because broad emissions targets may not be implemented in a way that affects sectors identically across countries. Moreover, performance standards can have lesser effects on competitiveness: although the standards may raise product costs, emissions prices also would impose the cost of the embodied emissions, further raising marginal production costs (Bernard et al., 2007; Fischer and Fox, 2007; Fischer, 2003). For these reasons, a set of countries may be willing to take on these kinds of TOAs even with a lack of GHG-reduction commitments by other countries.

TOAs could emerge outside of the context of an existing treaty, but they also could be negotiated under the umbrella of the UNFCCC. Even in this framework, though, many forms are conceivable. For instance, one could have a single Technology Protocol under which various technology-specific commitments are structured. Such a package could recognize complementarities among components. Or the UNFCCC could have multiple technology-by-technology protocols, in which case countries could select which to join and not necessarily join all the protocols. As noted, such arrangements also are possible outside the UNFCCC; additional examples are the APP and the G8. Barrett (2003) proposes to set-up technology protocols by stages, drawing an institutional line between a R&D protocol, and a deployment and standards protocol, similar to some of the distinctions we made in TOAs.

Alternatively, TOAs could be incorporated into emissions-oriented agreements in a policies and measures (PAMs) format in which countries trade-off one component for another in the negotiations. A similar idea was adopted by the General Agreement on Trade in Services as a schedule of

18 A good example is the United States nonparticipation in the Global Fund to fight AIDS, tuberculosis, and malaria.

commitments. This option would recognize that preferences for a particular set of policy approaches may diverge across countries due to the different socioeconomic characteristics of nations or due to the uncertain nature of the costs, benefits, and strategies for reducing GHGs and the negotiators' perceptions of the risks. For example, a country that is more optimistic about future technological potential may prefer to engage in less near-term mitigation in favour of more R&D now and stricter caps later. A country that is more risk averse about impinging upon economic growth and more pessimistic about the speed of technological progress may be willing to accept intensity-based targets. Another country may have different expectations about the marginal benefits and be willing to accept a certain carbon tax (or safety valve) but not to risk a sharp run-up in energy costs.

However, while opening up a menu of policies could broaden the opportunities for agreement along some lines, it also would increase the number of negotiation parameters substantially and may create complexity that might not be administratively manageable. It also raises important difficulties in evaluating the trade-offs in effort and effectiveness and in measuring compliance (Fischer et al., 2005). In terms of emissions reductions, R&D and mandatory policies have very different time profiles and certainty of effectiveness. The credibility of long-term commitments is another important issue raised by Montgomery and Smith (2005). They argue for technology-oriented policies, given the difficulty in committing future governments to costly, stringent emissions targets. However, current reductions are certain and negotiators may be uncomfortable trading off certain reductions with uncertain results from investments in technological efforts. In this case, parallel R&D and mandatory emissions-reduction agreements may be more likely to bear fruit.

At this point, starting substantial negotiations on TOAs under the UNFCCC umbrella will be challenging, potentially requiring a new consideration of PAMs and technology agendas and a way to incorporate countries not party to the Kyoto Protocol. The most promising opportunity may be a review of the whole structure of the Kyoto Protocol, pursuant to Article 9, which could open the door to other types of agreements, such as TOAs.

5.4.3 Interactions with other agreements

No climate policy operates in a vacuum. Rather, it operates in a world of complex interlinkages through global trade and myriad governing rules defined by other international agreements. These forces and obligations impact the effectiveness of a climate agreement and vice-versa. Therefore, climate agreements should be evaluated in the broader context and negotiators should note opportunities to improve the functioning and compatibility of all international agreements. Given the broad span of mitigation and adaptation options, efforts on the climate front obviously will overlap with those in the areas of energy, air pollution, biodiversity, agriculture, development, and public health. Asselt et al. (2005) provide an overview of these interlinkages across international institutions and discuss linkages related to biodiversity, food supply, poverty, energy supply, trade and finance, and air quality. In this section, we consider those agreements most likely to interact with TOAs.

Convention on Biological Diversity

The Convention on Biological Diversity (CBD) has as its goal "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources." Conflicts may arise with TOAs that have the potential to impact native habitat. Likely candidates are TOAs related to agriculture in developing countries, such as soil or forest sequestration. However, any TOA that affects land use should be sensitive to CBD goals. Renewable energy targets are a good example, as they can involve wind turbine siting, hydroelectric dams, or biomass cultivation requiring deforestation.

The Montreal Protocol

The Montreal Protocol offers an example of how agreements could run at cross-purposes. CDM crediting for implementing HFC 23-reduction technologies is said to create a perverse incentive for developing countries to continue to produce HCFC 22 that is supposed to be regulated as an ODS under the Montreal Protocol[19]. TOAs should be aware of any direct or indirect effects on phase-out incentives and consider options that create compatible incentives.[20] This example also raises the issue of whether by agreeing to TOAs, developing countries may forego opportunities for CDM credits, thereby affecting their incentives to participate.

World Trade Organization

The World Trade Organization (WTO) agreements are likely to interact with TOAs, particularly mandates, in several ways. On the one hand, the rules governing global trade place restrictions on the policy options one might consider for coping with extraterritorial emissions. On the other hand, because of these rules, certain kinds of TOAs may be useful substitutes for other kinds of emissions policies.

The guiding principle of "national treatment" requires importing countries to treat foreign goods the same way they treat "like" domestic goods, once these goods have entered the market.[21] For the most part, this requirement means that countries must impose environmental taxes or regulations, like carbon taxes or energy efficiency standards, equally on domestic as well as imported goods. The WTO agreements also specify when taxes may be border-adjustable; importantly, taxes on inputs to production are border-adjustable only when the goods are physically incorporated into the exported products, thus excluding emissions taxes.[22]

Global trade can limit the effectiveness of climate agreements (TOA or emissions targets approach) when significant shares of emitting countries do not participate in implementing similar policies. Since regulations restricting emissions impose economic costs, they change relative prices internationally and cause emissions leakage by giving non-participants a competitive advantage in emissions-intensive production. However, the WTO obligations prevent countries that are participating in a climate agreement from imposing taxes or regulations on imported products according to their production processes, including their GHG-emissions profiles. In other words, they eliminate trade measures as a vehicle for inducing participation, compliance, and enforcement with climate agreements and limit options for preventing leakage. Consequently, TOAs that do not adversely affect competitiveness emerge as more palatable – and possibly more effective – policies.

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19 HFC 23 is a by-product of HCFC 22 and has a high global warming potential (GWP). Although HCFC 22 is also a GHG, it is not regulated under the Kyoto Protocol due to its regulation as an ODS under the Montreal Protocol. Developing countries are committed to freeze production and consumption of HCFC 22 used for refrigerators by 2015 and phase it out by 2040 under the Montreal Protocol. However, they do not yet have a stepwise phase-out commitment between 2015 and 2040, and CDM crediting for HFC 23 reduction seems to create an incentive to continue to produce HCFC 22 because of double incomes from sales of HCFC 22 and CDM. Currently, credits from HFC 23 reduction dominate the largest share of CDM market.

20 A TOA related to energy efficiency in refrigeration technology could be an example. A multilateral fund for destroying HFC 23 is also an option, as proposed by Wara (2006).

21 Article III of the General Agreement on Tariffs and Trade (GATT).

22 The GATT (1994) Agreement on Interpretation and Application of Article VI, XVI, and XXIII of the General Agreement on Tariffs and Trade. A revision in the Uruguay Round broadened the category of adjustable taxes to allow rebates for indirect taxes on goods and services if they are "consumed" in the production of the exported product: "in addition to physically incorporated inputs, export rebates are permitted on 'energy, fuels and oil used in the production process'" (GATT Agreement on Subsidies and Countervailing Measures, Annex II, footnote 61). This expansion raises critical questions for policies concerning energy or greenhouse gas emissions, such as whether specific taxes on energy are adjustable, and if so, whether adjustments only may be applied to exports and not to imports. The U.S. government has been of the view that this footnote to the Subsidy Code should not open the door to broad new border tax adjustments on energy and was intended solely as a technical adjustment for certain country-specific approaches to taxation (Charnovitz, 1994). However, the issue has not been clearly settled among legal experts (Fischer et al., 2004).

Knowledge-sharing and R&D-oriented agreements, as well as mandates on consumption goods (like energy-efficiency standards), neither generate much in the way of competitiveness effects nor do they run afoul of national treatment. Mandates for production technologies are more likely to be costly and have adverse economic impacts, so the ability to agree on them may in part be determined by the international competitiveness of the sector. However, performance standards still may be politically preferred to emissions price policies because performance standards can have lesser effects on competitiveness where they result in smaller product price increases (Bernard et al., 2007; Fischer and Fox, 2007).

Indeed, the WTO agreements prohibit subsidies to domestic producers that burden foreign producers with a competitive disadvantage. Agriculture, however, remains a notable exception, as trade barrier reductions still are being negotiated that could affect policies directed toward biomass. The restrictions also may affect TOAs in that direct production subsidies to producers of climate-friendly technologies, like wind energy, may be disputed by other countries with wind turbine producers. Deployment subsidies that do not discriminate based on the origin of the technology product should not run afoul of this test, unless they are so large as to affect the competitiveness of the utilizing industry (e.g., subsidizing adoption of less energy-intensive technologies in the steel industry to the point of lowering their production costs). Considering the nature of the interactions between environmental and trade agreements, negotiators may be well advised to look beyond climate-oriented agreements and to pursue strategies to remove inconsistencies with other multilateral obligations. New agreements (like TOAs) also may be as likely to create their own inconsistencies as they are to create synergies. Linking these issues has the potential not only to improve consistency but also to facilitate collaboration and agreement by extending the zone of possible agreement.[23]

5.5 Conclusion

Our aim has been to assess the possibilities for using international TOAs in the context of addressing global climate change. The motivations for considering TOAs for international climate agreements are numerous, ranging from improving the efficiency of markets for technological innovation, to expanding opportunities for international agreement, to spurring necessary socioeconomic and technological change. TOAs have been implemented successfully to address problems other than climate change and they tend to fall into four categories: knowledge sharing and coordination; RD&D; technology transfer; and technology deployment mandates, standards, and incentives.

To understand some of the design issues and tradeoffs among TOAs, we identify five useful criteria: environmental effectiveness, technological effectiveness, cost-effectiveness, incentives for participation and compliance, and administrative feasibility. While the existing agreements provide important lessons, they vary substantially in their designs, circumstances, and perceived success. Still, several conclusions can be drawn conceptually based on both these experiences and more general features of the different kinds of TOAs.

In the case of climate change, the environmental effectiveness of an agreement is typically evaluated in terms of emission reductions and, ultimately, atmospheric concentrations. TOAs in the first three categories (knowledge sharing, RD&D and technology transfer) are not likely to be effective on their own for achieving significant GHG reductions, and are better seen as complements, fulfilling the criteria for technological effectiveness where other environmental agreements may be insufficient. An exception may be technology transfer programs, if accompanied by significant finan-

[23] See Haas (1980) and Sebenius (1983) on issue linkage and Raustiala and Victor (2004) on overlapping institutions in the development of multilateral environmental agreements.

cial resources. As emissions reduction is essential for climate change mitigation, only TOAs of the fourth category—technology mandates, standards, or incentives—appear to have the potential to be effective in environmental terms as a substitute for emissions target-based agreements.

Considering effects of TOAs on actual technical progress is difficult, given the long time lags and uncertainty involved in the process. Therefore, the technological effectiveness of a TOA should be seen in context of its purpose. Agreements aimed at enhancing implementation could be judged, for instance, based on the number of installations they realize and agreements aimed at increasing research spending could be judged on additional research effort that is encouraged or, better yet, the additional scientific and technical advances achieved. RD&D agreements in particular would need to be structured with appropriate accountability mechanisms, since it is otherwise difficult to judge whether research funding is truly additional. One option would be to structure an agreement around RD&D levels (e.g., a certain share of GDP) rather than an increment to existing investment.

Cost-effectiveness must also be taken into account and this again depends on the type of TOA, its specific design, and the role it is intended to play relative to other policies. Knowledge-sharing agreements can be highly cost-effective in the sense that they are inexpensive and can lead to more efficient spending of domestic R&D funds and more cost-effective implementation of domestic policy. RD&D agreements can be beneficial so long as they generate additional research, reduce unproductive duplication of effort, and help overcome failures in the market for innovation. Technology transfer agreements can be cost-effective if the reductions generated are relatively less costly than alternative opportunities. These agreements also should be viewed more broadly, since their value may be in complementary international development goals and in securing agreement on the part of developing countries to other commitments, now or in the future. In practice, most technology-transfer agreements have been implemented as funds, which do not always provide an efficient allocation mechanism.

Technology mandates, standards, or incentives could be cost-effective additions if appropriately targeted and designed. For individual, trade-sensitive sectors, performance standards have the potential to be more cost-effective than an emissions pricing program if they prevent sufficient emissions leakage. They also may have specific ancillary benefits. However, when thinking about using such mandates for a broad set of sectors, it seems unlikely that policymakers can set the standards such that the overall program is as cost-effective as a uniform emissions-price program (such as cap-and-trade) with long-term targets, which can better exploit opportunities for cost savings across sectors. Aside from addressing leakage, technology or sector-specific mandates and the like can be cost-effective in conjunction with emissions policies if they are used to address other market deficiencies, such as the demand for energy efficiency or international coordination problems. However, poorly designed policies run the risk of governments being unsuited to "picking winners," of creating undesired lock-in of technology, and of reducing flexibility and incentives for further innovation.

Incentives for participation and compliance depend on both the type and ambition of the agreement. The inexpensive and limited nature of most knowledge-sharing and joint RD&D agreements historically has encouraged participation, but concerns over intellectual property may loom if the knowledge shared extends beyond more basic research toward nearly commercial technologies for which domestic constituencies exist. Mutual commitments to domestic energy RD&D without an international cost-sharing component would not have this problem. Technology transfer, since it typically involves commercial technologies, can be inhibited by lesser intellectual property protection in developing countries and concerns about industrial competitiveness. A question is whether the gains from the reductions (or the export support for the technology providers) are deemed to be worth the losses. Such agreements may need to be linked to other issues, such as international trade and development policy, to engage participation.

Technological mandates and standards entail larger costs and, therefore, a higher hurdle for participation. However, there are some reasons why they may be easier to agree upon than emissions targets or prices. First, since they do not require payments for emissions up to the standard, the impact on product costs and competitiveness is potentially smaller, making agreement easier when some major players are not inclined to participate. Second, mutual agreements on technology standards may embody a more level international playing field within the affected sector, while broad emissions targets provide no assurance as to the evenness of application to the same sectors across countries. Third, technology mandates may be attractive to specific countries if they are expected to provide ancillary benefits, such as local air quality or energy efficiency improvements.

Administrative feasibility should not be problematic for TOAs, assuming domestic agencies are responsible for implementation. Nonetheless, joint programs may only be effective if avenues for coordination are established among domestic agencies. In cases with many participants, international institutions may be needed to facilitate implementation. In existing TOAs, the administrative funding required has not been large relative to that required for the implementation of broad emissions-target approaches. However, more expansive TOAs could entail significant costs and could be as or more administratively complex as emissions policies. In summary, TOAs of all types have the potential to be valuable components of an overall international climate policy portfolio. TOAs can address important problems in the market for technological innovation and will likely operate best in conjunction with appropriate emissions-reduction policies, particularly market-based ones. This complementarity could be mutually reinforcing: as emissions-reduction policies spur the uptake of new technologies and increase the profitability of innovation, TOAs spur additional innovation to lower the costs of mitigation and improve the social and political acceptability of emissions targets. TOAs could be negotiated separately, linked together, or incorporated into the climate policy framework in a PAMs approach. More modest TOAs have the advantage of being able to be negotiated and implemented by a smaller set of countries, potentially outside of the UNFCCC.

The use of TOAs as an environmentally effective substitute for an emissions-based approach is limited to the category of standards, mandates, or substantial financial incentives. These would need to be applied on a sector-by-sector, if not technology-by-technology, basis, which can be limiting practically. This approach may make the most sense in certain specific settings: for highly trade-sensitive sectors that make agreement upon targets and timetables difficult; for sectors not otherwise covered by emissions trading programs (e.g., possibly vehicles or end-use energy demand, depending on domestic policies); for sectors that can benefit from international coordination (e.g., building codes, appliance standards, regulation of vessels for international transportation); and for situations where significant ancillary benefits are foreseen. For a comprehensive program of reducing global emissions, TOAs are best viewed as playing an important supporting role, with a well-designed and flexible emissions-reduction policy with long-term targets as the main attraction.

Chapter 6 Balancing market-based and technology-oriented agreements

At the outset of this thesis, a theoretical analysis has explained why the emission-target regime of the Kyoto Protocol has not reached universal participation, and how technology-oriented agreements could help resolve this (Chapter 3). Although this is not the only problem of the Kyoto Protocol, it is often considered as one of its most essential shortcomings (see Chapter 1). Chapter 5, subsequently, has gone in greater detail by evaluating past and potential future technology-oriented agreements and has subjected them to a criteria analysis. Before proceeding to chapters that explore what technology-oriented agreements may look like in practice, how they compare with market-based approaches in the case of technology transfer, and how international technology agreements may co-exist with continuing cap-and-trade-based agreements, it would help to clarify the main characteristics of international market-based instruments, and where exactly they differ fundamentally from technology-oriented agreements.

In this light, this brief chapter generalises the findings of the earlier chapters on technology-oriented agreements to such a degree that they can be compared to market-based international agreements. This comparison is useful to bring out the main contrasts between market-based and technology-oriented agreements, and to thus make the discussion more concrete when, later on, co-existing technology-oriented agreements and market-based instruments are discussed.

The method of this chapter is similar to the method in Chapter 5. First, the international market-based approaches and technology-oriented agreements will be discussed in general. These approaches (all international instruments, to be distinguished from nationally implemented policy) include a follow-up of the existing Kyoto Protocol and a number of other often-mentioned proposals for the future. In the second section, the criteria from Chapter 5 will be used to discuss some general versions of international market-based agreements: a carbon tax, a cap-and-trade with and without a safety valve, and a multi-staged market-based agreement. The discussion of technology-oriented agreements in Chapter 5 will be summarised briefly as well. In the last section, the main differences between market-based and technology-oriented agreements will be discussed, including the advantages and drawbacks of each of them.

6.1 Introduction to international market-based approaches

Market-based approaches are often only thought of as national or regional policy instruments. In the context of this thesis, however, they comprise all international policy instruments that use a combination of the market and economic incentives to reach a policy goal. They are different from regulatory (sometimes also named command-and-control) approaches, including technology-oriented agreements, as they are merely changing the conditions for production and consumption, through that exert a price effect, and avoid being specific in prescribing the one or the other measure or technology, leaving that choice to the market. Market-based approaches can be used on the international level as well as domestically. Domestic market-based approaches require a political decision by the government and are often easily enforceable, as taxation and registration institutions are usually arranged on the national level. It goes at the expense of significant sovereignty to delegate such powers to an international institution, and also distributional effects are politically problematic (Ekins and Barker, 2001). Arguably, the international community has only managed to do so for two international institutions: the UN Security Council (through a combination of majority and consensus voting) and the World Trade Organisation (WTO) (through committee decision), and even in those contexts the enforcement sometimes leads to problems.

The international climate policy literature, particularly those papers that were published prior to the Kyoto Protocol agreement in 1997, and the literature aiming at post-2012 proposals, has discussed a number of market-based approaches. This section briefly describes the most important generic proposals. All of them have more detailed variants with extra features, specific targets, country allocations and burden sharing rules[24], but for contrasting them against technology-oriented approaches on fundamental characteristics, the details do not matter so much. Chapter 9 will discuss a few of them further for an institutional compatibility analysis with technology-oriented agreements.

The four types of market-based approaches discussed here are an emissions trading variant akin to the Kyoto Protocol, a global carbon tax, an emissions trading variant with a safety valve, and a multi-stage approach. These are briefly introduced in this section, and are discussed in further detail in the criteria discussion in section 6.2.

The first market-based approach is the international emissions trading model that was pioneered by the *Kyoto Protocol continuing after 2012*. This would mean that the current basic design of the Kyoto Protocol, including targets for a number but not all Parties, international allowance trading, a Clean Development Mechanism (CDM) and the current compliance regime are maintained.[25] In the "Kyoto-Continued" case, the Parties taking on targets might change, probably by expanding the list of Annex B Parties with an emission reduction target, but the general principle that there are developing countries that are exempt from emission targets and can participate voluntarily through the CDM remains, and industrialised countries with emission targets. The emission target level would presumably be different in a next commitment period, although it is assumed that the process for agreeing on future periods remains similar to the method adopted in the Kyoto Protocol, so negotiations for periods in the relatively short term, so about 5 or at most 10 years. Referring back to Chapter 3, an emissions trading approach is an effect-based approach where the environmental outcome is certain against uncertain costs.

A *carbon tax* is the other side of the same coin; although its design is notably different from an emissions trading instrument, it is still a market-based approach. Proposals for a global tax vary on details such as participation conditions, commodity under taxation (fossil fuels or carbon emissions) and the destination of the revenues (Cooper, 1998; Nordhaus, 1998; Stiglitz, 2006), but have one necessary similarity: they all have to be implemented on the national level, as there is no international government that can tax (Barrett, 2007). An international agreement on a global carbon tax would therefore necessarily involve governments signing up to it and subsequently implementing such a tax in their own countries. In order to create a level-playing field, these taxes should be harmonised as much as possible and enforced by an international organisation, for instance through trade barriers. As has been argued in Chapter 3, a carbon tax would essentially be an effort-based system where the cost is fixed and the environmental outcome is uncertain.

Responding to criticism on the Kyoto Protocol that it would lead to exorbitantly high costs (Nordhaus, 1998) and the uncertainties in target setting, an *emissions trading scheme with a safety valve* has been suggested by Pizer (1999), based on early work by Weitzman (1974) and endorsed (although and slightly modified) by Victor (2001). Such a scheme would work as follows. Initially a government would distribute (through auction, grandfathering or a combination) carbon emission allowances similar to a normal emissions trading model, and businesses would have to comply with the targets set. Initially, the market would look for the most cost-effective emission reductions. However, if the carbon price were to exceed a given "trigger price", the government would

[24] For an exhaustive overview, see Bodansky (2004).

[25] By design, the Kyoto Protocol is a market-based policy instrument as it implements an international emissions trading market, of which the CDM is a special, because project-based, case. Also its implementation in signatories is often market-based. The EU Emissions Trading Scheme is the best example of this. However, some of its implementation might not be done by means of market-based instruments.

offer an unlimited amount of allowances for that price, even though businesses exceed their initially allowed emissions. Although safety valve approach has been called a hybrid between an emissions trading scheme and a tax system, it primarily caps costs, not emissions, so in effect it is more akin a tax on emissions, and is thus an effort-based system. However, if the emission reductions are considered insufficient, the trigger price can be modified to a higher level thus resulting in more emission reductions.

Another approach combining different concepts in one treaty is a *multi-stage system* (Höhne, 2005; Elzen, 2002; Berk and Elzen, 2001). In such a system, the basic design features of emissions trading à la Kyoto will be maintained, but apart from the Annex B and non-Annex B categories, an intermediate stage is introduced to account for a "middle category" of emerging economies. Those countries are developing countries with rapidly industrialising economies and growing incomes. They have little historical responsibility for climate change, but increasingly contribute to the global greenhouse gas emissions, with future contributions exceeding those of the industrialised countries. These countries argue that their economies should not be constrained by an emission reduction target, but Annex-B countries argue that their contribution to the future problem also cannot be ignored. Two variants of a middle target are discussed: carbon or energy intensity targets, where the emerging economies should reduce their emissions relative to GDP, or no-lose targets, where they get an absolute target (possibly sectoral), remain without consequences if they exceed their target, and can sell emission allowances if they reduce emissions below the no-lose target. The countries would graduate into the different stages by per capita income level.

Chapter 5 introduces a taxonomy of *technology-oriented agreements* (TOAs), which is also used in Chapter 3. It distinguishes four types: (1) knowledge sharing and coordination; (2) research, development and demonstration (RD&D); (3) technology transfer; and (4) technology deployment mandates, standards, and incentives. Of these, technology incentives (part of type 4) could be considered market-based instruments. If for instance a technology is subsidised, a market instrument rather than a regulatory instrument is employed, even though it can be technology-specific.

Building on Chapter 3 and this introduction, the distinctions between market-based and regulatory, and effect- and effort-based, are summarised in Table 6.1.

Table 6.1 Attribution of agreements to effect/effort-based and market-based or regulatory

	Effort-based	Effect-based
Market-based	• Carbon tax • Safety valve • TOA-Type 4 (Incentives)	• Kyoto Continued • Multi-stage
Regulatory (or command-and-control)	• TOA-Type 1 (Knowledge sharing and coordination, e.g. CSLF (see Chapter 5)) • TOA-Type 2 (RD&D, e.g., part of “Combined R&D and standards”) • TOA-Type 3 (Technology transfer)	• TOA-Type 4 (mandates and standards, e.g. the “CCS Technology Mandate” (see Chapter 5))

6.2 Criteria discussion of market-based approaches

The market-based approaches introduced in Section 6.1 will now be discussed based on the same set of criteria as the one used for technology-oriented agreements. A more extensive discussion of the criteria can be found in Section 5.2.3, but a brief summary of the criteria is given here:

- "Environmental effectiveness" is the extent to which the agreement is certain to achieve emission reductions in time;

- "Technological effectiveness" is the extent to which the agreement promotes innovation and technological change required to address climate change;
- "Cost-effectiveness and economic efficiency" is the extent to which the agreement inherently achieves the lowest cost, as well as the best balance between cost and benefits;
- "Incentives for participation and compliance" describes whether the agreements has sufficient benefits for participants to reach a degree of self-enforcing;
- "Administrative feasibility" discusses whether the legal, institutional and practical means exist to implement the agreement in an effective and cost-effective manner.

The criteria discussion in Chapter 5 is primarily empirical and evaluated the performance of concrete TOAs based on detailed information. The discussion in this section will be on more general agreements with many unknowns about the details, e.g., on whether the targets are strict or lenient, on the breadth of participation and on the costs of the agreement. Still, the resulting discussion will give insights that might allow for a general comparison of TOAs and market-based approaches in Section 6.3.

6.2.1 International emissions trading à la Kyoto

Although the Kyoto Protocol has been accused of not going far enough in its ambition to cut greenhouse gas emissions, the countries that have ratified the treaty are generally showing less of a greenhouse gas intensive emissions path than the countries that have not, and most are likely to comply with their commitments. This speaks for the environmental effectiveness of a follow-up agreement, although the overflow allowances in Russia and the Ukraine, if used, could lower the emissions reduction considerably. In general, the additionality provisions in the CDM are considered a sufficient guarantee that greenhouse gas emission reductions claimed in the CDM are real, although there is criticism as well, and doubts about the contributions to sustainable development (Schneider et al., 2007). Overall, "international emissions trading à la Kyoto" could be environmentally effective, provided that the problem of overallocation of Assigned Amount Units (AAUs) to particularly the Former Soviet Union (the “hot air” problem) is solved, and that stricter targets are agreed upon and complied with.

With regard to technological effectiveness, the short commitment periods, relatively weak price signal, and the regulatory uncertainty after 2012 have so far not led to signs of technological change or innovation, and unless Parties can agree on deeper emission reductions, a more extended commitment period or a longer timeframe, a continuation of Kyoto is unlikely to change this. The relatively shallow commitments of Kyoto led to implementation of measures that often amount to incremental changes in energy production (such as fuel switch) and reductions of non-CO_2 greenhouse gas emissions. In addition, there is the problem of markets generally under-investing in innovation; the technology market failure (see Chapter 5, particularly Jaffe et al. (2005)).

Cost effectiveness in emissions trading schemes is generally high, provided that it can be implemented against relatively low transaction costs. Although start-up costs are significant, the transaction costs have come down fast for the CDM as well as for the other emissions trading schemes. A follow-up of Kyoto can benefit from the experiences and investments made in the first commitment period, thus enhancing the ease of administrative implementation. Economic efficiency is difficult to predict upfront, but it has been calculated that the costs of Kyoto are significantly lower than initially projected (IPCC, 2007c), and that it has been effective, although its effects have been limited. Overall, it is difficult to say whether any agreement is economically efficient, but, depending on the targets set, a follow-up of Kyoto might generate similar results.

The weak point of an international emissions trading approach, as argued in Chapter 3 and in many publications (Aldy et al., 2003; Victor, 2001) are its incentives for participation and compliance. The interest profile of cost and benefits of climate change are such that signing up for an emissions trading pact is not in line with the interests of those countries most crucial for achieving its aims. The compliance mechanism in Kyoto is more likely to drive non-complying Parties away from the protocol than back into its arms. Enforcement is notoriously difficult in any international agreement, and it not explicitly arranged in the Kyoto Protocol. It is difficult to see how these issues can be repaired in a follow-up international emissions trading scheme.

6.2.2 Global carbon tax

As discussed in Chapter 3, a global carbon tax is an effort-based agreement, where the costs can be predicted but the environmental outcome is uncertain. The environmental effectiveness therefore depends on the level of the tax – a high carbon tax can be as effective as an emission target, but the emission reductions are not guaranteed. The technological effectiveness might be higher than in the case of an emissions trading agreement, as a tax is normally installed in perpetuity, whereas emission targets would have to be fixed per trading period, after which in principle everything is open until a new agreement arises. The long-term price signal of a tax is therefore likely to be stronger, although the technology market failure still exists.

In terms of cost-effectiveness, in theory a carbon tax can be as cost-effective as an emission trading scheme, but in an international playing field it is virtually impossible to find the optimal price (Weitzman, 1974). As mentioned in the introduction, in practice, a global tax would have to be installed in each separate country and preferably, it would be harmonised across countries, making it even harder to tune the tax to suit an international target for emission reduction. Transaction costs for a tax, contrary to emissions trading, are low, as no institutions for trade or brokerage, nor any carbon trading specialists would have to be installed to deal with the scheme, and administrative feasibility is also high. Economic efficiency depends fully on the level of the tax, but again is difficult to determine or predict.

A carbon tax has similar problems as emissions trading in terms of incentives for participation and compliance, although the cost predictability may make it more attractive than an emissions trading scheme. Although governments may officially sign up for a global tax and install it in their countries, the collection of the tax cannot be enforced, or governments could strategically decide to compensate those affected by tax breaks or refunds, outside the view or the influence of international enforcers, to control the cost for the businesses or consumers. Trade measures, such as border-adjustable taxes for carbon-emitting products, are proposed as a means to enforce a carbon tax, but the WTO allowance of border adjustments for taxes may exclude emission taxes (Coninck et al., 2008a). Problems of compliance and enforcement therefore remain unresolved.

6.2.3 Emissions trading with safety valve

As emissions trading with a safety valve is a hybrid of emissions trading and a carbon tax, it shares their outcomes of the criteria assessment. If the trigger price is not reached, the system is akin to an emissions trading scheme; if the trigger price is exceeded, it is a carbon tax. The outcome therefore depends much on the emission targets and the level of the price cap.

The environmental effectiveness of emissions trading with a "safety valve" is similar to that of a global carbon tax – similarly, unless the "trigger price" is set high enough for companies to start abating greenhouse gases, the pollution will continue and companies will just pay a cost per tonne of CO_2, which is essentially the same as a tax. Its effectiveness in bringing about technological change is probably more similar to international emissions trading, as it necessarily shares the fixed trading period feature. Cost-effectiveness and economic efficiency depend on the trigger price. If it is set at the equilibrium level of where emission reductions over time would be dynamically optimal, a safety valve approach can be very efficient, but, as noted in the previous section, it is already difficult to achieve this in a national system, and it is even more complex to harmonise this in an international scheme. Incentives for participation and compliance are not fully solved, although, similar to the carbon tax, the price cap gives some certainty on costs. The administrative realisation of any emissions trading scheme is not easy and the administrative feasibility is therefore not considered high, although adding a price cap to the existing Kyoto Protocol system might make it easier to implement.

6.2.4 Multi-stage with intensity targets or no-lose targets

In the multi-stage scheme, the criteria assessment of the lower and higher stages (those without any obligation and those with an absolute cap) are similar to the international emissions trading variant in Section 6.2.1. It is the middle category, with either an intensity target or a no-lose target, that I will focus on for this discussion, particularly for the environmental, technological and cost effectiveness criteria.

As both the no-lose and the intensity targets are flexible, the environmental effectiveness is uncertain and depends on the target chosen. A strict intensity target combined with high production and consumption growth might still increase emissions substantially, although probably less than in a business as usual scenario. Similarly, a strict no-lose target might result in emission reductions in some sectors, whereas others will not respond to the possible incentive of selling emission credits. If a no-lose target is set on a country level and not per sector, or even per installation or business, such a scheme may result in a collective action problem where some sectors will pollute more and compensate the emission reductions achieved in another sector, thus denying the other sectors of compensation for their emission reductions. Technological effectiveness is uncertain in both cases, and, similarly to emissions trading, depends on the target and the length of the commitment period. Cost-effectiveness would most likely be high for the no-lose case, as only those measures that lead to cost-effective emission reductions would be implemented. Economic efficiency is considered high compared to an emissions trading scheme where emerging economies are not given any constraint, as these emissions increasingly determine the future emissions and emission reductions achieved under intensity or no-lose targets are most likely relatively affordable.

The administrative feasibility of both intensity and no-lose targets is rather low, as the baseline-setting in both cases probably requires extensive data collection, uncertain projections, and complex negotiations. If there is to be trading in emissions between the industrialised countries and the intensity-constrained countries, it is not straightforward to translate intensity in absolute emission reductions. For the remainder, the administrative complexity is similar to the international emissions trading system.

The incentives for participation and compliance need to be seen in the light of the treaty as a whole, and not only the middle stage. Throughout the negotiations, developing countries have emphasised that industrialised countries should take action first, and that developing countries will not accept any targets as they do not bear responsibility for the climate change problem and their capabilities to take measures is more limited. Although this is true for the past, this is changing in the near future, and one of the reasons the US did not ratify the Kyoto Protocol was because of the absence of emission targets for large developing countries. The multi-stage proposal was designed to solve that deadlock. The idea is that the US would ratify an international treaty if it has provisions for emission reductions in the large developing countries, and that developing countries would agree if it would not limit their economic development. The proposal may indeed help. But the design does not make the inherent problems of compliance and enforcement go away.

6.2.5 Technology-oriented agreements

For a discussion of the criteria in different types of potential post-2012 technology-oriented agreements, see Section 5.3.5. Clearly, the criteria assessment depends on the type of agreement – the substance of the agreement and therefore the environmental and technological effectiveness will vary much depending on that.

Administrative feasibility of TOAs has been discussed for separate agreements in Chapter 5, but not for the set of agreements that would be needed if TOAs alone would have to mitigate climate change. In that case, for all relevant sectors worldwide, agreements would have to be made, adding up to an environmental outcome that is as cost-effective as possible. This might become very complex and would render a low the administrative feasibility.

6.3 Contrasting market-based and technology-oriented approaches

The discussions in Chapter 5 (for the TOAs) as well as the assessment in this chapter (for the market-based instruments) bring out some areas where technology- and market-based approaches for post-2012 climate policy differ. Based on the criteria, they are summarised in a very generic way in Table 6.2.

Table 6.2 Generalised, high-level comparison of market-based and technology-oriented approaches to international climate agreements.

	Market-based approaches	Technology-oriented approaches
Environmental effectiveness	Strong targets, taxes and price caps can be environmentally effective, but weak effort-based agreements are not	Strong, Type-4 agreements aimed at implementation of technologies can be effective but weak, Type 1, 2 or 3 agreements not
Technological effectiveness	Moderate if credible long-term targets cannot be set. Market plagued by technology market failure	High, although governments picking the wrong winners can reduce the technological effectiveness
Cost-effectiveness and economic efficiency	High	Can be low if not aligned well, but if the technology targets are chosen well, can be improved.
Incentives for participation and compliance	Has significant problems that are difficult to solve. Taxes and safety valves have benefit because of cost predictability	Relatively high because of perceived first-mover advantages. Agreement among governments that technology is important for solving climate change. Cost predictability high.
Administrative feasibility	High for taxes; moderate to low for emissions-trading based agreements	High for single agreements, but the whole set of agreements can get complex and accountability issues may arise.

It becomes clear that neither market-based nor technology-oriented agreements can be rejected on grounds of environmental effectiveness or administrative feasibility. The major differences are in the fields of technological effectiveness, and incentives for participation and compliance, and cost-effectiveness. Technology-oriented agreements seem to provide better prospects for the former two, whereas market-based approaches are more likely to lead to the lowest overall system costs.

It has already been discussed in detail why market-based approaches are more likely to lead to cost-effective implementation of climate policy; markets are better at picking winners than governments. It is also obvious why technology-oriented agreements score better on technological effectiveness; they are designed to solve the technology market failure and are tailor-made towards technological change and innovation; it is more than merely a by-product like in the case of emission caps or taxes.

Why the incentives for participation and compliance are problematic for emission-targeted approaches has been argued extensively in Chapter 3. The question then arises why technology-oriented agreements would be better at this. There are three general arguments for that. A more extensive explanation is given in Chapters 3 and 5. First, there is an interest of practically all Parties in the UNFCCC in technology, as demonstrated by the setup of mechanisms aimed at greater diffusion of technology. The second argument relates to the perceived first-mover advantages that can increase participation of those countries that feel they either need access to the technology in question, or that they are able to export the technology, thus helping their own industry sectors perform better. Such interests can also be there in the case of an emissions trading regime of a tax, but the benefits are not so clear as in technology-oriented agreements. Thirdly, the predictability of cost is greater when they are determined on a per-sector or a per-technology basis than in the case of the whole economy, where each business will have to figure out for itself how much of the cost will fall on him. Predictability of cost, to some degree, may be worth it to sacrifice some cost-effectiveness.

In summary, markets are unlikely to lead to the optimal technology path to reduce emissions but are more cost-effective, and as a whole easier to implement. However, in technological effectiveness, they are outperformed by TOAs, and possibly also in the field of participation and compliance. This leads to the main conclusion in Chapter 5: technology-oriented agreements are perhaps best applied in conjunction with market-based instruments. The issue of technology transfer may be a case in point for that. The next chapter will explore whether technology-oriented funds or market-based mechanisms are more effective in transferring technologies.

Chapter 7 The issue of technology transfer: markets or funds?[26,27]

7.1 Introduction

Technology transfer is an extensively debated issue , both in the academic literature and in the climate negotiations[28]. Arguably, the only broad agreement with regard to technology transfer and climate change might be that it is tremendously important (see e.g., Forsyth, 2007; Koehler et al., 2007 but also older references such as Nakicenovic and Victor, 1993). What technology transfer exactly comprises, how it can best be promoted, what its most crucial barriers are and who should pay for what aspects are all being discussed. Most empirical technology transfer work is based on case studies of technologies or countries (e.g., Forsyth, 2005; Martinot et al., 1997, and many references in IPCC, 2000a), and aims to derive success and failure factors from those cases (Ramanathan, 2002). Although such studies yield valuable insights, the multi-faceted characteristics of technology transfer and the inevitable localised nature of effective policies to overcome barriers still make it challenging to make predictions on effective policy.

Views on barriers to technology transfer are generally converging, although a blueprint of a concrete and successful strategy to overcome them has not yet been formulated. Indeed, the very term of technology transfer has been contested, and alternatives such as "technology cooperation", emphasising the process nature of the action rather than the perception that technology transfer is an "event", can also be found in literature (Heaton et al., 1994) and this consensus has indeed emerged. Despite this, technology transfer is sometimes for practical reasons still defined as only the transfer of the technology design plus property right to reproduce, although it is always acknowledged that without the transfer of "know-how", the technology transfer is likely to be less successful (Lewis and Wiser, 2007). Attempts to translate the various barrier analyses into concrete policy have been made early on (e.g., Martinot et al., 1997), but remain to be implemented.

The discussion in this chapter will focus on technology transfer of "environmentally sound technologies" (IPCC, 2000a; Andersen et al., 2007), particularly those relevant to climate change mitigation. The transfer of technology is more complex than the word leads to suspect: it integrates "human beings, know-how, physical objects and techniques" (Karani, 2001). More simply said, technology transfer cannot be hardware transfer alone; it should necessarily involve the build-up of capacity to handle the technology and the raising of awareness among users and other stakeholders, including civil society (Reddy, 1991; Lall, 1992; IPCC, 2000a; Forsyth, 2005; 2007). Given these requirements, which are both difficult to meet and difficult to verify, it is first of all hard to declare any technology transfer projects a success, and secondly to formulate conditions that will render projects with the objective of technology transfer successful.

The IPCC (2000a) and Worrell et al. (2001) structure technology transfer in a five-stage process, the stages being: assessment, agreement, implementation, evaluation and adjustment, potentially followed by replication (also called diffusion)[29]. The process nature of technology transfer and the long-term commitment that necessarily accompanies it has led to questioning whether grants or subsidies are suitable for bringing about technology transfer. The long-term commitments and

[26] Acknowledgements: my co-authors Frauke Haake, Nico van der Linden, Carolyn Fischer, Richard Newell and Takahiro Ueno, as well as Rob Youngman and Remko Ybema, and a number of anonymous reviewers.

[27] Section 7.2 has been published in Climate Policy (Coninck et al., 2008b). References to section numbers have been modified to make them consistent with the outline of this thesis, and some edits have been made. Some duplication with other sections in this chapter has emerged as the journal paper reads as a stand-alone document, but for the policy comparison in this chapter some further introduction was necessary.

[28] The debate on technology transfer in the academic literature has seen contributions from development economics, social science, and political science, as well as from engineering disciplines. In the UNFCCC, the most discussion on technology transfer was in Bali, and plays in both Subsidiary Bodies (IISD, 2007)

[29] Note the parallel with the stages of international institution formation in chapter 1.

significant efforts into after-sales seem less compatible with a subsidy or grant provided upfront. On the other hand, finance barriers to technology transfer of environmentally sound technologies are particularly high, and funds are seen as the obvious solution. Barriers other than the cost of the new technology have been identified, however, and include the lack of appropriateness of the foreign technology for the local circumstances, the capacity of the recipient institutions to accommodate the technology, the lack of skilled labour and the lack of entrepreneurial activity in the recipient country (Andersen et al., 2007; Ramanathan, 2002; Karani, 2001; IPCC, 2000a). Barriers related to intellectual property rights (IPR) are also often mentioned, although in some cases they are not considered to be high for several reasons (Barton, 2007) and can be overcome by paying a relatively small royalty fee. IPR, however, is perceived as a major issue by developing countries (Ockwell et al., 2008). Another barrier is the capacity of the technology-recipient country to absorb the technology. This barrier encompasses issues related to institutional capacity, knowledge, social adoption, and suitability of the technology for local conditions and use (Reddy, 1991). It is clear that an instrument that addresses only the issue of costs will not solve the whole problem, which is the reason that funds would have been designed to also take broader enabling issues into account.

This chapter aims to bring to the fore whether strategies to enhance technology transfer have worked out for the Clean Development Mechanism (CDM) and the Global Environment Facility (GEF). The role of this chapter in this thesis is to make explicit the implications of these lessons for a technology-oriented climate regime. The CDM, representing a market-based approach, and GEF, a fund representing a more regulatory approach, are two international policies that are generally thought to enhance technology transfer in the field of climate change mitigation. Their different nature may give interesting insights into the contrast of market and regulatory instruments for technology transfer.

The CDM could be seen as representing the Annex-I approach to technology transfer, the initiative being mainly with the private sector and the cost being an outcome of constructed market forces. The discussion of technology transfer in the CDM, in Section 7.2, is based on an evaluation of the origin of technology in the CDM as part of the EU FP6-funded TETRIS project. It yields detailed results for the first 63 projects, and includes investment sums analysis. In the evaluation, the perspective of the technology-exporting countries is also taken into account: it investigates which countries (mostly Annex-I) benefit from hardware exports. Developing countries, conversely, often prefer a technology transfer fund and have actively pursued this during the negotiations of a new mandate under UNFCCC's Article 4.5[30]. The most prominent example of such a fund is the Global Environment Facility (GEF), in operation since 1991, and the financial instrument of the UNFCCC. The performance of the GEF, where possible in terms of technology transfer, will be assessed based on independent literature and official evaluations. The international policy instruments will be introduced in more detail in their respective sections.

In addition to the international climate policy instruments, it might be useful to have an upfront look at successful policies for other international environmental issues that share characteristics with climate change. The Montreal Protocol's Multilateral Fund (MLF) is often mentioned as a success story of technology transfer (Andersen et al., 2007; Luken and Grof, 2006), and even Kofi Annan, in his days as Secretary General of the United Nations. The Montreal Protocol has been called "perhaps the single most successful international agreement to date", partly because of the MLF's achievements. The MLF aims to meet the incremental cost of Montreal Protocol compliance in Article 5 (developing) countries. Andersen et al. (2007) claim large degrees of technology trans-

[30] Text of UNFCCC Article 4.5: "The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention. In this process, the developed country Parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties. Other Parties and organizations in a position to do so may also assist in facilitating the transfer of such technologies."

fer for the MLF based on case studies. The major sectors are refrigeration, air conditioning, solvents, and foams, and the MLF's budget, established through periodical replenishments, was US$ 400 million over 2006-2008, and US$ 2.1 billion (spent on 5520 projects) in 1991-2006 (IPCC/TEAP, 2005; Andersen et al., 2007). The funding in the MLF by developed countries is contingent upon the ratio of their funding of the UN, and proved sufficient to cover the costs of compliance to the Montreal Protocol for developing countries, and to convince these nations to ratify the Montreal Protocol and agree on ODS targets for the long term. What helped was that the substitutes for ozone-depleting substances, in the form of "soft CFCs", such as HCFCs, or other replacements, were already largely available in industries in developed countries. The costs of these measures turned out to be significantly lower than initially projected (Hammit, 2000; Andersen et al., 2007), and some of the funds could be devoted to covering the cost of use of patented processes initially developed in industrialised countries. A published UNIDO[31] evaluation of sustainable development impacts of the MLF arrived at many positive benefits, although in some projects there were negative impacts on product quality or employment (Luken and Grof, 2006).

In hindsight, with full insight in the ozone problem and its causes, and knowing the solutions and what they cost, solving the ozone problem seems like a clear-cut decision. It was not necessarily so at the time of agreement of the Montreal Protocol. There was still some uncertainty as to the causes and effects of the ozone hole. When the Montreal Protocol was agreed, the cost-benefit relation of 1:11 that is now found in the literature (Barrett, 2007) was of a wholly different order. The extent and costs of the effects were uncertain, and the costs of solving the problem were estimated significantly higher than they turned out to be (Hammit, 2000). Still, however, although it involved multi-billion dollar industries, the scope of the solutions to the ozone problem was relatively limited. The largest sectors it covered were refrigeration, air conditioning and foams. The MLF in the Montreal Protocol, however, has clearly shown that a fund can make a difference and can be effective in transferring technologies. In this chapter, however, the MLF is not considered as part of the evaluation of climate change instruments. Although the climate and the ozone problems share some characteristics – both are atmospheric problems, rely on international coordination for their solutions – they also differ in several determining respects. The scale and economic impacts of both the climate problem and its solutions are larger than the ozone problem to such a degree that they would significantly affect the institutional design, making a comparative evaluation inappropriate. Nevertheless, Section 7.5 will revert back to the MLF to investigate whether lessons can be learned.

This chapter will first evaluate the technology transfer results of the market-based CDM (Section 7.2), and subsequently the GEF as a fund (Section 7.3). It will then make a comparative analysis of the two in Section 7.4, and discuss conclusions in Section 7.5.

7.2 Technology transfer in market-based mechanisms: the Clean Development Mechanism

The Clean Development Mechanism (CDM) is one of the flexible mechanisms of the Kyoto Protocol and has two purposes: to allow Annex B countries to comply with their Kyoto obligations through emission reductions generated in non-Annex B countries, and to assist non-Annex B countries in achieving sustainable development (UNFCCC, 1997a). The CDM Executive Board safeguards that the emission reductions are real and measurable, while the Designated National Authorities in the host countries are responsible for the fulfilment of the sustainable development criterion. Numerous evaluations have been conducted to establish whether the CDM lives up to the expectations, whereby especially the sustainable development contribution of the CDM was questioned (see e.g. Ellis et al., 2007), as the additionality of the greenhouse gas emission reduc-

[31] The UN Industrial Development Organisation is one of the implementing bodies of the MLF.

tions is thought to be sufficiently guaranteed through the stringent mechanism for registration with the UNFCCC. The flexibility in applying the sustainable development definition and the prerogative of the host country to determine whether it takes place have led to ambiguity and a lack of transparency on how the sustainable development criterion is handled (Cosbey et al., 2005).

Although not an explicit policy goal of the CDM, it is often associated with the transfer of technologies from industrialised to developing countries. Much has been written about how technology transfer under the CDM might be enhanced, pointing at for instance the strategies of credit-purchasing governments (Aslam, 2001) or at mobilising synergies between private sector involvement and capacity building (Davidson, 2001). As the number of projects under the CDM is now on the rise, it is possible to go beyond the speculation on future improvements and empirically evaluate the level of technology transfer taking place in the current CDM project portfolio.

Transfer of technology has several aspects: the transfer of hardware, in terms of the actual installations and equipment, and the 'soft' technology transfer, in the form of knowledge transfer and capacity building. This paper first generally assesses technology transfer as a whole, including soft technology, and determines whether technology transfer took place according to the definition adopted in Section 7.2.1. Next, it focuses on two aspects of 'hard' technology transfer: it first assesses in detail the origin of technology of the 63 CDM projects that were registered with the UNFCCC on 1st January 2006, and in addition provides a rough analysis of the volume of exports from industrialised countries to the CDM host countries.

The latter question is relevant for two purposes. Firstly, the outcome gives an indication of the investments in cleaner, foreign technologies that CDM generates. Secondly, it provides an additional ground for the development of cleaner technologies in industrialised countries, and for gaining experience with these technologies, in order to be able to export to countries that have not been willing or able to develop them.

Section 7.2.1 explains the methodology that is used in the analysis. Section 7.2.2 provides results for the overall technology transfer analysis, and Section 7.2.3 for the hardware and investment analysis. Section 7.2.4, finally, discusses the conclusions that can be drawn.

7.2.1 Approach for the technology transfer analysis

There is surprisingly little consensus on what technology transfer comprises. The literature shows a broad array of definitions (Wilkins, 2002; Kline et al., 2004). In this paper, we adopt the broad definition of the IPCC (2000a):

> *"A broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, NGOs and research/education institutions."*

Projects looking at technology transfer often focus not so much on the question whether technology transfer took place, but on the effectiveness of the technology transfer. In the context of climate change, for instance, criteria include "whether emissions are reduced" or "whether the local community is involved in the activity" (IPCC, 2000a). As these criteria are already inherently positive for the CDM, given its requirements for emission reduction, additionality, public comment procedures, and sustainable development, we have not used them.

Given the IPCC definition, in the context of this paper, we will first evaluate three criteria that can be applied to registered CDM projects and that evaluate all aspects of technology transfer:
1. Whether technologies deployed in CDM originate from outside the host country, or

2. Whether the technologies that are implemented in CDM are indeed new or improved and do not represent business as usual in the host country of the project, or
3. Whether the knowledge and capacity to implement the technology in the project is originating from outside the host country.

The evaluated CDM project portfolio consists of all registered CDM projects by January 1st, 2006. The total number of projects is 63, situated in 20 different countries. The Project Design Documents (PDDs) (UNFCCC, 2006) were used to obtain a detailed description of the project activity, including in some cases an assessment of whether technology transfer has taken place. Sometimes, the PDDs gave sufficient information on the technology origin, but in other cases, the project developer was interviewed by e-mail to obtain missing information. This resulted in an overall, high-level evaluation of hard and soft technology transfer.

After evaluating all projects, the second step entailed further analysis of the projects that comply with the 1st criterion (i.e. projects that show hard technology transfer), evaluating the countries that export the various technologies and the capital costs of the installations used in the projects. The sum of the total capital costs of projects that show technology transfer equalled the value of the exports that companies from Annex-B countries have been able to make as a consequence of the CDM.

Although the approach outlined above fits the purpose of evaluating technology transfer in the CDM, it has a number of limitations. First of all, according to the definition in IPCC (2000a), which includes technology transfer inside a country, e.g. from the one region to the other, or from urban to rural areas, we do not show the full, real technology transfer. The fact that domestic technology transfer may be a significant flow is illustrated by investment numbers – the lion's share of all investment in most developing countries are domestic investments (Ellis et al., 2007). As we disregard a potentially large amount of technology transfer, the resulting numbers may be an underestimation.

Another limitation is data availability, particularly for the 2nd and the 3rd criterion. In the case of the question whether the technology is "new or improved", there is much room for interpretation and information on the state-of-the-art or 'average' technology in specific countries is often hard to obtain. This is the main reason why we focus on the hard technology transfer in Section 7.2.3.

For the 3rd criterion, the question whether knowledge transfer or 'soft' technology transfer has taken place, is surrounded by even greater uncertainties. Not only is the criterion itself rather subjective (e.g., in an extreme case, knowledge transfer could even occur by sending a user a manual of an installation), the source of information is problematic, as we have to rely on the PDD only for this. Many PDDs do not mention 'soft technology transfer', and the ones that do, use it to demonstrate additionality or ancillary benefits. Because the claim of knowledge transfer or capacity building cannot be evaluated independently and the project approval partly depends on it, the writer of the PDD has an incentive to exaggerate the level of knowledge transfer or capacity building associated with his project. The reliability of the assessment of particularly the 3rd criterion is therefore reduced significantly.

7.2.2 Results of the broad technology transfer analysis

The 63 CDM projects that were registered on January 1st, 2006, were evaluated based on the criteria in Section 7.2.1. The projects in the portfolio involve the sectors of electricity, waste, industry, agriculture, thermal energy, and the residential sector.

The technologies of the registered projects were biogas, bioenergy, hydropower, wind energy, fuel switch and energy efficiency, all of which reduce CO_2, methane capture from swine manure and landfill gas capture (reducing CH_4), N_2O avoidance and HFC-23 destruction. The host countries were Argentina, Armenia, Bangladesh, Bhutan, Bolivia, Chile, China, Costa Rica, Fiji, Guatemala, Honduras, India, Mexico, Morocco, Nepal, Panama, Peru, Korea, South Africa and Sri Lanka (UNEP/Risoe, 2006). The project development and financing arrangement vary significantly across the project portfolio. While some of the projects were initiated unilaterally, others were heavily financed by development agencies, were helped by World Bank funding, or had contracted buyers via national tender constructions before registration with the CDM Executive Board.

The emissions reductions per technology are summarised in Table 7.1.

Table 7.1 Summary of emission reductions by technology in the 63 registered CDM projects by January 1st, 2006

Technology	Number of projects	Share in number of projects	Annual emission reduction (tCO_2-eq)	Share of total emission reduction
Biogas	6	10%	387,591	1.4%
Biomass	10	16%	302,735	1.1%
Energy efficiency	1	2%	6,580	0.0%
Fuel switch	1	2%	19,438	0.1%
HFC-23 destruction	3	5%	8,233,566	28.9%
Hydropower	22	35%	775,471	2.7%
Landfill gas	10	16%	2,712,395	9.5%
Methane capture	3	5%	410,378	1.4%
N_2O destruction	2	3%	15,111,165	53.0%
Wind energy	5	8%	573,013	2.0%
Total	63		28,532,332	

As has been noted on many occasions (see e.g. Capoor and Ambrosi, 2006), the share of renewable energy projects in the total share of projects is significant in this snapshot of the CDM project portfolio, but it is small in the market share of Certified Emission Reductions (CERs) compared to the large-scale non-CO_2 greenhouse gas emission reduction projects. Especially N_2O and HFC-23 destruction dominate the CER portfolio, as well as landfill gas projects. Normally, a lower level of sustainable development is associated with CDM projects providing large-scale, industrial, non-energy-sector emission reductions. Particularly the low cost of HFC-23 projects (IPCC/TEAP, 2005), the associated windfall profits on CERs and the perverse incentives such HFC projects provide for the production of ozone-depleting HCFC-22 have generated much concern. A large part of the projects in the portfolio uses technologies that originate from the host country and therefore do not generate technology transfer as defined in criterion 1 (see Table 7.2). In those cases where the technology originates from outside the host country, it comes mainly from the European Union and a small part uses technology from the United States, Japan or Switzerland.

Moreover, in almost 60% of the projects, we could confirm that new or improved technology was used (criterion 2). The projects in the group that use new or improved technology included all projects that met criterion 1 with respect to the use of foreign technology. The technologies that were new or improved, but also supplied from inside the host country, involved for instance swine manure methane capture projects in Chile, and biomass projects in India.

In addition, according to the PDDs, almost half of the projects involved some degree of capacity building or knowledge transfer (criterion 3). This mostly involved the employment of local workers, who require training and courses to operate the technology.

The summary of the evaluation of the criteria is in Table 7.2 and in Figure 7.1.

Table 7.2 Summary of results of the technology transfer criteria analysis

Criterion	Result indicator	Number of projects meeting criterion	Share of projects meeting criterion
1. Origin of technology used	Europe	23	37%
	Host country	26	41%
	Other (mainly Japan, US)	7	11%
	No data	7	11%
2. New or improved technology, new in the country	Technology transfer	37	59%
	No Technology transfer	22	35%
	Unclear	3	5%
	No data	1	2%
3. Capacity building or knowledge transfer required	Capacity building	29	46%
	No capacity building	33	52%
	Unclear	1	2%
	No data	0	0%

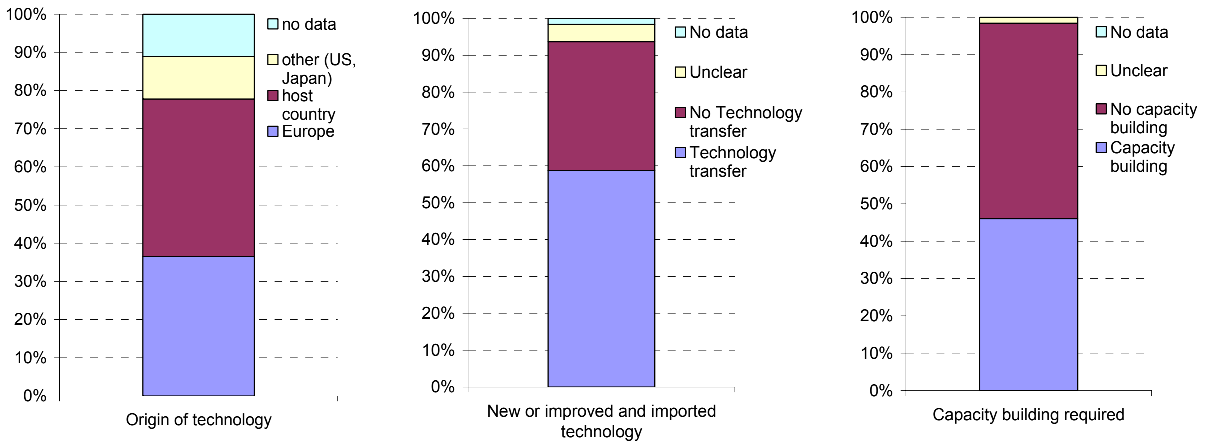


Figure 7.1 Summary of results of the technology transfer criteria analysis in share of the projects

7.2.3 Origin of technology and international capital flows

Zooming in from broad technology transfer to transfer of 'hardware', it is observed that the origin of specific technologies is very widespread. The technology for landfill gas comes mainly from the Netherlands although some is of host-country origin, technology for N_2O reduction comes mainly from France (for some: no data found), and technology for HFC-23 destruction originates from Japan, the UK and Germany. Methane capture from swine manure in Chile is a locally developed technology.

In the power sector, hydropower technology is partly imported from the EU (Spain and France), Japan, Switzerland and the United States, and partly supplied by the host country (India, Peru, Sri Lanka). Wind energy technology originates from Spain and Denmark. Bioenergy for electricity generation originates without exception from the host country.

As for thermal energy, the biogas installations are partly from the host country, and for another part data are unavailable. With respect to the one efficiency project, its technology originates from the host country, i.e. South Africa. The project that involves fuel switch in industry uses technology from Germany.

The technology transfer results per technology are summarised in Table 7.3.

Table 7.3 Summary of technology transfer and origin of hardware per technology

Technology	Number of projects with technology outside host country of total projects	Percentage of projects technology outside host country	Origin of technology
Biogas	0 of 6	0%	China, India
Biomass	0 of 10	0%	India
Energy efficiency	0 of 1	0%	South Africa
Fuel switch	1 of 1	100%	Germany, United States
HFC-23	2 of 3	67%	Germany, Japan, United Kingdom
Hydropower	12 of 22	55%	China, Australia, France, India, Japan, Panama, Brazil, Peru, Spain, Sri Lanka, Switzerland, United States
Landfill gas	8 of 10	80%	Belgium, Netherlands, Japan, France, Brazil, United States
Methane capture	0 of 3	0%	Chile
N_2O destruction	2 of 2	100%	France
Wind energy	4 of 5	80%	Spain/Denmark

It is remarkable that many of the projects that might be able to comply with 'sustainability quality brands', such as the CDM Gold Standard (Ecofys, 2005), do not feature technology transfer. The small projects in terms of greenhouse gas emission reductions, energy efficiency, fuel switch in industry, biogas and small-scale biomass based energy, use host country technology, whereas the large-scale projects, especially in the non-CO_2 greenhouse gases, use technology from the European Union or Japan. The power sector shows a more mixed picture; with respect to wind energy, all projects of which the technology origin could be determined show technology originating from the European Union, whereas hydropower technology comes from all over the world. The origin of technology is shown in Figure 7.2.

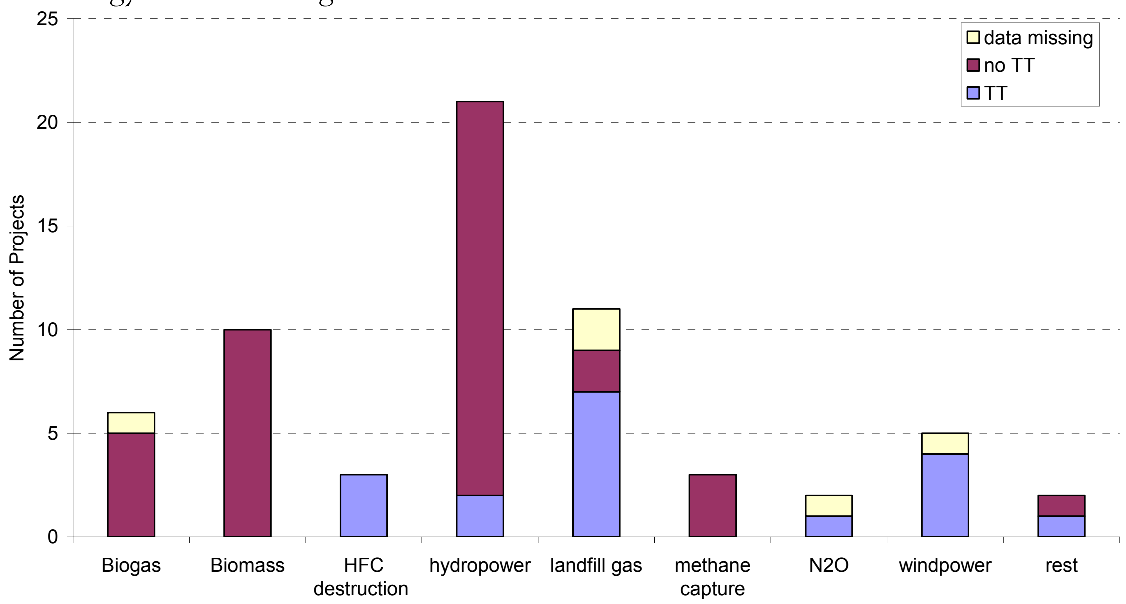


Figure 7.2 Overview of technology transfer per technology (Haake, 2006). For biogas, biomass, hydropower and methane capture, most of the projects use technology from the host country. For HFC and N_2O destruction, landfill gas, and wind energy, most of the projects used technology from the European Union or Japan

Even when the greenhouse gas reduction and the technology are known, the size of the investment is not necessarily obvious. For capital costs, the size of the installation is relevant, as opposed to the reduction in tonne CO_2-eq. For wind energy, for instance, the capital costs are expressed in installed capacity (€/MW) but the emission reductions on the produced electricity are expressed in tCO_2/kWh. These units are not readily convertible, as a wind energy project with a load factor of 20% produces less electricity, and therefore reduces fewer emissions than a project with a load factor of 30%, which may be the case in good wind locations. One needs a significantly higher investment to reach the same GWh electricity production for a less favourable wind location. Similarly, run-of-river hydropower plants have a very different load factor than dam-based hydropower plants. For non-power projects, the investment costs have to be expressed in other units; per tonne of HFC-23 or N_2O destroyed, or per tCO_2 in the case of fuel switch.

The investment costs in this analysis are technology-specific but have not been made location-specific. This is a serious limitation, but general assumptions had to be made of projects that function under fairly diverse conditions. The investment costs are calculated based on the size of the project and the greenhouse gas emission reduction, and on generalised assumptions on investment costs per unit size. The numbers do not include costs for any soft technology transfer (such as knowledge, capabilities). Table 7.4 shows the investment costs that are used for different technologies that were transferred. A pragmatic approach was adopted to evaluate investment costs, which was more often led by data availability than by the question what would be the most suitable metric for the investment costs. The numbers in Table 7.4 should therefore be regarded with much care, and only be used in a general way. Only the projects that meet criterion 1 (see Section 7.2) involve the transboundary movement of technology transfer-associated capital flows, and therefore only those projects are considered in the investment flow analysis.

Table 7.4 Assumptions on metric and investment costs for technologies that are transferred under the registered CDM projects as of 1st of January 2006

Technology	Unit for investment costs	Investment costs	Reference and clarification
Landfill gas	€/kW	1,200[32]	Based on Jansen (1992) and SCS Engineers (1994) (1.5 million US$ for 1 MW), and the average GHG reduction per MW in the CDM registered projects of UNEP Risoe is 51.
Hydropower	€/kW	1,958	Investment costs for small-scale hydro from Sambeek et al. (2003) - MEP tariffs - 2004-2005. It is assumed that 55% of the total investment costs of 3560 €/kW are 'technology costs' and are associated with tech transfer.
Wind power	€/kW	1,000	Investment costs for small-scale hydro from Sambeek et al. (2003) - MEP tariffs - 2004-2005. It is assumed that some 91% of the total investment costs of 1100 €/kW are 'technology costs' and are associated with tech transfer.
HFC-23 destruction	€/tHFC-23/yr	15,000	Based on 'expert judgment' of € 3 million for 200 tHFC-23/yr (Harnisch and Hendriks, 2000)
N_2O destruction	€/tN_2O/yr	176	Based on the PDD of the Korean CDM project, which claims an offer by Rhodia of France of € 6.5 million for 29,500 tN_2O
Fuel switch (coal to gas)	€/tCO_2-eq/yr	23	Based on the PDD of the sole coal-to-gas project (for steam production) in the portfolio: 550000 US$ for reduction of 19,438 tCO_2-eq

32 Most of the investment costs are for the turbine, converting the landfill gas into usable electricity. Many projects, however, don't generate electricity and only claim the emission reductions from the methane flaring. In the case of flaring, the investment costs are: 0.35*1200 because the electricity production is 65% of the total investment cost.

The main uncertainties and assumptions occur in the following steps and data:

- There are uncertainties in the technology transfer database to start with. For instance: the Dutch supplier of landfill gas technology uses turbines from Germany. These secondary earnings are not taken into account;
- The investment metric has been generalised in many respects. For instance: the unit of € per MW for landfill gas projects is not the most appropriate one- per tonne of waste would principally be more suitable;
- The investment costs themselves originate from different data sources, and in many cases are on an aggregate level. Investment costs for hydropower projects, for instance, vary greatly depending on the project circumstances and the technology used;
- No ranges are given, only 'best estimates'.

According to the data in Haake (2006), transfer of hardware technology took place in 30 of the 63 projects. However, because in several projects the technology originated from more than one country, the total number of entries in our analysis is 34. In the case with more than one country, it is assumed that the investment value is shared equally among the technology-exporting countries.

Table 7.5 shows the greenhouse gas emission reductions per exporting country and per technology in tCO_2-eq per year. The total amounts to 25.4 $MtCO_2$-eq per year, which constitutes 89% of all emission reductions of registered CDM projects on January 1st, 2006. EU Member States supply technology associated with 23.5 $MtCO_2$-eq/yr of emission reduction and other countries (mainly Japan) supply the remaining 1.9 $MtCO_2$-eq/yr.

Table 7.5 Greenhouse gas emission reductions through the technology of exporting country, and per technology (numbers in $ktCO_2$-eq/yr). The numbers between brackets indicate the total number of projects that transfer hardware technology from the country. Columns and rows may not add up correctly because of rounding errors

Technology exporting country (# of projects)	Landfill gas	Hydro power	Wind energy	Fuel switch	HFC-23	N_2O destruction	Total GHG reductions in host country through transferred technology
Belgium (2)	87						87
Denmark (1)			26				26
France (8)	70	135				15,111	15,316
Germany (3)		30		10	3,834		3,873
Netherlands (3)	752						752
Spain (7)		48	366				414
United Kingdom (1)					3,000		3,000
USA (5)	279	30	26	10			345
Japan (3)	135	0.3			1,400		1,535
Switzerland (1)		30					30
Total (34)	1,323	274	417	19	8,234	15,111	

Based on the above, the detailed project data in our databases and using the investment costs in Table 7.4, the total investment value per technology and per exporting country can be calculated. The numbers are given in Table 7.6.

Table 7.6 Investment costs per technology and exporting country for the registered CDM projects as of 1st January 2006. Numbers are in million €, and columns and rows may not add up correctly because of rounding errors

Technology exporting country (# of projects)	Landfill gas	Hydro power	Wind energy	Fuel switch	HFC-23	N_2O destruction	Total
Belgium (2)	0.7						0.7
Denmark (1)			13				13
France (8)	0.6	83				8.6	92
Germany (3)		29		0.2	4.9		34
Netherlands (3)	9.1						9.1
Spain (7)		23	212				235
United Kingdom (1)					3.8		3.8
USA (5)	8.0	29	13	0.2			50
Japan (3)	2.0	0.1			1.8		3.9
Switzerland (1)		29					29
Total (34)	21	194	238	0.4	11	8.6	472
Share in total	4%	41%	50%	0%	2%	2%	

Renewable energy technologies dominate the investment portfolio in the registered CDM projects where hardware technology is transferred. Spain exports the highest value of technology, primarily through its supply of wind energy. France also has a high export value, primarily through hydropower. The United States, Germany and Japan also export a substantial value of technology. Denmark, the Netherlands, the United Kingdom, Switzerland and Belgium all have small shares. The results per country are given in Figure 7.3.

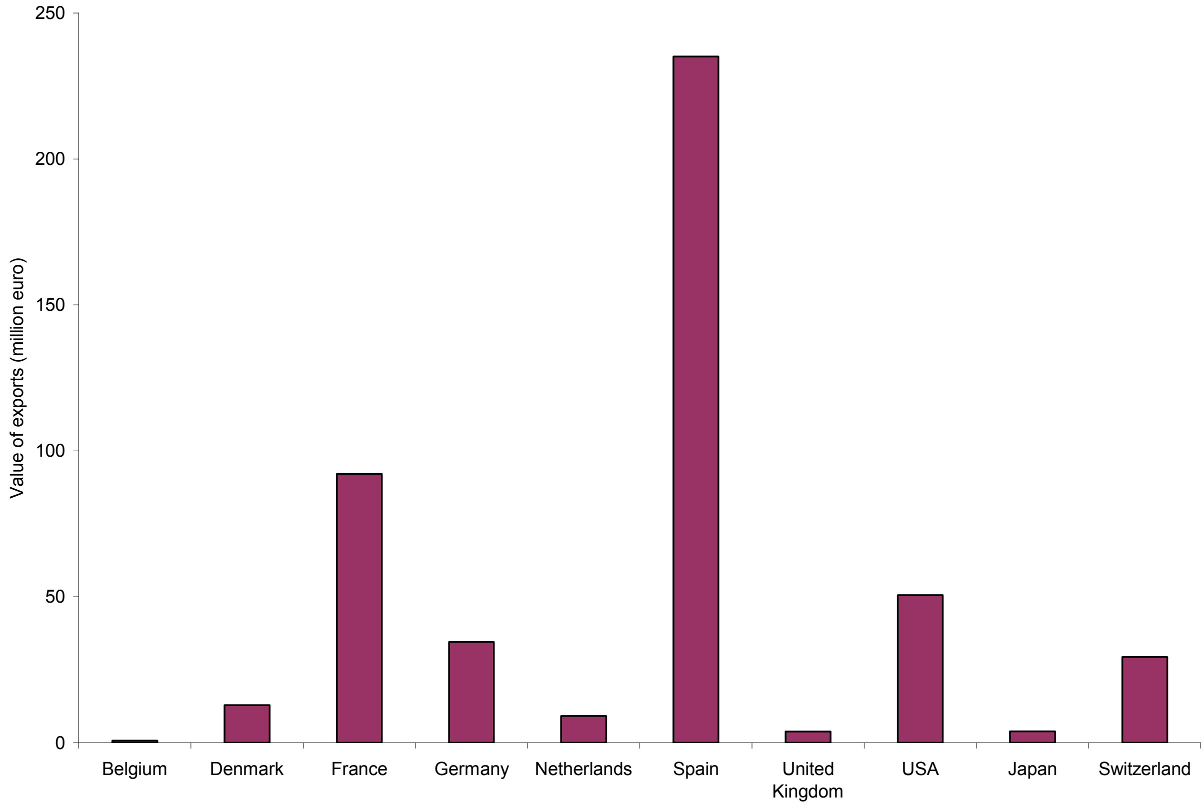


Figure 7.3 Value of exports per technology exporting Annex-B country used for CDM projects in €

7.2.4 Technology transfer in the CDM: discussion and conclusion

We have analysed the portfolio of registered CDM projects on 1st January 2006 to clarify whether and how much technology transfer takes place in the CDM. We have found that a significant share of the projects uses technology from outside the host country, notably in large-scale non-CO_2 greenhouse gas projects and in wind energy. The lion's share of the technology used in the projects originates from either the EU or the host country. In most of the projects, new or improved technologies were used, and in many projects knowledge transfer and capacity building took place, although these numbers are uncertain. The outcomes confirm that many of the projects that resulted in hard technology transfer also involved knowledge transfer and capacity building associated with the transfer of new technologies.

In terms of hard technology transfer, the EU exported technology in over one third of the projects registered under the CDM in the beginning of 2006, notably in non-CO_2 greenhouse gases, wind energy and some of the hydropower projects. In bioenergy, thermal/efficiency and some hydropower and landfill gas projects, much of the technology was locally produced. In general, hardware technology transfer takes place to a larger extent in projects that reduce non-CO_2 greenhouse gases than in renewable energy and energy efficiency projects. The exception is wind energy, for which all projects used technology from the EU.

The value of the investment in technologies originating from industrialised countries is estimated at approximately € 470 million, of which € 390 million comes from the European Union. Most is spent on renewable energy: about half on wind energy, 40% on hydropower, and the contribution of non-CO_2 greenhouse gas reducing projects is very small: 4, 2, and 2 % of the total for landfill gas, HFC-23 and N_2O, respectively. The investment analysis is surrounded by many uncertainties and assumptions. The numbers should therefore be regarded as a mere approximation of the actual benefits for Annex-B companies in the CDM.

It can be insightful to compare these numbers to other money flows. Compared to total foreign direct investment in developing countries, for instance, which amounted to approximately € 50 billion in 2002 (Ellis et al., 2007), the investments associated with CDM are small.

It is remarkable that the allegation that CER-buying countries sponsor their own private sector through buying CERs only from projects that use national technology is not supported by the above data. The large buyers of CERs, such as the United Kingdom, the Netherlands, Japan and Italy, are not the countries that export the highest value of technology to the host countries for CDM projects. It should also be noted that the United States, though not a Kyoto Party, has exported technology valued at around € 50 million, which constitutes around 10% of the total export value for CDM projects at the time.

What is the potential for extrapolation of these numbers to the more recent CDM portfolio, which throughout 2006 and 2007 has grown significantly? Several developments have taken place that will significantly influence the numbers presented above, both in the direction of more technology transfer and in the direction of less. First of all, the number of projects has increased rapidly, as well as the number of technologies. As we have not elaborately analysed these new technologies, we can only speculate about their origin, but given the rise in technologies that are widely used in Europe and Japan, particularly in the renewable energy and industrial efficiency sectors, it can be expected that the potential for technology transfer (and the export potential for companies in those countries) to developing countries has not been exhausted. Secondly, and contradicting the first point, there is a trend towards the development of high-technology industries in particularly emerging economies, such as wind turbine industries in India and China. Although these industries still need to gain experience, their location gives them an advantage in terms of costs, and this is likely to increase their market share in the CDM. The balance of these developments might be that the amount of exports of climate-friendly CDM-compatible technologies from industrialised countries will increase, but the number of projects without technology transfer, or, for that matter, with non-Annex-B to non-Annex-B technology transfer, will also rise. The extent of these increases will depend on the post-2012 regime and the market that it will provide for the CDM. Thirdly, another recent development is that the share of non-CO_2 projects is decreasing and the renewable energy projects dominate not only the project portfolio, but are also on the rise in the CER portfolio. This is likely to be associated with an increase in the overall international investments as a result of the CDM.

Although it became clear from this paper that the CDM generates both hard and soft technology transfer, both the broad data on technology transfer and the cost data should be considered carefully as they suffer from limited data availability and many arguable assumptions. In order to retrieve better data, local visits and more readily available information are essential. A possibility to resolve the question around technology transfer in the CDM in a better way that this paper could do is to encourage project developers to let DOEs report on technology transfer during the validation and/or the verification phases of their project. This reporting should be done voluntarily, as there is currently no mechanism to oblige such reporting. Positive results, however, particularly on soft technology transfer, could increase support for the CDM as its benefits would be portrayed with more emphasis.

7.3 Technology transfer through funds: the Global Environment Facility

7.3.1 Method

This section will discuss specifically and into some depth the performance of the GEF. Although the premise of this chapter is that the transfer of environmentally sound technologies for climate change is discussed, the literature on technology transfer by the GEF is scant. It is not possible to identify the origin of the technology hardware, as has been done in Section 7.2 for the CDM, for each and every project in the GEF.

Hence, a different approach to the technology transfer assessment had to be adopted, consequently leading to a lower level of detail than the CDM evaluation in the previous section. The evaluation reported here only consists of the study of official GEF evaluation studies and independent literature sources related to the GEF performance in their climate change programme. In the 1990s, this programme primarily consisted of enabling activities and projects in energy efficiency and renewable energy, and later on the portfolio was extended to include sustainable transportation, adaptation, and new low-GHG energy technologies. None of the evaluation studies addressed technology transfer specifically. However, the following approximation of the three technology transfer criteria for CDM will be used:

- In the case of projects that lead to the implementation of technology, the procedures of the GEF require only the funding of the incremental costs of the technologies implemented. This means that in general, the technologies will not have been implemented widely in the host country of the GEF project. In this sense, GEF projects are likely to meet criterion #2 in Section 7.2
- The GEF also funds a number of enabling activities in its climate change programme. Enabling activities comprise capacity building, a favourable regulatory framework development and promotion, awareness raising, technical assistance, and enacting of codes and standards (Martinot and McDoom, 2000). Activities like capacity building are part of all projects. These enabling activities all contribute to “soft” technology transfer, and to meeting criterion #3 in Section 7.2.

Based on these parallels, and concluding that technology transfer is inherent in the GEF’s activities, the performance of the GEF projects can be used as an indicator for whether the GEF is effective in delivering technology transfer. In addition, the size of the GEF’s activities (in greenhouse gas emissions reduction and generated investment) indicates the quantitative contribution of the GEF and makes it comparable to the CDM contribution. Unfortunately, however, an analysis of criterion #1 in Section 7.2 was not possible, thus making the performance of the GEF and the CDM incomparable in that regard.

7.3.2 Introduction to the GEF

The GEF was started by the World Bank in 1991 as a pilot programme, and co-governed by UNEP and UNDP. It was inspired by the Brundtland findings on sustainable development that developing countries need assistance to "leapfrog the polluting and wasteful stages of industrialisation" (Jordan, 1994). Later on, after the Rio Convention in 1992, it became the financial mechanism for the Conventions on biodiversity and climate change. A summary of characteristics of the GEF as of 2004 is provided in Table 7.7.

The initial contribution, for the pilot 1991-1994 period, was relatively small at US$ 1.2 billion, but the contributions have grown to US$ 3-4 billion over the next periods. The GEF has never been without criticism. Already during its pilot period, the project implementation and governance structure were criticised both by internal and external evaluators (Jordan, 1994; Bowles, 1996). A continuing objection relates to the top-down nature of the GEF and the lack of recognition of local circumstances in project awarding. Consequently, a number of changes was carried out, including a more democratic voting system and limited involvement of NGOs as observers to GEF's governing council (Bowles, 1996). However, developing countries in the UNFCCC negotiations still regularly comment on the donor dominance in the GEF.

Table 7.7 Summary of the GEF main features (GEF, 2004)

Objective	Fund projects and programmes that protect the global environment in developing countries
Areas of work	Biodiversity, international waters, land degradation, ozone depletion[33], persistent organic pollutants and in climate change: renewable energy, energy efficiency, sustainable transportation, adaptation, new low-GHG energy technologies, and enabling activities
Budget	Through periodical replenishment 2007-2010: US$ 3.13 billion (for all areas of work)
Funds and projects	1991-2006: > 650 projects in the climate change area; around US$ 2,5 billion in grants.
Achievements	Closed projects with GHG estimates: cumulatively 224 $MtCO_2$ (27 projects, direct and replication effects). For total current portfolio, this number is estimated at 1,7 $GtCO_2$.

7.3.3 Performance of the GEF

The Monitoring and Evaluation Office of the GEF (with help of independent consultants) has evaluated the project portfolio of the climate change programme based on several indicators: market reform impact, greenhouse gas emissions impacts, effectiveness of greenhouse gas strategies, and the level of strategic response (GEF, 2004). The most quantifiable indicator is the impact on greenhouse gas emissions. The 27 projects from 1991-2004 that had been closed upon the time of the evaluation are projected to result in a cumulative 97 $MtCO_2$ in direct project emission reductions, and 224 $MtCO_2$ if the replication of the projects will be as expected. The same projection for

[33] The GEF supplemented MLF activities for countries with economies in transition, for example Russia. It spent a total of US$ 359 million between 1991 and 2004 on this, resulting in a reduction of 99% in CFC consumption and a total halt to ODS production.

the entire current portfolio of over 600 projects in the climate change programme would lead to cumulative emissions reductions of 430 $MtCO_2$ and 1,7 $GtCO_2$, respectively, over the coming 10 to 30 years. If the latter number is translated into a yearly number by dividing it by the average lifetime of 20 years, the GEF incremental impact on greenhouse gas emissions would be approximately 100 $MtCO_2$ per year (GEF, 2004). As stated above, technology transfer as such was not evaluated.

It is interesting to note which types of projects in the GEF portfolio yielded the best results. The sectors in which the GEF was most successful (in terms of greenhouse gas reduction impacts) were found to be the energy efficiency and carbon sequestration/fugitive emissions. These projects also have relatively low investment costs. Although there were some positive results in renewable energy as well, with several large projects that reduced emissions substantially, the main contributions were from energy efficiency. These projects have also been evaluated and discussed in the peer-reviewed literature (Martinot and Borg, 1998) and lessons have been formulated (Birner and Martinot, 2005).[34] The latter have focussed on the results of market transformation efforts for supply- and demand-side energy efficiency projects. Their positive evaluation of lighting, industrial boilers, refrigerators, building chillers and demand-side management projects in China, Poland, Thailand, Mexico, and seven other countries (united in one lighting programme) pleads for a collection of interventions that can be done on the supply and the demand-side of energy. It also highlights that "new institutions and regulatory changes are among the most important outcomes for sustained market transformation" (Birner and Martinot, 2005). In this case, therefore, it seems that the enabling activities are most effective for energy efficiency projects – indicating that the main barrier is not cost, but should be found in awareness and institutional issues.

In terms of geographical distribution, it is noted that 75% of the emission reductions were from only 12 projects; nine of these large projects took place in China, and the other three in India, Russia and Brazil. The GEF has something in common here with the CDM, which also disproportionally concentrates in large, emerging economies. A difference is that the GEF also funds projects in Eastern Europe and the Former Soviet Union, whereas CDM does not attend to those countries (Joint Implementation, another flexible mechanism in the Kyoto Protocol, does).

The GEF is generally positively evaluated in terms of the project impacts, although not all projects are successful in achieving their targets. However, its size is nowhere near the reductions needed to address climate change, even if the replication effects are taken into account. In this field, it is notably different from MLF (see Section 7.1), which was large enough to solve the entire ODS challenge for developing countries. The GEF also performs better in some sectors (particularly end-use sectors) and countries (particularly large emerging economies) than in others.

As stated at the beginning of this section, this analysis has made the assumption that the projects funded by the GEF have provided technology transfer to the target countries. In many cases this is likely to be true, as it is the inherent policy of the funds to only fund new technologies and to provide for soft technology transfer alongside the hardware. Although the claim that the positive project results in the GEF involve technology transfer therefore remains unsubstantiated by empirical data, it is safe to say that transfer of technologies had to take place to a significant degree.

7.4 Comparing technology transfer in markets and funds

Comparing the CDM and the GEF yields interesting quantitative insights. In terms of greenhouse gas reductions and technology transfer, the CDM easily outperforms the GEF. The assessment in Section 7.2 only covered the first 63 registered projects, with emission reductions of about 28

[34] Note the overlap in authors between the publications in peer-reviewed journals and the GEF evaluations.

$MtCO_2$ per year. The September 2007 number of projects was over 800, leading to over 170 $MtCO_2$ emission reductions per year (UNEP/Risoe, 2007). This has been achieved in only four years of active operation of the CDM, whereas the GEF has achieved only about half of those emission reductions in over 15 years of operation, including a rather blunt assumption that replication was successful. The associated investment flows with CDM are highly uncertain, but certainly amount to several billions by now, and are projected to grow further (World Bank, 2006).

From this, it seems that the scope of a market-based mechanism is larger than the scope of a fund. The scope of the CDM (i.e., the extent to which it can make a difference towards solving a problem) is on the order of the Kyoto Protocol's targets. It is fully conceivable that stricter targets under a follow-up of the Kyoto Protocol, or for instance stricter emission caps in the EU Emissions Trading Scheme, would lead to a higher demand for CERs, and a growth in the market well beyond current levels. The demand for CDM projects is created through an emission cap. For the GEF, every dollar committed directly comes from industrialised country's budget, often a development aid budget. The GEF is already quite large, and the size of the fund would have to be tremendous if it would be made responsible for all required emission reductions in developing countries.

A measure for cost-effectiveness for technology transfer does not exist, as technology transfer is too heterogeneous of an activity to allow for measurement in a single-unit way. Cost-effectiveness of climate change mitigation efforts is normally expressed by indicating carbon price – the cost of one tonne of CO_2-eq reduced. Indirect effects, for instance of capacity building programmes, are excluded from such analysis. The CER price in the case of the CDM would determine the cost effectiveness of the CDM – the price has roughly been between 3 and 12 US$/t$CO_2$-eq over the past few years. The GEF (2004) reports lower carbon costs of its projects: on average 0.35 US$/t$CO_2$-eq, with the lowest category being energy efficiency projects (0.21 US$/t$CO_2$-eq) and the most expensive alternative transport (0.90 US$/t$CO_2$-eq; still significantly lower than the CER price). Although these numbers suggest that the GEF has been more cost-effective than the CDM, the reported figures are not comparable and do not support firm conclusions cost-effectiveness for at least three reasons: hidden costs, project selection and design differences.

Hidden costs are particularly the CDM, but also in the GEF expenditures. The CDM, for instance, has not directly funded enabling activities. Its development has been helped considerably by numerous capacity building programmes, including some funded by the World Bank, by buyer country governments (often using ODA), and by the GEF. Indeed, the carbon market has taken off much faster in countries that have seen many capacity building efforts, although this is not the determining factor whether the CDM takes of in a host country. Other factors include the willingness and speed of the government to approve projects and the general investment climate of the country. It can be concluded that a market-based mechanism such as the CDM requires enabling activities through other means in order to function to its full potential.

Second, market-based mechanisms like the CDM favour certain types of projects and certain countries. Large-scale projects that reduce potent non-CO_2 greenhouse gases are clearly preferred by the market because of economies of scale on the benefit side – they lead to greater greenhouse gas emission reductions and thus to more CERs that can be sold. In addition, the CDM procedures around monitoring and verification are favourable to centralised projects, such as industrial projects and some applications of renewable energy, and give demand-side energy efficiency and transportation projects less of a chance. The GEF claims to reach the highest cost-effectiveness on efficiency and transportation projects, which often have low or negative carbon costs.

There is also geographical selection in the CDM. CDM money, more than GEF, follows foreign direct investment flows, meaning that countries with high levels of foreign investment benefit disproportionally from the CDM. Countries with marginalised economies, primarily countries in Africa, in practice have little access to the funding available through the CDM. Although the CDM regulators have actively tried to correct some of these problems, by agreeing on fast-track procedures for small-scale projects and in for instance the "Nairobi Framework of Action" to achieve a more geographically balanced project portfolio, these issues are inherent in the design of any market mechanism. In the GEF, the geographical distribution is not much better, but there is more room for intervention. The GEF reserves a considerable budget for projects in least-developed countries, including Africa.

Third, the design of the mechanism matters to how cost-effectiveness can be determined. The expenditures of the GEF exclude contributions by other donors; the GEF works on the basis of co-financing. The reported carbon costs are therefore relatively low. The numbers for the CDM report a carbon price, which hides that many emission reductions have been achieved at a lower cost than the price paid by the buyer. The carbon price can include significant profits for the project developer. This is particularly the case for non-CO_2 greenhouse gas projects, such as the HFC-23 destruction projects in China and India. The cost of HFC-23 destruction projects are around 0.20 US$/t$CO_2$-eq (IPCC/TEAP, 2005), but credits are sold at 3 US$/t$CO_2$-eq. This has led to a vehement discussion of windfall profits for project developers (Wara, 2006). It also shows that the cost-effectiveness of the CDM and GEF is not so easily compared.

The analysis does clearly show that the GEF claims to have performed well in some sectors where the CDM has not been able to achieve much. The most striking is that where in the CDM only a small proportion of the projects consist of energy efficiency projects, the GEF climate programme evaluation concludes that energy efficiency projects are among the fund's most successful. This can be explained by the type of projects that apparently work better for energy efficiency: projects aimed at regulatory reform or market transformation can be funded under the GEF but not under the CDM[35]. Conversely, the CDM has a large share of renewable energy projects, which is a category considered less successful in the GEF. Also for the CDM, this did not come naturally; the rules have accommodated small-scale (often renewables) projects by agreeing on separate rules for small projects that have reduced transaction costs considerably, and thus helped particularly renewable energy projects.

7.5 Conclusion

This chapter has evaluated technology transfer in two international environmental policy instruments: one market-based mechanism (the CDM), and a fund: the GEF. The CDM has provoked some hardware technology transfer in its first 63 projects, and is presumably helping "soft" technology transfer to a limited degree. Stimulating more creative business constructions, and presumably improving alignment of enabling activities, however, could lead to more technology transfer, which would benefit both the technology exporting countries and the host countries. The GEF has been effective in implementing greenhouse gas reducing energy technologies in developing countries that were previously not in use, and has provided transfer of capabilities in various enabling activities. However, it has a smaller scope than the CDM, and a less rapid growth as its funds are not market-driven but depend on government replenishments.

It can be concluded that for the climate change problem, where, contrary to the ozone problem, a fund is not sufficient to come anywhere near a full solution, market-based mechanisms and funds can complement each other in order to reach overall goals. The bulk of the emission reductions will necessarily have to come from market-based mechanisms, which require strict emission targets or equivalent commitments in a post-2012 agreement. However, funds can facilitate further

[35] This may change. In order to enlarge the scope of the CDM, reform measures are proposed that might allow crediting for programmatic activities or even sectoral policies (Bosi and Ellis, 2005).

development of market-based instruments through enabling activities, and by covering sectors and countries that are disadvantaged and therefore underperforming in a market environment.

The Montreal Protocol and its MLF are often mentioned as an example for the climate change regime. It is probably inappropriate, however, to compare the MLF with the CDM or even the GEF directly. Although the lessons in terms of practical fund design that can be learned from the MLF should certainly not be ignored, the design of a climate change fund that would have the same relative effect on climate change mitigation as the MLF had on ODSs is challenging, due to the mere size of the problem and the scope of sectors it will have to cover. Comparing the investments the IEA (2006) claims are needed to address climate change over the coming years, it is two to three orders of magnitude higher than the sums that have been devoted to the MLF.

The analysis above has made clear that suggestions that a technology fund can provide a solution to the climate change problem, as it has done for the ozone problem, do not do justice to the scope of climate change mitigation and the necessary size of such a fund. However, both in geographical distribution and in project type, the decision-makers in a fund can deliberately correct disadvantageous circumstances in particular sectors or regions. Funds may play a role in helping markets work better in sectors or countries where markets do not provide appropriate incentives, or by providing capacity building, training, and knowledge transfer that improve the functioning of markets. A fund could be focused on enabling activities such as buying off IPR royalties, on energy efficiency and transportation projects, and making sure that African countries get an appropriate share. It can be concluded that by using market forces and complementing them with fund-based activities, technology transfer could be enhanced more effectively.

If we generalise these findings to technology-oriented agreements that aim at providing technology transfer, we can carefully conclude that they can be effective, by being designed as a specific complement to a demand-pull mechanism, but should not be relied on to provide all technology transfer that is needed to reduce emissions to address climate change. The demand-pull for technologies has so far been provided by the market-based CDM.

Chapter 8 Feasibility of hypothetical international technology-oriented agreements[36]

8.1 Introduction

This chapter is the first part of a research report that explores the compatibility of a cap-and-trade regime with a different form of international agreements to address climate change: technology-oriented agreements (TOAs). The aim of the chapter is to identify a number of TOAs, and assess their environmental effectiveness, costs, and political feasibility. The second part of the project (Chapter 10) will select two of the TOAs discussed in this chapter, and will analyse their compatibility with a number of cap-and-trade variants.

TOAs are defined as those international agreements that are aimed at advancing research, development, demonstration, and/or deployment of technologies (see Chapter 6). With respect to TOAs to address global climate change, these technologies would be aimed specifically at reducing GHG emissions. A general review of such agreements, including an examination of their potential relevance for climate change, was already conducted (Coninck et al., 2008a). Four types of TOAs are distinguished:
- Knowledge sharing and coordination;
- Research, development and demonstration (RD&D);
- Technology transfer; and
- Technology deployment mandates, standards, and incentives.

The dominance of economic instruments in current thinking around climate policymaking have kept TOAs from playing a role in the discussions and studies on international agreements in the context of climate change. The current deadlock in the climate negotiations around a market-based agreement has however renewed interest in other types of agreements. This is inspired by the thought that it may be worthwhile to sacrifice some of global cost effectiveness in exchange of political support and compliance with an agreement (Barrett, 2003). In addition, initiatives by the United States, supported by a number of emerging economies, such as the Asia-Pacific Partnership, have indicated that the interest in technology as a solution-targeted approach (rather than emissions as a problem-targeted approach) is rising. Concerns, however, have been raised about environmental effectiveness and costs of such technology-oriented initiatives (see e.g. Höhne, 2005). Besides political feasibility, we explore these aspects of international agreements to address climate change as well.

The discussion of alternatives to the Kyoto Protocol in this chapter should not be seen as a critique to the Kyoto Protocol, or to the UNFCCC as such. Rather, the authors feel that it is worth exploring an alternative in the case that the important post-2012 follow-up of Kyoto will not gain sufficient support among the global players. The agreements described here may provide a different way to achieve the much-needed emission reductions, but can also complement a cap-and trade regime.

The method taken to examine the proposed TOAs comprises a political constraints framework, which is developed in Section 8.2. Section 8.3 goes on in describing the agreements proposed here, in terms of expected emissions reduction (i.e. environmental effectiveness) and costs. The agree-

[36] A synthesis of this chapter and chapter 10 has been submitted to Climate Policy in January 2008. This chapter is part of a report commissioned by the Netherlands Programme on Scientific Assessment and Policy Analysis (WAB) Climate Change, report number 500102013. It has been written by Heleen de Coninck, Stefan Bakker and Bob van der Zwaan at ECN, Eric Massey at IVM, and Martin Junginger at NW&S. The authors acknowledge helpful comments from Merrilee Bonney, Michel den Elzen, Ronald Flipphi, Onno Kuik, Marc Londo, Jeroen Peters, Richard Tol, and Takahiro Ueno.

ments are never global but involve a group of relevant countries. They are in the fields of bioethanol from sugarcane, ammonia production, cement production, CO_2 capture and storage, carbon efficiency in cars, and nuclear energy. With the exception of the nuclear energy case, which discusses an existing deal between the US and India, all TOAs do not yet actually exist in the form presented here. Each section that discusses the characteristics of the agreement, its environmental effectiveness and costs, also assesses the political feasibility according to the framework in Section 8.2. Section 8.4, lastly, will discuss the TOAs in an integrated manner and will draw some conclusion.

8.2 Political feasibility framework[37]

While there are varying definitions of "political feasibility" (of policy proposals) at its core it can be characterized as a policy proposal being palatable enough to a majority of parties so as to overcome enough resistance that would inhibit the policy's adoption and/or implementation. For example, if one were to ask what the political feasibility is of instituting a 100% tariff on all new cars imported into the Netherlands or the EU, what is meant is that, will such a proposal meet with enough approval by those in power to impose it as well as those who would be affected by it.

As the above description suggests, feasibility can be seen as overcoming some form of resistance, resistance itself implies the presence of certain constraints that would inhibit the approval of a policy proposal (May, 1986). Thus, if these constraints were to be enumerated and assessed, then one could have some understanding of the likelihood of a proposal gaining acceptance. Understanding the constraints a proposal might face is however, only a part of assessing feasibility. There exist also certain influencing factors that contextualize the policy proposal and help set the stage for creating a strategy to overcome the constraints. It is then the combined understanding of the influencing factors as well as the points of constraint that can form the basis of a feasibility assessment.[38]

Interestingly, not much attention has been given to the assessment of political feasibility as such in either public policy literature or political science writings. The concept has been phrased in different ways, e.g. in criteria analysis for international climate regimes (see e.g. Aldy et al., 2003 or Chapter 6 and 7). The lack of generic work on political feasibility is indeed surprising as public policy is heavily governed by its surrounding political climate and a framework for navigating a policy proposal through the political waters would be most useful. Be that as it may, this section attempts to construct a framework that could be useful in assessing the political feasibility of Technology-Oriented Agreements (TOAs) for climate change. It is loosely based upon the works of Majone (1989), May (1986), Meltsner (1972) and Webber (1986). Essentially, this section lists and briefly describes the most important factors and constraints to be considered, and presents them in the form of descriptive questions. This framework is not prescriptive nor is it a straightforward model but should be seen as a focusing aid to be applied to each of the six TOA case studies. In the end, by asking the questions set out here of each case study, one should gain a greater understanding of the likelihood that the TOA in question might gain acceptance.

8.2.1 Influencing factors

Influencing factors are factors that help contextualize the policy proposal within the "political" arena by highlighting external elements that can have direct and indirect influence over the ac-

[37] Credits for this section go to Eric Massey (IVM).
[38] While there is a direct relation between factors and constraints, this paper does not attempt to construct or detail those influencing links between the two, as it would unduly expand the scope of this short paper and is not entirely necessary for understanding the framework. It would however be an interesting exercise in the future on it own right.

ceptability of the proposal. There are four key factors to be considered for a feasibility assessment: actors, resources, time frame & timing, and leverage points.

Actors

Actors (Meltsner, 1972) refer to the parties to whom you are making your policy proposal and whose acceptance you must win. The first step in any feasibility assessment is to outline the actors (i.e. the people) that will be involved in the negotiation and assess their motivations, beliefs and bargaining power in light of the proposed policy option.

Actor's motivation refers to the person or parties' desires, drives, goals or objectives. Every actor has some motivation for taking part in negotiations, in terms of TOAs perhaps the party wants new technologies to boost industrial production, perhaps they are generally interested in reducing their GHG emissions, or perhaps they are interested in money to support their farmers. These are simplistic examples but whichever the case, if possible one should try to pinpoint as many motivations of the other party and see if they fall in line with the proposal. If not exactly, can the proposal be adjusted to square better with their motivations?

Actor's beliefs in this case refer to the attitudes and values held by an actor. In some sense this can be seen as the core of any political feasibility assessment as it is attitudes and values that make up one's politics. Any policy proposal must of course not run counter to the beliefs one holds, it would be useless to advocate a transfer of nuclear technology if the country or actors involved in the negotiations are fundamentally opposed to nuclear energy. Thus one should attempt to outline the attitudes and values of the actors involved and look at the policy proposal in light of those beliefs. A related and perhaps further step would be to target the policy proposal towards those actors (if the situation allows) whose beliefs are most in line with that of the proposal. This however may not always be the case and the proposal then, if possible, might be altered to fit as close as possible with the other parties beliefs.

Actor's bargaining power refers to the amount of political clout or power the actor has to accept or reject your policy proposal. The underlying point here is twofold. Firstly, it is to identify, out of the pool of actors, who has the most clout and secondly to make a judgment whether to engage that actor or if possible avoid that actor. For example, which ministry has more clout, the Ministry of Finance or Ministry of Environment? Would it be more advantageous to hold negotiations with the Finance Ministry if they are in a better position to see that your proposal gets accepted? While this is probably not a fundamental criterion like *actor's beliefs* it is an important one all the same and should be taken into consideration when possible.

Resources

Resources, materiel or otherwise, here refers to the relation of what parties have on offer in relation to each other. The concept is plainly straightforward and in general, subconsciously assessed by most people prior to any push for a policy proposal. Nevertheless, it is important to reiterate the concept, as it is an integral part of a feasibility assessment framework. In relation to pushing for TOAs, one should assess what actual resources one has to offer and if in fact that the other party wants these as well (this is related to Actors above and to the constraints detailed below). Moreover, one should consider unrelated resources that might act as "deal sweeteners". These are things that have no relation to the policy proposal at hand but are resources that the other party might be seeking and that if offered in combination with the proposal make it more likely to be adopted. Note that in some cases different resources will need to be identified for the different actors, depending on the number of actors involved in the negotiation.

Time frame and timing

Time frame and timing are important elements to any feasibility assessment and must be considered with care.

Time frame refers the length of time expected by the proponent of the proposal to be used in the *adoption* and *implementation* of the proposal. In other words, how much time is needed to convince others that the proposal should be accepted? In general: the more time there is, the better the chances of acceptance. Thus, how much time is available for negotiations should be specified in an exact manner. The same principle applies to time for implementation. How long will the party itself have to implement the proposal? Twenty years for the phase out of old coal fired generators for the adoption of new gas powered turbines is more attractive than five years. One should try to identify the minimum and maximum time frame that the other party has or expects for implementation.

Timing is in some cases more crucial to assess than time frame and as the colloquial phrase goes, "timing is everything". Timing here refers to the opportune and inopportune moments for pushing your proposal (i.e. policy windows). This involves taking stock of what is happening within the larger policy and political environment surrounding the proposal that might help make it more attractive on the one hand or divert attention from it on the other. A few examples: A good time to try and force Type 3 (technology transfer) or Type 4 (technology deployment mandates, standards, or incentives) TOAs might be within the context of larger trade negotiations. An inopportune time to open negotiations on a proposal is prior to parliamentary elections, as there is a risk of having the deal undone by the new government. Perhaps an opportune moment for negotiations is just after a new government is formed. Another external condition that may facilitate an agreement is whether the countries involved find themselves in a period of economic prosperity; when budgets of governments are not too constrained and there is room for something extra. The downside of such a "good timing" may be, conversely, that, in case government or economic conditions change, the agreement may not be complied with in the end. While these are just simple examples, the idea is that just as with time frame, one should take timing into account and if possible sketch out within the larger time frame the best and worst moments to advocate for the proposal.

Leverage points

Leverage points are preferably related but possibly unrelated issues that can be used to enhance the attractiveness of a proposal. A key question to ask of the proposal is what other policy problems or issues can it be linked to so as to leverage it. These leverage points can come in various forms. Perhaps the proposal helps to address other key issues on the policy agenda (e.g. greater use of local biofuels can help increase energy security). Perhaps a particular event has recently occurred that draws focus to the issue being proposed (focusing events) raising it on the policy agenda and giving it a sense of urgency (e.g. the 2003 heat waves in Europe highlighted the need for early warning systems and an adequate policy of dealing with the elderly and infirm, prior to this they were not on the policy agenda). Whichever the case, one should try to identify and enumerate any leverage points associated with the original proposal.

8.2.2 Constraints

Identifying constraints helps highlight what key difficulties the proposal might encounter during its promotion and thus aid in the design of a proposal that is more likely to win approval. In the end however, if there are too many constraints to be surmounted then the proposal will have little chance of success. Constraints are in most cases double edged and apply reflexively to the party promoting the proposal as well as to the parties being asked to accept the proposal. Thus they must be calculated for both sides. Constraints are different from "Influencing factors" (Section 8.2.1) in that they are not political but inherent to existing physical, economic, legal, social and institutional features of the proposal.

Economic
It goes without saying that most transactions involved with promoting, adopting, and implementing a policy proposal involve some financial matters. The central questions surrounding this constraint are as follows: What are the economic resources and what is the budget for extending the proposal? What are the financial obligations for other parties associated with accepting the proposal? Do they have financial resources to accept it? What will be the cost for all involved if they accept the proposal? Do all actors have enough?

Physical and technical
While a proposal might be interesting and well received by all parties, there is the chance that some external factor could inhibit its likelihood of adoption or implementation. A carbon efficiency standard that is agreed to apply in 10 years time might not yet be technically achievable at present, so barriers need to be overcome. Assessing these constraints is very context-specific and it is difficult to make generalizations. Nevertheless, looking at it through the lens of TOAs a few generic questions emerge, although greater specification will be needed when looking at a specific TOA proposal. In general, are there any physical/technical barriers that could inhibit a Type 2, 3 or 4 agreement? Does the receiving party/country have adequate technical and physical infrastructure to comply with the proposal?

Legal and contractual
These constraints are concerned with any institutional or legal barriers that could prevent the adoption or implementation of the proposal. In short, is the institutional, legal and regulatory infrastructure equipped to address the proposal? Will any laws need to be changed so that it can be accepted? Would the proposal require regulatory approval and by whom? For example, the transfer of nuclear technology may require approval from the ministry of defence and may be inconsistent with earlier laws and regulations. These institutional hurdles should be enumerated so that the requisite steps can be taken. These are constraints that revolve around any prior commitments or obligations that might prevent or in some way hinder the proposal from going forward. For example perhaps there is a trade agreement that states that by doing X for one party one is obliged to do the same for another party. Or perhaps by doing Y for one party, that party will be required to do Z in return (but may not be in a position to fulfil that commitment). In addition, one must ask question of legal accountability of the actors that one will be negotiating with. Are they trustworthy? Will corruption be an issue?

Social and equity
Similar to factor of *Actor's Beliefs* social constraints are concerned with the beliefs and prejudices of the wider social audience or, possibly, the public at large. As with some of the other constraints this is very context-specific and difficult to generalize, however, it need only be taken into account for those issues that could be controversial. Thus the first question to ask is, could the proposal be socially controversial (either in one's own country or in the one receiving the proposal)? Some options, such as solar energy are general accepted, while nuclear energy is a lightening rod for attention. Second, is the proposal socially acceptable for the general public and the other parties? While nuclear energy itself is quite acceptable in some countries, the transfer of nuclear technology might not be.

Equity constraints may be difficult to judge yet it is still a point to be taken into consideration. It revolves around the notion of the fairness of a proposal and how it will be seen by those that might accept it. Essentially, will the proposal be seen as equitable and fair or will others feel cheated by it? Are the interested parties being given enough? Should one party, if possible, be offering more? Does the proposal offer economic benefits to already richer countries; does it enhance inequity in the world, or in a country? For example, a tax reduction for the upper income classes is usually not seen as equitable. A good way of judging this constraint is to have a good outline of the *actor's motivations* as well as your own *resources*.

Institutional
This is similarly linked to *Actor's Bargaining power* and is concerned with negotiating/bargaining powers and political clout. Is the negotiating party the right party to be advocating the proposal, and do they have enough weight to push it through? Is there a need to seek help from others to support the proposal? Is the proposal advocated to the right people on the right level; do they have enough clout to accept it? A junior staff member attempting to convince a deputy minister will most likely have more difficulties than a minister attempting to convince a deputy minister. Will the proposal be in a safe investment environment? Is, in terms of a country, the climate politically stable? Are the institutions that need to be formed or burdened with the agreement the right ones?

8.2.3 Political feasibility assessment framework

In the following sections, various proposals for TOAs will be assessed on their political feasibility. First, for a number of government actors involved, the constraints will be discussed in a matrix form as in the table below. The table also contains a summary of the constraints as well as the framework for the applicability of the constraints to the actors is included here:

Constraints:	Actors	
	Actor 1	Actor n
Economic • What are the economic resources and what is your budget for extending the proposal? • What are the financial obligations for the other party associated with accepting your proposal? • Is there enough budget to accept it? • What will be the cost for the receiving party if they accept the proposal? • Do you have enough funding?		
Physical and technical • Are there any physical/technical barriers that could inhibit a Type 2, 3 or 4 agreement? • Does the receiving party/country have adequate technical and physical infrastructure to receive the proposal? • Does the receiving party have enough technical resources for the maintenance of the proposal?		
Legal and contractual • Is the institutional, legal and regulatory infrastructure equipped to address the proposal? • Will any laws need to be changed so that the proposal can be accepted? • Would the proposal require regulatory approval and from whom? • Are there any prior commitments or obligations that might prevent or in some way hinder the proposal from going forward?		
Social and equity • Could the proposal be socially controversial in any of the countries involved? • Is the proposal socially acceptable for the general public and the other parties? • Will the proposal be seen as equitable and fair or will others feel cheated by it? • Are the interested parties being given enough and if possible, be offering more?		
Institutional • Are the right parties involved to be advocating the proposal, do they have enough weight? • Is additional support required? • Is the proposal advocated to the right people, do they have enough clout to accept it? • Is the negotiation party/country politically and economically stable? • Will corruption be an issue?		

Subsequently, the other influencing factors will be discussed for the potential treaty. Based on the number of constraints for actors, and the extent to which the other influencing factors are relevant and conducive to the proposed treaty, the TOAs will be assessed for their political feasibility.

8.3 Cases of technology-oriented agreements

In this section, a variety of technology-oriented agreements (TOAs) for addressing climate change is explored. We distinguish four types of TOAs: 1) knowledge sharing and coordination; 2) research, development and demonstration; 3) technology transfer; and 4) technology mandates, incentives and standards (Coninck et al., 2008a)

The technologies selected are:
- Bioethanol from sugar cane (elements of type 2 and 3)
- Nuclear energy: the US/India deal (elements of type 1, 2 and 3)
- Cement industry (elements of type 3 and 4)
- Ammonia production (elements of type 3 and 4)
- CO_2 capture and storage in the electricity sector (type 4)
- Carbon efficiency standards in cars (type 4)

It is assumed in the discussions that there is some degree of institutional embedding of the TOA in the UNFCCC. This could be in a similar manner the Kyoto Protocol was agreed on but with a subgroup of countries. In that case it would be firmly "inside" of the UNFCCC and the UNFCCC would measure, report and verify the outcomes. Another possibility is that the TOA outcomes are registered at the UNFCCC – there would be "oversight" of the UNFCCC on its implementation but no accountability. Lastly, it is possible to include agreements outside the UNFCCC, with or without formal reporting. For the TOA substance in this chapter, the institutional embedding is not crucial; in Chapter 9 this will be discussed in more detail.

Each TOA description contains the basic rules for cooperation on technology. It will explore a case of a limited number of participating countries. It will describe the technology at hand, including the overall emission reduction potential the technology can achieve. It will then establish the emission reduction and costs that are associated with the case TOA. Each section will conclude with a discussion of the political feasibility framework that was introduced in Section 8.2.

8.3.1 Bioethanol from sugar cane[39]

With rising oil prices and growing concerns regarding anthropogenic climate change, biomass transportation fuels (biofuels) have received increasing attention and policy support. For example in the US, the production of ethanol from corn has reached peak levels, while in the EU, the target of 5.75% biofuels in 2010 (equivalent to about 750 PJ) has caused a strong increase in the production of biodiesel from rape seed and ethanol from grains (EurObserv'ER, 2006). However, the feedstocks used in developed countries (corn, rape seed, wheat) only allow for small greenhouse gas emission reductions (IEA, 2004). Also, given the recent ambitious new targets set by the EU, it is likely that the demand for biofuels beyond 2010 will only further increase (European Council, 2007). Even when taking into account additional production in the EU, expectations are that only about 414 of the required 750 PJ will be met by domestic production. Advanced biofuel technologies (so-called second generation technologies) based on cellulose material are expected to have more favourable energy balances and a higher production per hectare, but are not expected to be commercially available until in another decade or so. In summary, it is expected that the EU will not be able to meet its ambitious biofuel targets by domestic production on its own.

[39] Credits for this section go to Martin Junginger (NW&S, University of Utrecht).

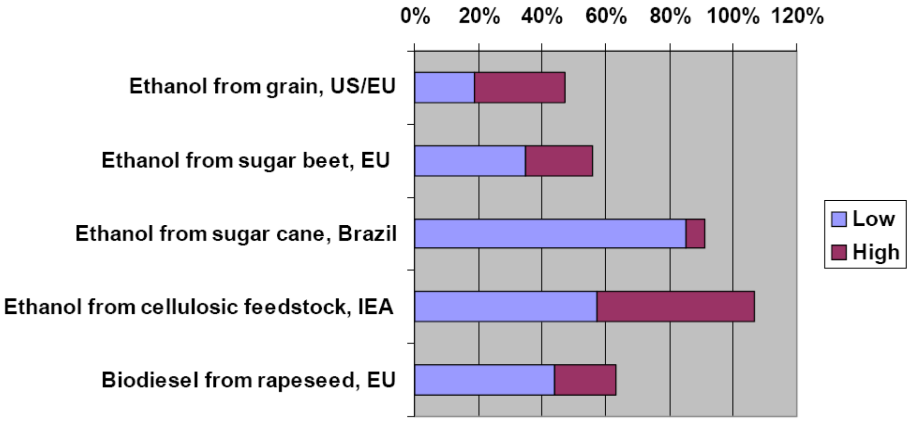


Figure 8.1 Reduction in well-to-wheel CO_2-equivalent GHG emissions per km, compared to gasoline (for ethanol) and diesel (for biodiesel) (IEA, 2004)

On the other hand, ethanol based on sugar cane in Brazil is a biofuel currently produced on a large-scale industrial basis that can already achieve GHG emission reductions of 80-90% (Figure 8.1). This is first of all due to the high photosynthetic efficiency of the sugarcane plant, a perennial grass whose cultivation is limited by plant physiology to tropical and sub-tropical regions. The sugarcane stalks contain the cane juice from which sucrose is extracted and/or bio-ethanol is created (Johnson and Matsika, 2006). Second, the high GHG efficiency is also due to the development of new, high-yield varieties of sugar cane, and technological development and up-scaling of the ethanol production process (Wall Bake et al., 2009). Next to a high GHG emission efficiency, ethanol from sugarcane is also highly competitive compared to oil-based gasoline. From 38 US$ per barrel, ethanol can compete with gasoline, and between 2004-2005, the consumer price of ethanol on energy content basis was only 50-80% of the price of gasoline (Walter, 2006; Figure 8.2).

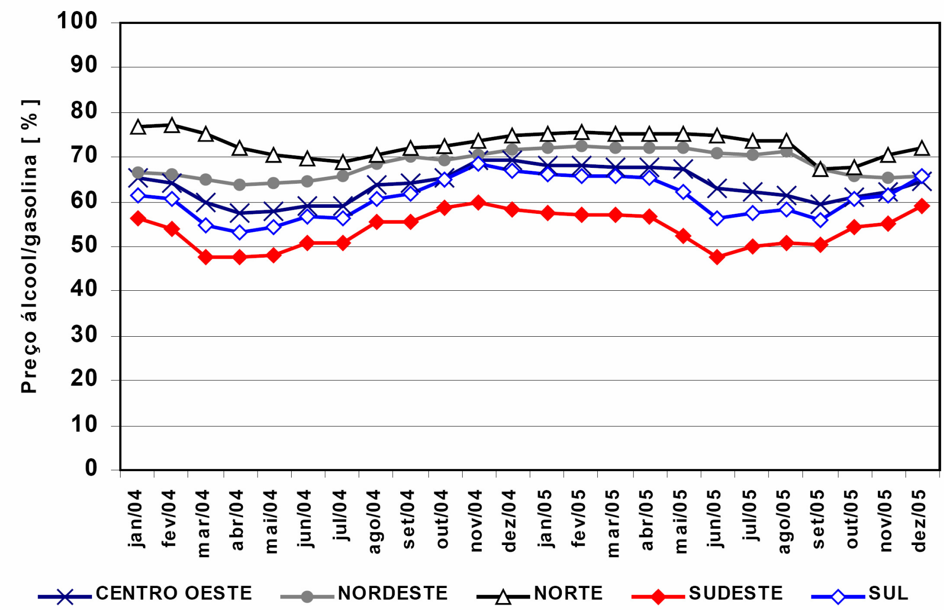


Figure 8.2 Ethanol prices as percentage of gasoline prices (on energy basis) in different parts of Brazil between 2004-2005 (Walter, 2006). ("Preço àlcool/gasoline" is "price of ethanol/gasoline")

In 2006, Brazil produced about 17 billion litres of ethanol, using about 3 million hectares of land (Smeets et al., 2006). This corresponds to an average yield of about 78 tonnes of cane and about 6,000 litres per hectare. Given the competitiveness of Brazilian ethanol and the demand for biofuels by the US and Europe, Brazil has increasingly exported ethanol to amongst others the US, Japan and Europe, about 2.5 billion litres in 2005, and about 3 billion litres in 2006 (Walter et al.

2007). Brazil expects to increase domestic production to 35 billion litres in 2015, of which about 6 billion litres (about 125 PJ) would be available for export. Thus, it is apparent that this will not be sufficient to meet the demand for biofuels in most EU/OECD countries.

Fortunately, Brazil is by far not the only country with soils suitable for sugar cane. Major other current producers include India, Thailand, Australia, and countries in the Caribbean and sub-Saharan Africa (see Table 8.15 in the Annex). Especially in the Southern African Development Community (SADC), the potential for (additional) sugarcane production is substantial, as in these countries the climatic conditions are favourable even with only marginal or any irrigation (Johnson and Matsika, 2006). In many of these countries, the total cultivated land is only a fraction of the total agricultural land available (temporary and permanent pastures, permanent crops, and temporary crops). Given the relatively low population density, the large potential of available land, and the suitability of the region to grow sugar cane, sub-Saharan Africa offers in principle ample potential to produce (excess) ethanol for export to e.g. the European Union. Sub-Saharan Africa has been identified as one of the most promising regions in terms of future biomass producing potential (Hoogwijk, 2004; Smeets et al., 2007), taking into account restrictions on land that is currently forested (Table 8.16 in the Annex), as only a small part of agricultural areas are currently . However, in order to be effective for climate change, firm guarantees that bioethanol production from sugar cane does not lead to significant land use emissions (as suggested in Searchinger et al. (2008)) need to be put in place.

The potential for biofuels production in sub-Saharan Africa has not gone unnoticed. For example, in July 2006 an association of 15 African nations signed a treaty to join the PANPP, an acronym of "Pays Africains Non-Producteurs de Pétrole" (in English: the "Pan-African Non-Petroleum Producers Association) (Biopact, 2006). Also, in December 2006, the first Pan-African biofuels conference was organized, at which numerous initiatives for biofuels production in Africa were presented (Green Power Conferences, 2006). However, repeating the Brazilian experience in Africa will require support from Brazil. The Brazilian sugarcane/ethanol sector has been developed gradually over thirty years, and extensive knowledge transfer is required. Brazilian stakeholders have also emphasised that they do not intend to become an ethanol-producing monopolistic, but rather would like to share their experience with other countries in e.g. Latin-American and Asia (see e.g. Orellana, 2006, Walter, 2006), and also specifically in African countries (Daniel, 2006).

Scope of the technology[40]

The agricultural sub-system

Sugarcane cultivation in Brazil is based on a ratoon-system, which means that after the first cut the same plant is cut several times on a yearly basis. Before planting in the first year, the soil is intensively prepared, nowadays mainly mechanical. After this the soil is furrowed and phosphate-rich fertilizers are applied, seeds are distributed and the furrows are closed and fertilizers and herbicides are applied once again. The stock is then treated with artificial fertilizers or ´filter cake´[41] once or twice again during cultivation in the first year. After 12-18 months the cane is ready for the first cut. For this it is (still) common to burn down the cane in order to simplify manual harvesting. Mechanical harvesting can be applied, e.g. currently it is used for approximately 25% of all sugarcane in São Paulo. After cutting and sometimes chopping cane stalks by a chopped cane harvester, the cane stalks are loaded in trucks and transported by trucks to the industrial plant. Burning and delays before processing such as loading and transport lead to significant losses of the amount of sucrose per ton stressing the importance of quick harvesting, loading and transportation. After the first harvest, the process is repeated excluding intensive soil treatments and planting. Depending on the rate of the declining yields the same stock can be used up to 5-7 harvests

[40] This section is largely based on Wall Bake et al. (2009).
[41] "Filter cake" is a residue of sugar and ethanol production, containing large amounts of nutrients.

nowadays. Yields decline with approximately 15% in the year after the first harvest and 6-8% in the years that follow. Declining yields depend on treatment of the stock during maintenance and harvesting but are mainly determined by the combination of applied variety and type of soil (Wall Bake et al., 2009).

The reductions achieved over time for the sugarcane production have been significant, about a factor of 3, from about 100 R$[42]/tonne cane (TC) to about 35 R$/tonne cane. Cost reductions for land rent, soil preparation and crop maintenance, were highly influenced by the increasing length of the ratoon system and the rising agricultural yields. Improved strength of new varieties against pests and drought, special breeds for varying soils and application of advanced management systems form the main explanations behind these increased yields. Harvesting costs declined mainly because of increasing yields in the manual process. Yields increased from 4.5-6 TC/man/day in 1977 to over 9 TC/man/day in 2004. Due to increasing ethanol plant sizes, average transportation distances doubled from 10 km in 1977 up to 20 in 2004, but loads increased significantly from 10 TC/truck to 40 TC/truck. Transportation costs declined mainly because of up-scaling, introduction of automated logistic systems, and improved infrastructure.

The industrial sub-system

At the plant, the sugarcane is washed and shredded, and using a set of 4-7 mill combinations juice sugar is extracted. The main objective of the milling process is to extract the largest possible amount of sucrose from the cane, a secondary, and increasingly important objective is the production of bagasse[43] with low moisture rates in order to feed the boilers. The boilers supply enough electricity and steam for the process to be self-sufficient, and in some cases to deliver excess electricity to the grid. The cane juice is filtered and treated by chemicals and pasteurized. In the following process, the molasses are fermented to produce a “wine” with an ethanol content of 7-10%. The wine is then distilled to 96% hydrated ethanol. Further dehydration up to 99.7% is achieved by addition of cyclohexane.

Industrial processing costs were reduced by approximately 70% during the past 30 years, from over R$1000 to R$250-350/m^3. First of all, the up-scaling of the average ethanol plant has led to lower specific investment and operation & maintenance (O&M) costs. While the average plant size used to be 120 m^3 per day in 1980, nowadays, plant sizes have increased to 1000 m^3 per day, resulting in cost reductions through economies of scale. Strongly correlated to scale, load factors play an important role in cost reductions. Load factors of 90% were found in the late 1970s, while nowadays load factors are typically around 95%, mainly because the number of crushing stops was decreased as a result of introduction of automated feeding and milling processes. In addition, the amount of operational days per year was raised from 160 in 1975, up to 190 days/year in 2005 (Wall Bake et al. 2009). This was mainly the result of the use new varieties, but also of a well-organized planting and harvesting logistics. Due to further development of new varieties and optimization of the harvesting logistic systems, the amount of operational days is expected to reach 200 days/year in the near future.

Total cost reductions and prospects for the future

As described above, significant cost reductions have been achieved in the Brazilian ethanol production system. Production costs have roughly been reduced by over a factor of three from 1975-2005 (see also Figure 8.4). For the future, further cost reductions are expected with cumulative production. Already today, the cost of production of ethanol in Brazil is estimated as US$ 200/m^3 for the producers with best economic performance, while the average production costs in Brazil are around US$ 280/m^3 (Walter, 2006).

[42] Brazilian Real (1€ equals about R$ 2,5).
[43] Bagasse is the fibers left after milling.

However, the experience for bringing costs down further does not necessarily have to be gained solely in Brazil. By enlarging the system boundaries, and applying knowledge (e.g. Brazilian cane varieties and ethanol plants) abroad, additional experience could be gained, which would likely lead to further improvements in the cane and ethanol production process.

Contents of the TOA

Given the problem description and rationale and the available technology, we propose the following type-2 and 3 (knowledge transfer) technology-orientated agreement:

Brazil will be the knowledge-supplying party. The knowledge transfer will include both expertise on the agricultural system (e.g. cane varieties for various soil types, pest control, use of vinasse as fertilizer etc.) and on the industrial ethanol production system (technical assistance with building large-scale ethanol plants)

The *Southern African Development Community (SADC)* will be the technology-receiving countries. As part of the TOA, Brazil and the SADC will sign a Memorandum of Understanding (MoU), in which they stipulate the intention to build up an ethanol industry.

As third party, the *European Union (EU)* will act as financing party of projects. In return, supply contracts are signed for the ethanol production to be exported to Europe to meet biofuels target and GHG emission reduction, possibly coupled to a fixed price (or a price range with minimum and maximum boundaries depending on the oil price developments). The commitment by the EU could be expanded by the introduction of flex-cars on its market; cars that can use both ethanol and gasoline.

The initial investments in the SADC countries may have to be done by EU government funds, but when the market picks up, commercial investors could come in. In the latter case, better oversight of the TOA would be necessary to see to it that the investments are done in a sustainable manner and adverse impacts are minimised.

The time horizon for this TOA will be 2020. The aim of the TOA is to utilize the Brazilian knowledge to set up an ethanol industry in the SADC countries. It is estimated that this could result in an increasing sugarcane/ethanol production, with an approximate (optimistic) annual growth rate of 23%, reaching a tentative 67 million m^3 ethanol in 2020 in the SADC countries (see also Figure 8.3). The production in 2007 will be based on 60 million tonnes of sugarcane (compared to 45 Mt actually produced in 2004), and rises to 880 Mt in 2020. This would require about 13.4 Mha in the SADC, equivalent to about 3.1% of their total agricultural area (see tables in the Annex). Note that yields/ha in some SADC countries could be higher than the Brazilian average, so possibly less land will be needed. This, as well as the land use, means that production could rise further after 2020.

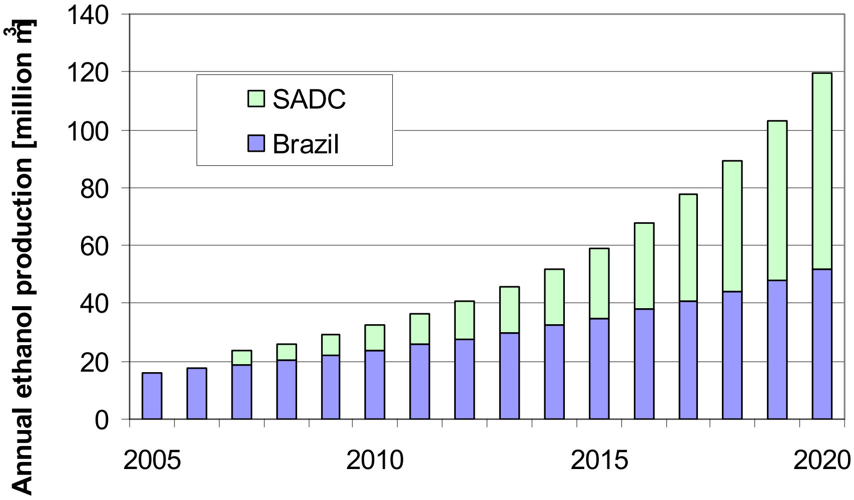


Figure 8.3 Potential ethanol production in Brazil and the SADC countries 2005-2020

Overall emission reduction potential and impact of the TOA

As mentioned earlier, the well-to-wheel GHG emission reduction range of ethanol from sugarcane compared to gasoline use is about 80-90% (IEA, 2004). In our scenario the ethanol will be transported to Europe. This will negatively influence the overall GHG balance, but in general, the losses of transporting a liquid with a high energy density by bulk freighter has a relatively small impact on the overall energy and GHG balance. In the scenario, a GHG emission reduction of 80% compared to gasoline is assumed.

This means that 67 million m^3 of ethanol could replace about 1400 PJ of fossil transportation fuels, which is equivalent to about 91 $MtCO_2$ emission reduction in 2020. Whether the ethanol is consumed locally or exported to Europe has only a marginal influence on the total emission reduction.

Next to this direct GHG emission reduction, the TOA will also have an impact on production costs of ethanol. It is expected that production costs will further decline with cumulative ethanol production. Taking the additional production in the SADC into account, it is expected that ethanol production costs will continue to follow the experience curve and decline approximately another 20-25% to about 230 US$/$m^3$ (see Figure 8.4). This will further increase the competitiveness of ethanol in comparison to gasoline and other fossil fuels. On the other side, the higher demand for bioethanol may drive the prices of the feedstocks for sugarcane up, which may compensate some of the learning effects.

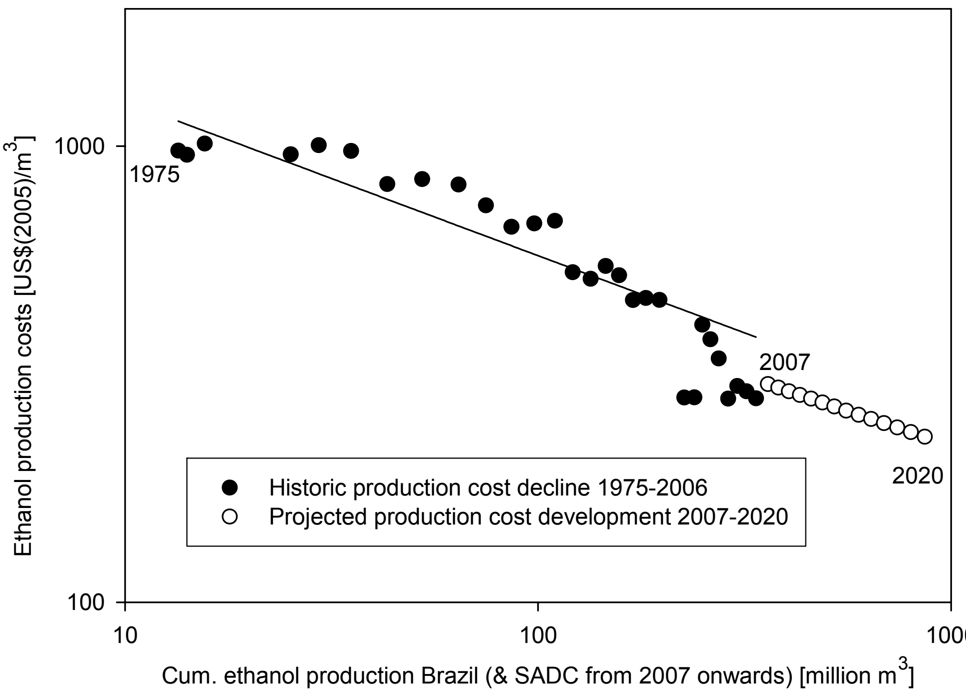


Figure 8.4 Historic ethanol production cost reduction in Brazil (1975-2006, based on Wall Bake et al., 2009) and anticipated further production cost reductions based on anticipated production volumes in Brazil and the SADC

Expected costs of the TOA

As was discussed earlier, ethanol can compete with oil-based gasoline from an oil price of 34 US$/barrel and higher. Given the current oil price developments, it is very likely that ethanol will be able to compete on the market on its own. However, significant upfront investments are still necessary. Current investment costs are about 125 R$/$m^3$ ethanol (about 45 €/m^3), and thus *investment* costs per tCO_2 avoided would roughly be 33 Euro/tonne, or (spread over the duration of the agreement (2007-2020) approximately 3000 M€. However, investment cost will further decrease over time as part of the total production costs (see above). Actual costs per tCO_2 could be zero or negative, given the competitiveness of ethanol (i.e., producers could possibly gain extra income by selling the GHG credits). This calculation also assumes that costs for sugarcane remain stable over this period in time; if the costs for sugarcane production rise, so will the costs for ethanol production.

Political feasibility of the bioethanol-TOA

The above paints a favourable picture for an international bioethanol agreement. However, there are a number of real constraints that inhibit the realisation of such an agreement, or can possibly even provide a genuine and righteous showstopper for the agreement to go forward. Table 8.1 assesses the constraints to the TOA implementation per actor.

Table 8.1 Actor-specific constraints of the sugar-cane based bioethanol TOA

Constraints	*Actor*		
	Brazil	*SADC*	*EU*
Economic		High interest rate and risk of investment	
Physical/technical		Land availability Food security	
Legal/contractual	Investment agreement with SADC needed		Trade agreement with SADC needed (i.e. change of current import barriers for ethanol)
Social/equity		Employment Land ownership Environmental issues; sustainable land-use	Concerns regarding the sustainability and land-use effects of sugarcane and ethanol production
Institutional		Political stability in SADC countries	

Each of the main constraints is described in some more detail below:

- Economic constraints: As ethanol production is competitive from 38 US$/barrel, competitiveness may further improve over time. Thus, it is expected that this TOA could be realized without any net costs. However, large investments will have to be made in regions which often have a poor infrastructure and a mediocre governance track record. Thus the risks for investments are relatively high, which may be translated into high interest rates. Possibly, this could partially be avoided by low-interest loans from the EU (e.g. as part of an trade agreement)
- Physical and technical constraints: as was shown, the general land potential in the SADC countries is considered large, but within the frame of this study, no detailed analysis was carried out to accurately assess the amount of suitable land for sugar cane. Also, it should be avoided that current food production is displaced by sugarcane for ethanol. Another important constraint is the physical infrastructure (roads, pipelines, electricity supply) that is required to transport the sugarcane and ethanol efficiently.
- Legal and contractual constraints: Currently, Europe has import tariffs in place for ethanol. However, Europe could (within the boundaries of WTO rules) make agreements with the SADC for annual import quotas (a similar agreement exists e.g. also for the US and a number of Caribbean countries). There could be however considerable resistance from actors within the EU (e.g. farmers and ethanol producers).
- Social/equity constraints: sugarcane production is likely to cause a number of social, environmental and other impacts, as was shown for Brazil (Smeets et al., 2007), including issues of land ownership, environmental impacts (use of water, fertilizers, pesticides etc.), biodiversity and social issues (e.g. hard labour conditions; impact of ethanol production on food prices). Although in the state of Sao Paulo, these problems are not considered prohibitive, they may prove to be in other parts of the world. Although sugarcane and ethanol production would create new employment opportunities, the kind of employment may not be preferred. In various EU countries (e.g. the UK, Germany, Belgium, the Netherlands) criteria are developed for the sustainable production of biomass. The sugarcane production would likely have to comply with these criteria, the criteria may have to be adapted for the specifics of this case and will have to be overseen by the implementing body of the TOA.
- Institutional constraints: some SADC members (such as Congo or Zimbabwe) have a very poor governance track record, while others (such as Botswana and Mozambique) are politically more stable and feature less corruption. Also, the EU, which currently leaves energy supply issues to the discretion of the Member States, would have to operate as one in order to make the agreement worthwhile.

With regard to the non-actor factors, in terms of resources, it can be observed that:

- Brazil has the technology off the shelf as well as a thriving ethanol industry
- The SADC have the geographical potential, and interest in additional sources of income
- The EU is interested in fuel security, GHG emission reductions and has the financial means

Regarding timing and time frame, the agreement feels particularly timely given the recently set biofuels target of 10% in 2020 in the EU (European Council, 2007), and the anticipated extra costs and pressure on land. In terms of leverage, the agreement holds the promise of clear benefits for each of the three actors involved, especially the economic feasibility of the proposed TOA.

8.3.2 Nuclear energy TOA: the US/India deal[44]

Radioactive waste, nuclear proliferation, reactor accidents, economic competitiveness, and public opinion continue to create concerns regarding the use of nuclear power and are barriers to nuclear energy policymaking. Still, worries over energy supply security, local air pollution, and global climate change provide reason to assess its potential share in domestic power production. It is difficult to predict with any confidence what the 21st century will hold for nuclear power, both at the national and global level, and whether in the long run nuclear energy may contribute, along with other energy resources, to the establishment of sustainable development.

While many countries have presently no plans to build nuclear power capacity and some are committed to gradually phase out their current domestic nuclear power production, others decisively continue to preserve a significant part of nuclear energy in their national electricity generation portfolio or are at the start of building up a prospected domestic nuclear energy capacity. At any rate, recent policy directions in an increasing number of countries show that nuclear energy is reappearing on the political agenda. While at present the globally installed nuclear capacity is approximately in status quo, it may increase again over the next two decades given e.g. the expected new build in countries like China and India. Its prospects beyond 2025 will depend on the relative weights given to the benefits and drawbacks of nuclear power, as well as the long-term sustainability features of all energy resources.

TOAs in the field of nuclear energy could be particularly worthwhile between developed and developing countries would be inspected, as there are several large industrialising nations, among which notably China and India, that for decades have been showing interest in the development of nuclear energy and today have optimistic plans for a major expansion of their existing domestic nuclear power installations. Recent developments suggest that nuclear energy TOAs may receive increased attention in the near future. An example is the "U.S.-India nuclear deal" that was closed in 2005, under which three decades of restrictions on nuclear cooperation between these two countries would be ended, and China's multiple official declarations to augment its domestic nuclear energy capacity and purchase associated foreign nuclear technology, among which in 2006 the announcement to buy 4 nuclear reactors from Westinghouse-Toshiba. This chapter assesses the recent U.S.-India nuclear energy deal as a TOA case study in the context of climate change. Just like the biomass-TOA should address impacts on biodiversity and land-use change, assessing a nuclear deal will have to take into account the consequences for the Nuclear Non-Proliferation Treaty (NPT)[45], to which the United States is a signatory, and nuclear proliferation concerns in general.

Scope of the US-India nuclear deal

The exact contents of the U.S.-India nuclear deal as announced by President George W. Bush and Prime Minister Manmohan Singh in July 2005, and agreed in detail in March 2006, are not public.

[44] Credits for this section go to Bob van der Zwaan (ECN).
[45] For the full text of the treaty, see http://www.un.org/events/npt2005/npttreaty.html.

What is clear that it would imply a major change in U.S. non-proliferation and export control laws and policies that until today have prohibited full nuclear cooperation with India. Since India exploded an atomic bomb in 1974, thereby violating U.S. and international efforts to prevent the spread of nuclear weapons, the U.S. has barred civil nuclear energy cooperation and trade with India. The U.S.-India nuclear deal would end these nuclear trade restrictions, and thereby allow a broader strategic and economic relationship between the U.S. and India, while the latter is informally accepted as a 'responsible possessor' of nuclear weapons. In exchange for this recognition, India ought to assume the practices related hereto, such as distinguishing its military nuclear facilities from civilian ones and putting all civilian nuclear plants under International Atomic Energy Agency (IAEA) safeguards (see e.g. Perkovich, 2005). After a process of collaboration between the U.S. Congress and administration to address some of the deal's major nuclear proliferation concerns, and correspondingly the introduction of some adaptations, the deal has now been approved by Congress (Levi and Ferguson, 2006). The resulting agreement still needs to be formally accepted by the Indian authorities, and is currently politically very controversial, before it can go into force. Furthermore, it needs approval from the Nuclear Suppliers Group (NSG), the international cartel of 45 countries that controls most global trade in nuclear technologies. The U.S. President has stated that his administration would work with its allies to adjust the relevant international nuclear regimes, notably that of the NSG, to enable nuclear reactor and fuel sales to India (Ganguly and Mistry, 2006).

Emission reduction potential

In the foreseeable future, coal is expected to provide most of India's electricity. For various reasons nuclear energy would probably become among the prime climate-friendly substitutes for the conventional use of coal for power production, rather than e.g. hydropower, renewables, or natural gas (Chikkatur, 2005). There is considerable uncertainty regarding the new nuclear capacity likely to be realized under the U.S.-India nuclear deal, but the significance of new nuclear build in terms of CO_2 emissions savings is likely to be large. For example, the construction by the U.S. of two 1 GWe reactors under the U.S.-India agreement achieves a reduction of about 15 $MtCO_2$ per year (under the assumption that a coal-based power plant emits approximately 7.5 $MtCO_2$/yr, and that India would not build those reactors without the deal). When all reactors built under the deal by either foreign or domestic constructors are taken into account, one may reach much higher figures. Accounting for India's track record of installing nuclear power plants, as well as the difficulties that are likely to arise when India shifts to a truly commercial nuclear power program, analysts claim that new nuclear capacity could be in the range of 10-20 GWe by 2020 (Victor, 2006). Such studies don't take into account the lengthy licensing procedures that characterize the Indian electricity sector, and that could lead to delays once the political clout and the resulting momentum have declined. Prime Minister Manmohan Singh has suggested that the U.S.-India nuclear deal could have even larger implications, perhaps the installation of up to 40 GWe nuclear power capacity over this time frame. Figure 8.5 depicts the expected annual CO_2 emissions reduction as function of the total capacity of newly installed nuclear power plants.

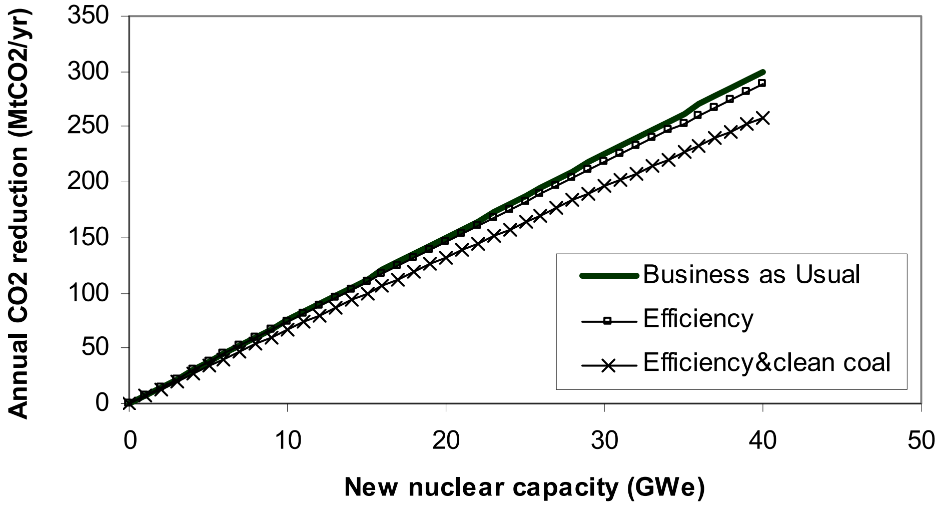


Figure 8.5 CO_2 reduction potential (in $MtCO_2/yr$) of new nuclear capacity (in GWe) in India (after Victor, 2006). Central case and two different baseline assumptions[46]

Emission reduction costs

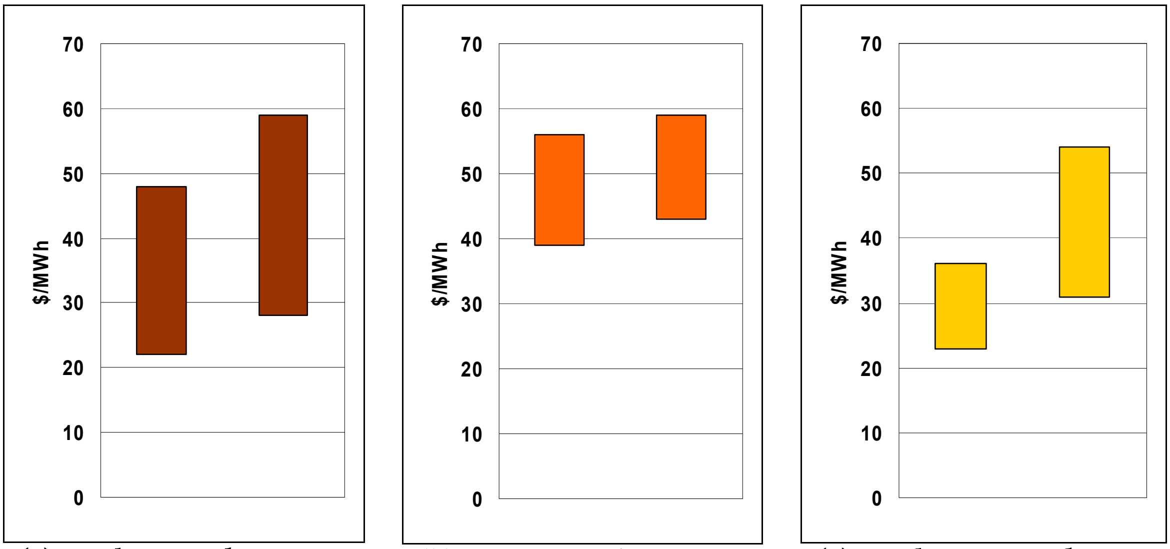
The construction of a new nuclear power plant requires large upfront investment costs. When in a liberalised power sector a limited planning role is reserved for government, it is often difficult to ascertain low costs of capital, which constitutes an impediment for the acquisition of the funds required for construction. Typically, capital requirements per unit of capacity are two times higher for nuclear power plants than for coal plants and three times higher than for natural gas based power plants. In order to render the difference in capital requirements between nuclear and fossil-based power production capacity surmountable, a significant role of government by creating the right investment environment seems essential. In the case of India, the power sector is not fully liberalized. State Electricity Boards control the electricity supply of the various states. Although capital is generally more difficult to get by in developing countries than in OECD countries, the state-controlled character of the Indian electricity sector may actually be conducive to nuclear electricity.

In terms of levelised production costs, nuclear energy is able to compete well with its two main counterparts in the electricity sector, coal and natural gas based power generation, basically as a result of the low fuel cost component. Figure 8.6 depicts the range of total levelised electricity production costs for coal, natural gas, and Generation-II[47] nuclear power plants, for two different discount rates. The electricity costs presented in Figure 8.6 cover all investment, fuel, and operation & maintenance costs over the entire lifetime (of typically 40 years) of the power plant (including costs associated with waste disposal and reactor decommissioning), do not include CO_2 emission prices or potentially other external environmental costs, do not account for possible power plant lifetime extensions, and account for modest fossil fuel price increases with respect to the prices for oil and natural gas prior to their high rise in 2005. For all three alternatives a dependency exists on especially where and under what operating conditions the electricity has been produced. The cost ranges indicated by the bars in the three charts of Figure 8.6 mostly reflect different domestic circumstances in OECD countries. On the basis of the data presented in this figure one can conclude that there are in principle no costs involved with the reduction of CO_2 emissions per unit of gener-

[46] N.B. The two other baseline assumptions correspond to, n * 0.1% efficiency gain of coal power plants for n installed GWe nuclear power plants, respectively, this efficiency gain plus a 1 GWe coal power plant equipped with CCS (at 100%) for every 10 GWe of installed nuclear power plants).

[47] Commercial nuclear power reactors, developed and built in the years 1965 – 1995, such as Pressurised or Boiling Water Reactors or Advanced gas-cooled reactors. Future generations include Generation IV, which involves inherently safe reactors and might be deployed from 2030 onwards.

ated electricity through the use of nuclear power. It may be assumed that power generation costs in India fall within the broad ranges as depicted in this figure.



(a) Coal: 5% and 10% (b) Gas: 5% and 10% (c) Nuclear: 5% and 10%

Figure 8.6 Range of total levelised electricity generation costs (in US$/MWh) for (a) coal, (b) natural gas, and (c) (generation-II) nuclear power plants for two discount rates (left bar 5%, and right bar 10%). Source: Zwaan (2008); data from OECD (2005b)

Political feasibility of the nuclear-TOA, including proliferation issues

While nuclear agreements are unlikely to be of a type 2 TOA (no common research funds are built for new reactor development), they probably are of a type 1 TOA (since through e.g. the Generation-IV (see footnote 8) program R&D is coordinated between different member states). If under formal government agreement advanced nuclear reactors are exported from the EU to e.g. China or India, then the agreement involved would clearly be of a type 3 TOA. On the other hand, since nuclear power plants involve negligible GHG emissions, they would intrinsically not be of a type 4 TOA (there are no standards to be set - standards could, on the contrary, apply to e.g. reactor operation safety and waste disposal, but these do not fall under climate change based TOAs).

The main political feasibility issue around the U.S.-India nuclear deal is around proliferation. The TOA does not only fundamentally transform the relationship between the two countries, but represents a challenge to the international nuclear disarmament and non-proliferation regime, as it could motivate other countries to proceed in their attempts to produce sensitive nuclear material and acquire nuclear weapons in the hope of eventually being recognized as a 'responsible possessor' of nuclear weapons. Whether with or without this deal, India would most likely proceed with the production of weapon-grade fissile material. It has been pointed out, however, that the U.S.-India nuclear deal would allow India to potentially accelerate the build-up of its stockpile of nuclear weapons materials (Mian et al., 2006). India's production of weapon grade plutonium is currently constrained by the competing demands of India's nuclear power reactors for its limited domestic supply of natural uranium. If India could import fuel for its civilian nuclear reactors, it could use more domestic uranium for the production of nuclear weapons materials.

India has not made definite commitments on whether reactors that are built in the future will be opened for inspection under IAEA safeguards agreements. India could decide to use these new reactors for nuclear weapons production and correspondingly exempt them from international inspections. Nor did India make promises to end its production of nuclear weapons material, whereas the five official nuclear weapons states have de facto stopped producing such material.

Positive aspects of the U.S.-India deal are that India agreed in principle to bring its civil nuclear plants – 14 of its total number of 22 nuclear facilities – under international safeguards as performed by the IAEA, to adhere to international guidelines on nuclear and missile export controls as prescribed by the NSG, to maintain a moratorium on nuclear testing (as long as other states do so too), and to support talks on proposals for a Fissile Material Cut-off Treaty (FMCT).

Table 8.2 summarises the constraints on this nuclear TOA.

Table 8.2 Actor-specific constraints of the nuclear TOA

Constraints	*Actor*	
	India	*United States*
Economic	Potential capital constraints to build the reactors	US industry is likely to benefit from the bill as a new export market is opened
Physical/technical		
Legal/contractual		The US is a signatory to the NPT, with which this deal is inconsistent.
Social/equity	Parliament is asking questions about the deal.	Concerns with US NGOs on consequences for international nuclear disarmament
Institutional	It's unclear whether bureaucratic licensing procedures in India pose challenges to the full implementation of the deal.	

In terms of resources, no large sums of money are involved in the deal. Only the investments that might take place as a result of the agreement could become considerable, but that is more of an enhancing factor than a constraint. The timing of the agreement seems to be conducive as the Indian electricity demand is growing rapidly (IEA, 2004), and US industry is deprived of an internal market for nuclear plants as a result of hampering domestic progress in that field, and uncertainties about nuclear waste management. As the deal does not have a final date, the time frame is not relevant. The leverage factor works positive on both sides as long as political consequences of violating the NPT are not considered.

Like perhaps with other cases of TOAs, there is the issue whether 'the deal' is made with a role for government, or whether it is struck solely between industrial partners. In the latter case the deal may not be seen as a TOA as referred to in this report. In the former case, however, it would qualify as an example of a TOA.

This section only aimed to describe some of the aspects of the recent deal between the U.S. and India. Other countries are imaginable as well, if concerns about NPT violation can be taken away. China has much potential for nuclear power plant construction. The question, however, is to what extent the U.S. and/or Chinese governments would be involved in such a deal[48]. In addition, not only deals between developing and developed countries are imaginable (as the above examples), but also between developed and developed (e.g. between the U.S., EU, Japan, Russia; within the EU recently between e.g. France and Finland), and even between developing countries (e.g. between South Africa and China). Accounting for all possible deals, the total emission reduction potential could in principle run in units of $GtCO_2$. An open question for this and other cases is whether plants will be sold under normal (liberalised) market conditions or whether special deals are struck or discounts applied. Varying assumptions on these imply different reduction cost estimates.

[48] The author's estimate is that it would probably not be made based on a purely industry-industry interaction, as at various levels governments would intervene.

8.3.3 Cement industry[49]

World production of cement in 2004 was 2.2 billion tonnes, resulting in 1.9 $GtCO_2$ emissions, or 5.5% of global CO_2 emissions (Price and Worrell, 2006). Cement production increased over 50% since 1990 or approximately 3% per year. This increase almost exclusively comes from developing countries, as the production in industrialised countries is more or less stable. China currently accounts for 44% of world cement production. It is projected China's share in world cement production maintains this level until 2020 and then slowly decreases (IEA, 2004). By 2030, around 50% of the world's cement production is projected to be in China and India alone (WBCSD, 2009).

Approximately 50% of cement CO_2 emissions are process-related: in the calcining process $CaCO_3$ is decomposed into CaO and CO_2. The other emissions are from fuel combustion in the clinker production process, where the different mineral components of clinker are formed at 1500 °C. The dominant fuel in most countries is coal or lignite, with significant shares of oil and gas in some countries. Different waste sources are also increasingly used, as the high temperatures in the kiln decompose most substances. In addition, in the production process large amounts of electricity are used (in raw meal grinding, rotating kiln, and finish grinding).

Scope of the technology

This TOA is applicable to the cement manufacturers. CO_2 emissions per tonne of cement produced can be reduced by application of a range of technologies:

- Efficient kiln types: state-of-the-art dry kilns with new suspension pre-heaters and pre-calciner make more efficient use of the kiln heat and use significantly less energy than other types of kilns. These are standard technology for new plants in Japan, but much less used in China (Tanaka, 2006). However in China the smaller-scale vertical shaft kilns are the preferred technology for the lion's share of production.
- Further waste heat utilisation to generate electricity (co-generation)
- More efficient use of electricity by improved grinding and cooling devices. This would however result only in reduced CO_2 emissions from power production.
- Alternative fuels: biomass 'waste' or fossil waste. However, no technology adjustments are needed, as all wastes can be burned in the standard kiln, except for maybe additional end-of-pipe measures to abate air pollutants.
- Blended cement: replacement of clinker with alternative minerals such as fly ash and blast furnace slag. No technological adjustments in the production process are needed, only infrastructure for sourcing, and perhaps market barriers such as acceptability. Note that in unblended cement 5% gypsum is used, and therefore 95% clinker content is the maximum.
- CO_2 capture and storage (CCS). CO_2 concentration in flue gas is relatively high, compared to coal-fired power plants, therefore post-combustion capture may be cheaper (but typical emissions per kiln may be lower). Retrofitting existing cement plants is possible, but some issues need to be looked into (e.g. impurities in flue gas, heat requirement for solvent regeneration. Oxy-fuel combustion may also have advantages, but impact on kiln design and calcination process needs to be assessed (Davidson, 2006).

[49] Credits for this section go to Stefan Bakker (ECN).

Contents of the cement-TOA[50]

The kiln technology options and CCS are the most applicable options for the TOA. The co-generation and electricity efficiency technology can be included if the reduction in power emissions is properly accounted for. Alternative fuel use is more difficult to include as it depends only on local conditions of waste sourcing. Blended cements also do not require a certain technology but may be included by agreeing on blending targets and cooperation on removal of market barriers and sourcing.

Efficient kilns are commercially applied in many countries, therefore TOA type 3 (technology transfer) or 4 (technology mandates, standards, incentive agreements) would be preferred. Blended cements and alternative fuels can also be included in this type as there as no technological barriers. CCS however has not been applied in cement plants yet and is still in the research phase, therefore Type-2 appears to be more applicable. Assumed timeline is 2013-2020. An alternative could be to extend the timeline (e.g. to 2030) and include CCS after 2020 in a Type 4 TOA.

Components of the cement agreement would be:

- Three large-scale demonstration plants with CCS in Annex-I countries (Japan, US and EU) before 2020;
- Technology mandates (state-of-the-art kiln) for new large-scale plants (e.g. >0.1 Mt cement/yr) in all participating countries;
- Technology transfer, including shared learning etc., and financial assistance, e.g. from Japan to China and from US/EU to India, to achieve these targets;
- Targets for low-clinker cements (i.e. blended cement), e.g. 75% clinker content average across 8 years for Annex-I and 85% for non-Annex-I;
- Option for emissions trading: non-Annex-I countries exceeding their target can sell credits to Annex-I countries that are short of their target;
- Targets for alternative fuel use.

In principle all countries can be included. The most relevant are listed in table 8.3 with important characteristics.

Table 8.3 Approximate cement production data of important world regions

	% of world cement production in 2004	Emission factor (tCO_2/t cement)	Share efficient kilns (dry and new dry)
US & Canada	5	0.95	65
EU	6	0.62	60[a]
Japan	3	0.66	100
China	44	1.03	44
India	5	0.88	50

Sources: Price and Worrell (2006), WBCSD (2002); Tanaka (2006).
[a]: average of Western Europe and Eastern Europe (Humphreys and Mahasenan, 2002).

Estimated emission reduction of the TOA

Assumed is that 50% of world cement production is included (large-scale plants in China, India, EU, North America).

- Efficient kilns: if roughly 500 Mt/yr capacity (large-scale plants) is added in developing countries from 2013 to 2020, with specific CO_2 emissions 10% lower (estimate) compared to otherwise applied technology, then impact in 2020 can be 50 $MtCO_2$/yr.

[50] The Cement Sustainability Initiative of the WBCSD (2009) proposes a sectoral agreement on cement production, and estimates that around 1$GtCO_2$ can be avoided by 2030, around 60% of which would be in developing Asia.

- Blended cements: from currently 10% (baseline) to 20%, or 5% to 15% in non-Annex-I, 5% of emissions will be saved (across 50% of global emissions of 3 $GtCO_2$), so impact can be 75 $MtCO_2$/yr in 2020.
- Alternative fuels: similar (at 10% increase against baseline)
- If CCS is included, large reductions after 2020 are achievable

The overall potential is in the order of 200 $MtCO_2$/yr. Including CCS after 2020 increases potential significantly (e.g. if 50% of all included capacity uses CCS reduction potential is more than 1 $GtCO_2$/yr). Impacts of the TOA will also be on the removal of non-technical barriers for blended cement and alternative fuels and technological learning for CCS.

Expected costs of the cement-TOA

Costs for blended cement and alternative fuels are very difficult to determined, and cost is likely not the most important factor for its utilisation. Efficient kiln technology is somewhat more expensive compared to other technology, and may be calculated and expressed in $/$tCO_2$. For CCS this can also be calculated (according to Davidson (2006) costs are in the same range as for CCS in power plants).

Political feasibility of a cement-TOA

A technology-based agreement on CO_2 emission from cement production has attractive elements for several important world regions, in both the industrialised and emerging economies. The potential impact on CO_2 emissions ranges from approximately 200 to more than 1000 Mt/yr, depending on the design of the agreement. Other important impacts include technological learning for application of CO_2 capture and storage in cement plants. The economic costs are likely to be relatively modest.

The constraints of a cement-TOA from the perspective of the most relevant actors are outlined in Table 8.4.

Table 8.4 Actor-specific constraints of a cement-TOA

Constraints	*Actor*		
	Japan	*China/India*	*United States*
Economic	Limited financial resources for international support; financing for 1 CCS demonstration plant	Some financing for national use	Limited financial resources for international support; financing for 1 CCS demonstration plant
Physical/technical	Sufficient infrastructure for waste material (fly-ash/slag) and fuel?	Infrastructure for waste fuel may not be sufficient	Sufficient infrastructure for waste material and fuel?
Legal/contractual	In case of CCS CO_2 storage might need to be institutionalised		In case of CCS CO_2 storage might need to be institutionalised; positive vote by senate needed
Social/equity		Are mandatory blending targets acceptable?	Acceptance of blended cements?
Institutional	Interaction with cap-and-trade mechanisms might need to be considered	China and India might consider possible reduction under the CDM	

Potential issues in terms of resources for the TOA include financing for implementation of technologies, technology transfer, including capacity building and knowledge transfer, and resources for demonstration plants. As all TOAs assessed here, there is a potential interaction in the timing of the agreement with potential post-2012 agreements such as a follow-up of the Kyoto Protocol. In terms of leverage points, the global cement industry might support a TOA more than a (sectoral) greenhouse gas emission limit.

8.3.4 A TOA on ammonia production[51]

Because of its many uses, ammonia is one of the most highly-produced inorganic chemicals. The worldwide production in 2004 was 163 million metric tons (ChemWeek, 2000; 2002; 2004). China produced 27.1% of the worldwide production followed by India with 8.4%, the United States with 8.6%. Large producers in the EU are Germany (2.5%), Poland (1.7%) and the Netherlands (1.7%). Most production takes places in large-scale plants. About 80% or more of the ammonia produced is used for fertilizing agricultural crops. Ammonia is also used for the production of plastics, fibers, explosives, and intermediates for dyes and pharmaceuticals. In 1974, the developing countries accounted for 27 % of ammonia capacity. By 1998, their share had increased to 51 %. In these countries, ammonia is used to produce urea for rice growing (IPTS, 2006). Also for the future, basically all new ammonia plants are to be built in developing countries.

Scope of the technology
Ammonia is synthesized from nitrogen and hydrogen by the following reaction:

$$N_2 + 3H_2 \rightarrow 2\ NH_3$$

[51] Credits for this section go to Martin Junginger (NW&S, University of Utrecht).

The best available source of nitrogen is from atmospheric air. The hydrogen required can be produced from various feedstocks but currently it is derived mostly from fossil fuels. Depending on the type of fossil fuel, two different methods are mainly applied to produce the hydrogen for ammonia production: steam reforming or partial oxidation.

As it can be seen from Table 8.5, currently, about 80 % of the ammonia production capacity worldwide is provided by the well-developed steam reforming process. High level process integration, innovative equipment design and improved catalysts are the main characteristics of ammonia plants today.

Table 8.5 Applied processes and feed stocks in the production of ammonia. The third column shows the related share of world capacity (1990) (European Commission data, in IPTS, 2006)

Feedstock	Process	% of world capacity
Natural gas	Steam reforming	77
Naphtha, LPG, refinery gas	Steam reforming	6
Heavy hydrocarbon fractions	Partial oxidation	3
Coke, coal	Partial oxidation	13.5
Water	Water electrolysis	0.5

There has been limited development work of the partial oxidation process in integrated plant concepts. At present, a typical plant is a blend of techniques offered by different licensors assembled by the selected contractor. Specific energy consumption (SEC) varies between about 28 GJ/tonne NH_3 for best available technology (BAT), to about 34 GJ/tonne NH_3 for the industry average, see table 8.6 and Figure 8.7 (Ramirez and Worrell, 2006). The achieved energy consumptions reported in Table 8.6 suggest that, compared to the steam reforming process, there is a potential for improvement of the energy efficiency of partial oxidation processes.

Taking the average SEC of 34 GJ/tonne NH_3, the total specific energy consumption for worldwide ammonia production was about 3.7 EJ in 2004, representing more than 1% of the worlds total final energy consumption (IEA, 2006b), or about the energy demand of the Netherlands.

Table 8.6 Cost differences and total energy demands for ammonia production (European Commission, in IPTS, 2006)

Feedstock	Process	Net primary energy cons. (GJ/t NH_3) (LHV)*	Relative investment
Natural gas	Steam reforming	28[a]	1
Heavy hydrocarbons	Partial oxidation	38	1.5
Coal	Partial oxidation	48	2-3

[a] Best achieved values; * LHV: Lower Heating Value

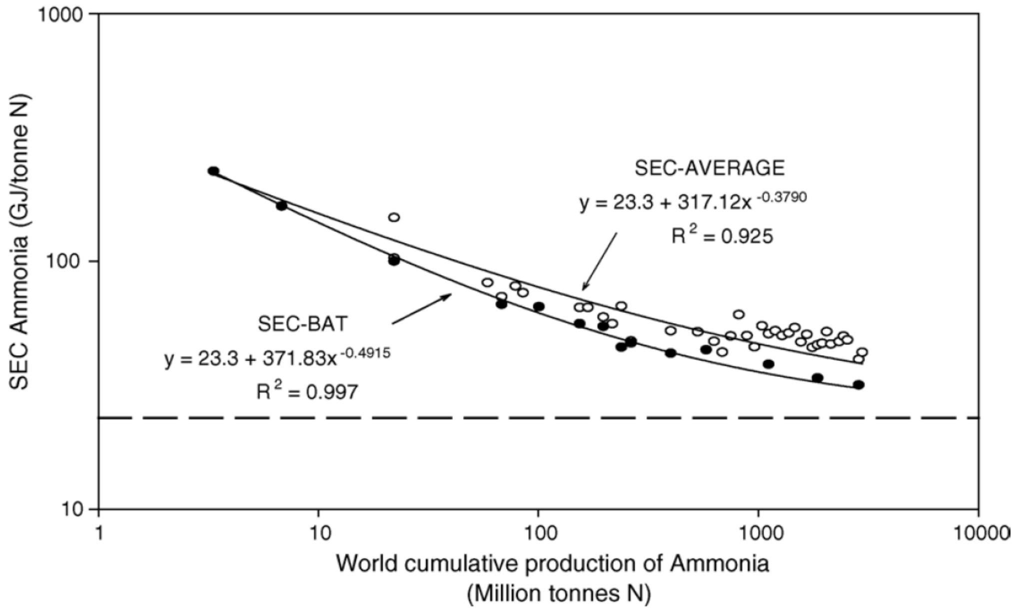


Figure 8.7 Trends in SEC and cumulative production of ammonia, BAT and average technologies from 1913-2001. Data in LHV, expressed per tonne N (Ramirez and Worrell, 2006)

However, there is no clear definition of a best available technology (BAT) plant, as these depend strongly n the chosen plant layout, feedstock etc. To achieve specific energy consumption (SEC) levels of 27.6-31.8 GJ/tNH_3, the BAT is to apply a combination of the following techniques (IPTS, 2006, not exhaustive):

- extended preheating of the hydrocarbon feed
- preheating of combustion air
- installation of a second generation gas turbine
- modifications of the furnace burners to assure an adequate distribution of gas turbine exhaust over the burners
- rearrangement of the convection coils and addition of additional surface
- pre-reforming in combination with a suitable steam saving project
- improved CO_2 removal
- low temperature desulphurisation
- isothermal shift conversion (mainly for new installations)
- use of smaller catalyst particles in ammonia converters
- low pressure ammonia synthesis catalyst
- use of a sulphur resistant catalyst for shift reaction of syngas from partial oxidation
- liquid nitrogen wash for final purification of the synthesis gas
- indirect cooling of the ammonia synthesis reactor
- hydrogen recovery from the purge gas of the ammonia synthesis
- implementation of an advanced process control system
- application of CO_2 capture and storage on pure CO_2 streams.

The European Union's ammonia industry produces approximately 11 million tonnes ammonia per year (2001), from around 50 plants, i.e. approximately 9% of current global production. While no new ammonia plants have been built in the EU after 1991, many of the existing plants have been revamped, and in general, expert knowledge is available on how to built BAT plants (IPTS, 2006).

Most new ammonia production capacity is expected to be built in developing countries, and in China and India. In 2004, three new ammonia plants were opened in 2004: a 0,7 Mt/yr plant in Iran, a 0,68 Mt/yr plant in Qatar, and a 0,2 Mt/yr plant in Turkmenistan. In addition, several companies announced in 2005 capacity increases in Bolivia, Brazil, China, Egypt, Lithuania, Russia, and Trinidad and Tobago that would add about 2.7 million tons of ammonia production capacity (USGS, 2005).

For the future, according to the 2006 world capacity survey of the international fertilizer association (Heffer and Prud'homme, 2006), global ammonia capacity is projected to increase by 35 Mt from 167 Mt in 2006 to 202 $MtNH_3$ in 2010. The annual capacity increase will average 7 $MtNH_3$ between 2006 and 2009. In 2010, an additional 15 Mt is anticipated, assuming all announced projects are completed on schedule. During the period from 2006 to 2010, the global consumption of nitrogen fertilizers is projected to increase at an annual rate of 1.8 per cent, reaching 99.1 Mt N in 2010 (Heffer and Prud'homme, 2006).

In Figure 8.8, the growth of ammonia production in China and India is displayed, while in Figure 8.9, the global ammonia production per world region is presented.

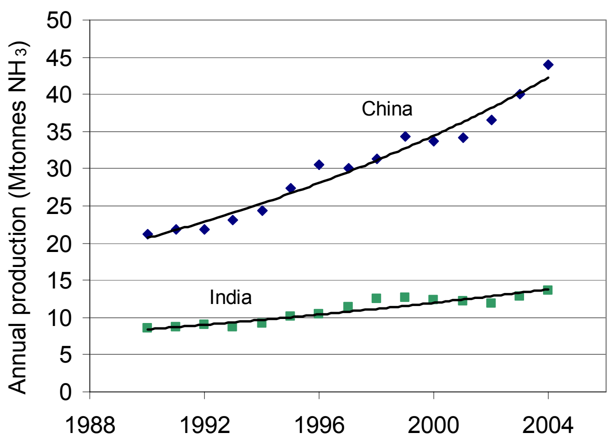


Figure 8.8 Growth of ammonia production in China and India (source data: Kramer, 2004)

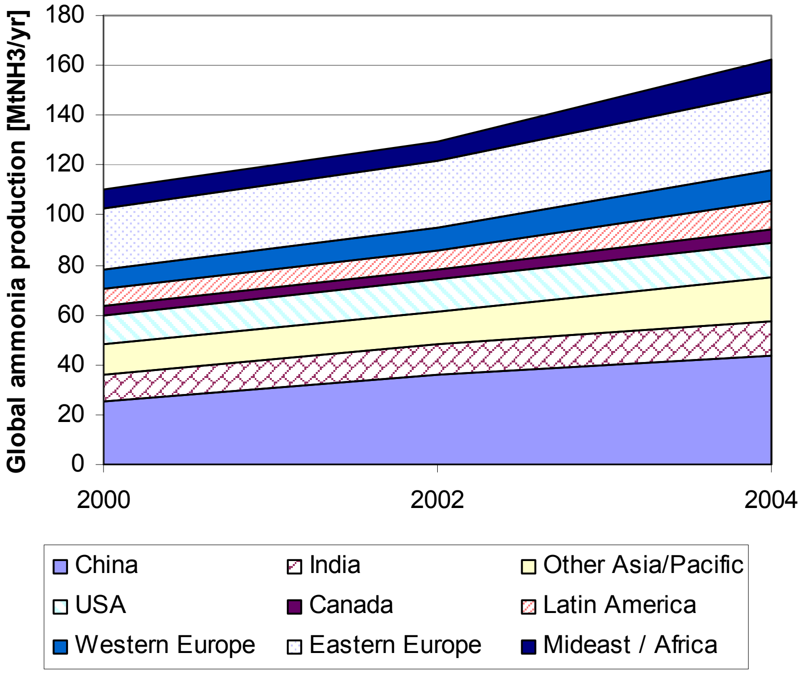


Figure 8.9 Global ammonia production per world region (source data: ChemWeek, 2000; 2002; 2004)

IPTS (2006) argues that most expertise on BAT technology is present in the industrialized countries, while the main further growth in production is expected in developing countries, and especially in China and India. This points at an opportunity for technology transfer and emission reductions.

Proposal for a TOA on ammonia production in China and India

An ammonia- TOA is envisioned between the EU on the one hand, and China and India on the other. The TOA would include that existing capacity is revamped and new capacity is built by BAT standards in these countries (containing elements of TOAs types 3 and 4), technology transfer within the next 5 years and mandate for only BAT plants until 2020. The BAT technology would be provided by EU manufacturers. Possible additional costs could be covered by EU governments in exchange for tradable emission permits. Possibly, the TOA could be carried out under the umbrella of the clean development mechanism (CDM), potentially in a sectoral-CDM context.

Next to the direct benefits of shifting from average to BAT, this would also mean that the BAT experience curve (see Figure 8.7) would be "extended" (i.e. more cumulative production with BAT technologies), which would result in further increases in energy efficiency and CO_2 emission reductions.

Overall reduction potential and expected impact of the TOA

Carbon dioxide is produced in accordance with stoichiometric conversion and can be recovered for further use as feedstock in a urea plant, for use in fertilizer production (ODDA process). The emission of CO_2 per tonne of ammonia cannot be given straightforward, as it depends on the plant layout and the further use of the ammonia. CO_2 can be used as reactant for ethanol production or liquefaction, in the beverage industry or as a coolant gas in nuclear reactors (IPCC, 2005). There is, however, an inevitable excess of CO_2 which is released as an emission from the process (IPTS, 2006). Much of these emissions (possibly around 30 $MtCO_2$/yr (IPCC, 2005)) can be captured and geologically stored at low cost as they are pure CO_2 emissions.

The carbon dioxide production in the steam/air reforming of natural gas is 1.15 – 1.40 kg/kg NH_3, dependent on the degree of air reforming (the figures do not include carbon dioxide in the combustion gases). A CO_2/NH_3 mole ratio of 0.5 (weight ratio 1.29), the stoichiometric ratio for urea production, is obtainable in the heat exchange reformer concepts. In partial oxidation of residual oils, CO_2 production is 2 – 2.6 tCO_2 per tNH_3, dependent on the feedstock C/H ratio.

When taking into account both the use of CO_2 in urea production and emissions from combustion gases and other energy inputs, and using US specific data, a net emission of about 1.82 tonnes CO_2 per tonne of ammonia can be calculated, i.e. as a rough estimate, 300 $MtCO_2$ of global ammonia production. For these 300 $MtCO_2$, China and India currently contribute about 105 $MtCO_2$. By extrapolating the production trends for China and India (see Figure 8.9) to 2020, we estimate that combined production will increase to 120 Mt of ammonia in 2020 (i.e. more than a doubling of annual production). Assuming business as usual (the same ratio of 1.82, i.e. no process improvements, use of CCS technology etc.) this would result in a CO_2 emission of about 220 Mt in 2020.

As shown in Figure 8.7, both the BAT and industry average technology have shown significant improvements in energy efficiency in the last few years. However, compared to the BAT, the industry average consumes still about 30% more energy (about 7 GJ/tonne NH_3). In case a plant changes from average to best available technology, a reduction of about 0.43 tonnes CO_2 / tonne ammonia can be achieved, i.e. about 70 Mt based on current annual ammonia production year. The global energy demand for ammonia production would be reduced by about 20% (0.75 EJ).

Specifically for China and India, the CO_2 reduction potential by revamping all currently existing capacity would be about 30 $MtCO_2$, and, if all new capacity will also be based on BAT technology, total annual reductions in 2020 could be above 50 $MtCO_2$.

Next to this direct emission reduction, the proposed TOA would have other impacts as well. First of all, the BAT technologies necessary to achieve lower CO_2 emissions also bring other benefits, such as lower NO_x emissions, more efficient use of materials (e.g. recycling of catalyst) and reduced emissions to water (IPTS, 2006). Secondly, in the calculations above, we have assumed that the level of the average and BAT technology remains constant, i.e. no technological learning. However, if the projected production scenario for China and India (and the Rest of World (ROW) assumed at 1.8% growth per year), this would lead to 1 cumulative doubling of production (from 3 to 6 $GtNH_3$ per year). Following the experience curve, this would imply that the achievable specific energy consumption of BAT could be lowered approximately by another 1.7 GJ per tNH_3.

Expected costs of the TOA

The costs of revamping existing plants are very difficult to estimate, as they depend to a large extent on the individual plant layout and technology, economic depreciation, technical lifetime of the plant, feedstock used and other factors. For a number of the BAT improvements mentioned earlier, in IPTS (2006) it is stated that cost benefits can be achieved, though only in a few cases payback times of the investment are estimated. Finally, profitability and pay-back time of investments depend strongly on (local) feedstock prices and (international) ammonia prices.

As a general example, the costs of revamping a 20 year old reduced primary reforming ammonia plant (1100 tonnes/day) are estimated at 5.7 M€ corresponding to approximately 17 €/tonne. Such a revamp would result in an energy efficiency improvement from 36 to 31.1 GJ/tNH_3 (IPTS, 2006). According to Vrooman (2004), general ammonia production costs in 2001 were around 100 US$/tonne ammonia (about 100 €/tonne in 2007, taking exchange rates and inflation into account).

For this specific example, in the case that all costs for the revamp are attributed to avoided CO_2 emissions, the costs would hypothetically be 48 €/tCO_2. However, as was discussed above substantial benefits can be gained by the lower fuel requirements, the extended life time of the plant etc. It is likely that revamps are already economical at high fuel prices, as the European experience has shown. Costs of storing the pure CO_2 emissions depend strongly on recompression, transport and geological storage costs, and could be between 10 and 30 US$/t$CO_2$.

Political feasibility of the ammonia-TOA
The feasibility of this TOA is determined by a number of constraints, as summarized in the feasibility matrix. No in-depth analysis has been performed of all possible constraints, so the feasibility matrix is not necessarily complete. The outcome is summarised in Table 8.7.

Table 8.7 Actor-specific constraints of the ammonia-TOA

Constraints	*Actor*	
	China and India	*EU*
Economic		Implementation of BAT technology may be detrimental to competitiveness of EU ammonia industry
Physical/technical	Feedstock changes may be required (e.g. from coal to natural gas)	
Legal/contractual	Legal requirements needed in India /china to comply with BAT level	
Social/equity	If CCS might be applied, there may be public acceptance issues associated with CO_2 storage.	
Institutional		

The potentially high costs of the revamp of ammonia plants may be a problem for all participating parties. In terms of timing and time framing of the TOA, the high current growth of ammonia production in India and China may constitute a window of opportunity. Leverage points may be the co-benefits of applying BAT.

8.3.5 Carbon dioxide capture and storage in the electricity sector

Scope of the technology
CO_2 capture and storage (CCS) comprises the capture of CO_2 from a large CO_2 point source, its subsequent transport, and storage in a geological reservoir. In this TOA, we limit the capture of CO_2 to newly built capacity[52] in the power sector, but it could also be applied to other sectors. Notably, there is much potential in refineries, ammonia production, hydrogen and gas processing. Transport will likely to be done through pipelines, and storage is expected to be done in either depleted gas- or oil fields or in saline formations. It is assumed that storage in coal beds will not be technically feasible in most locations, and that the potential for Enhanced Oil Recovery (EOR) is too limited to make a big economic difference. The costs of CCS are therefore the sum of the capture cost from a (new) gas- or coal-fired power plant, the transport cost and the storage cost. Data from the IPCC Special Report (IPCC, 2005) are used for this.

Contents of the CCS-TOA
The type of TOA that is relevant for the technology at stake depends on the maturity of the technology. When it is still in the research phase and needs to proceed to demonstration, a Type 2 agreement might be best suited. When the technology is technically feasible but still faces eco-

[52] Including replacement.

nomic or institutional barriers, a Type 4 agreement, targeted at overcoming those barriers, might be best suited.

The different components of CCS each have different levels of maturity (see IPCC, 2005). Transport and the storage options that are selected for this TOA are generally regarded as technically mature. In capture, the situation is more complex. Major technological hurdles are not expected, but capture of CO_2 with a full-scale gas- or coal-fired power plant currently remains to be demonstrated. It is expected, however, that by the time this TOA is in operation (2012 – 2020), there will be several large-scale demonstrations of CCS in operation. Also, the instruments considered on the EU and the national level do consist of Type-4 instruments. It is therefore assumed that CCS is mature enough to be included in a Type-4 TOA, meaning a mandate, incentive or standard aimed at CCS deployment should be employed.

The generally cited proposal for a technology-oriented agreement was discussed and explored by Edmonds and Wise (1998). This agreement involves the following:

- Any new fossil fuel electric power capacity in Annex I nations installed after the year 2020 must scrub and dispose of the carbon from its exhaust stream;
- Any new synthetic fuels capacity must capture and dispose of carbon released in the conversion process; and
- Non-Annex I nations that participate must undertake the same obligations that Annex I nations undertake when their per capita income, measured by purchasing power parity equals the average for Annex I nations in 2020.

Edmonds and Wise conclude that it can be environmentally effective (i.e., concentrations can remain below 550 ppm CO_2-eq) but the overall costs will be higher than the costs for an cap-and-trade-based approach. They explicitly consider the protocol as a "backstop" option – an emergency agreement if other, more cost-effective ones, turn out to be difficult to realise politically or institutionally. We may have arrived at the point where this is relevant, as it is projected that a GHG concentration level of 550 ppm CO_2-eq is probably not low enough to prevent serious impacts of climate change, and there is no global follow-up to the Kyoto Protocol in sight.

The TOA is inspired by what Edmonds and Wise propose, but treats a number of issues differently. Firstly, reflecting the higher urgency of emission reductions and the open situation after 2012, the TOA proposes to let the protocol start in 2013 and run until 2020, when it will be renewed and expanded, or replaced by something better. Secondly, the country involvement is different. A smaller group of countries is envisaged, and major emitters that are developing countries also get a mandatory target. However, mechanisms are included to compensate for the costs made by those countries. A graduation mechanism, as in the proposal by Edmonds and Wise, is not envisaged. If new countries report to participate in the protocol, their entry conditions need to be negotiated. Thirdly, because the TOA is restricted to the power sector, synfuel plants are not included (but could be covered in a different protocol).

The elements of the "Low-Emission Power" protocol are the following:

1. Annex I countries involved commit to enact domestic legislation that requires all new and replacement fossil-fuel-based power capacity, as well as all fossil-fuel-based capacity that is older than 35 years, to install CO_2 capture and to store the CO_2. This is most likely done by replacing or repowering the power plant given that the age of the plant would make retrofitting unattractive.
2. Up to 50% of the target for Annex-I countries involved can be done by providing for an equal amount of low-carbon power capacity implementation (renewables or CCS) in the non-Annex-I countries involved[53].

[53] This could be expanded to a CDM-type mechanism where equivalent reductions in GHG or CO_2 emissions could be traded.

3. Involved non-Annex-I countries commit to enact domestic legislation that requires 50% of new and replacement fossil-fuel-based power capacity to capture and store their CO_2, in addition to the capacity that is installed as a consequence of point 2.
4. Annex-I and non-Annex I countries commit to cooperate to facilitate technology transfer by:
5. Establishing a fund to which Annex-I countries contribute and which non-Annex-I countries can apply to for help in realising their commitments under 3[54], and for capacity building and awareness raising programmes. The required contributions are not established in detail here, but should be significant in relation to the aim of the fund;
6. Making provisions to ensure that intellectual property rights for renewable and CCS-related technologies are guaranteed in the involved Annex-I and non-Annex countries alike, but do not form a barrier to implementation of those technologies anywhere;
7. All countries involved enact legislation that arranges for sufficiently permanent storage of the CO_2. This legislation should meet internationally developed and agreed standards for best practice.

In terms of geographical coverage of the agreement, CCS might be relevant for all countries that depend heavily on fossil fuels for their electricity production. However, some countries are more likely candidates for participation in a TOA, for instance those countries with fast-growing and substantial greenhouse gas emissions, ample national fossil fuel resources, growing gas- or coal-fired power capacity, and with much potential for CO_2 storage. For this agreement, the following countries and regions are selected: China, European Union (EU), India, Russia and the United States (USA).

It is assumed that all countries involved have sufficient national CO_2 storage capacity. India appears to be the only country for which this may be problematic as there are no reliable capacity estimates for that country, and initial scans do not reveal a large area of suitable underground.

Emission reduction of the CCS-TOA

The overall reduction potential in the five countries and regions is calculated based on the IEA World Energy Outlook (IEA, 2006b). The scenario projects a significant increase in coal-fired power capacity that has sobered in countries like the United States and also China, so the numbers should be regarded an upper bound. Given some rough assumptions, through the incremental and replacement capacity that is likely to be built in the years 2013 – 2020, the overall emissions of CCS-prone capacity are calculated. What happens without the TOA or any other climate policy in place is outlined in Table 8.8.

[54] This fund is a replica of the Multilateral Fund of the Montreal Protocol.

Table 8.8 Estimation of baseline emissions of new and replacement fossil-fuel-based electricity generation from 2013 to 2020

Country	New capacity 2005-2030[55]	Intra-polation for 2013-2020	Yearly electricity generation[56]	Assumed share in the mix	Assumed emission factor of electricity[57]	Yearly electricity generation	Yearly baseline CO_2 emissions
	GW	GW	TWh		$kgCO_2/kWh$	TWh	$GtCO_2/yr$
COAL							
China	1089	348	1307	80%	0,762	1045	0,80
EU	862	276	1034	40%	0,762	414	0,32
India	330	106	396	80%	0,762	317	0,24
Russia	153	49	184	20%	0,762	37	0,03
USA	750	240	900	60%	0,762	540	0,41
Total			*3821*			*2353*	
GAS							
China	1089	348	1307	10%	0,367	131	0,05
EU	862	276	1034	20%	0,367	207	0,08
India	330	106	396	10%	0,367	40	0,01
Russia	153	49	184	70%	0,367	129	0,05
USA	750	240	900	20%	0,367	180	0,07
Total						*686*	

Given an assumed emission reduction of about 86% for both coal- and gas-fired power plants, the annual technical potential for emission reductions of the CCS protocol is 1.8 $GtCO_2$ over the period 2013-2020, and the cumulative potential is 14 $GtCO_2$.

If the TOA was implemented as outlined above, emissions from newly built coal- and gas-fired power generation would decrease by 86%. The overall emission reduction for the five regions and countries evaluated here would amount to an annual 1.3 $GtCO_2$, with a cumulative result of 10 $GtCO_2$ over the period 2013-2020. The results are in Table 8.9. Because of the wide coverage of the TOA, and the stringent targets, the emission reduction is large, and the CCS-TOA can therefore be qualified as environmentally effective.

There are a number of impacts that have not been taken into account in the calculation in Table 8.9. First, if there is a view at an agreement, there may be a potential perverse effect: before 2012, countries (or companies in countries) may rapidly install fossil-fuel-based power plants to avoid the obligation after 2012. Second, since the agreement involves only a small number of countries for this analysis, leakage to countries not involved in the agreement could happen. Electricity import from countries not involved has not been taken into account.

[55] Reference scenario, IEA (2006c).
[56] Number are halved because of the linear increase in new capacity from 2013 to 2020 (so in 2016 50% of the capacity has been added)
[57] Based on IPCC (2005), table TS3, Pulverised Coal (PC) for coal-fired electricity generation, Natural Gas Combined Cycle (NGCC) for gas-fired.

Table 8.9 Estimated emission reduction for the CCS-TOA

Country	Assumed emission factor of electricity with CCS[58]	%CCS implementation in CCS Protocol	Yearly CO_2 emissions under CCS protocol	Yearly CO_2 emissions reduction	Cumulative CO_2 emission reduction 2013-2020
	$kgCO_2/kWh$		$GtCO_2/yr$	$GtCO_2/yr$	$GtCO_2$
COAL					
China	0,110	50%	0,46	0,34	2,7
EU	0,110	100%	0,05	0,27	2,2
India	0,110	50%	0,14	0,10	0,8
Russia	0,110	100%	0,00	0,02	0,2
USA	0,110	100%	0,06	0,35	2,8
Subtotal				*1,09*	*8,72*
GAS					
China	0,052	50%	0,03	0,02	0,2
EU	0,052	100%	0,01	0,07	0,5
India	0,052	50%	0,01	0,01	0,0
Russia	0,052	100%	0,01	0,04	0,3
USA	0,052	100%	0,01	0,06	0,5
Subtotal				*0,19*	*1,51*
Total				**1,28**	**10,23**

Expected costs of the TOA

Table 8.10 expresses the costs for the CCS-TOA in US$/$tCO_2$. These costs have been established by multiplying the additional investment in CO_2 capture installations per MW installed with the total capacity of power generation with CCS that will be installed under the TOA, based on IPCC (2005). The numbers in IPCC, however, are global numbers, and do not take into account differences in investment costs in countries where material, labour and land may be cheaper. Based on the capital costs of coal-fired power plants in various countries (IAEA, 2000), however, the incremental costs for CO_2 capture are indexed to the unity value of the United States and the European Union (which are assumed to be equal). In that way, different capital costs for China, India and Russia are obtained (0.63 for China, and 0.85 for India and Russia).

It should be noted that the calculation is rather rough and has a large uncertainty for a number of reasons. Firstly, it is based on "best estimate" numbers in the IPCC Special Report of 2005, and does not take into accounting learning effects that may have taken place by the time of the start of the TOA, in 2013. In addition, the mitigation costs are only calculated over the period 2013 – 2020, rather than over the lifetime of the power plant (30 to 40 years). The numbers are also not discounted. Given these simplifications, Table 8.10 probably overestimates the costs.

On the other hand, although the capital costs of CO_2 capture make up the largest share of the costs of CCS, transport and storage costs are not taken into account in Table 8.10, and are likely to add significantly, especially in countries where storage locations are not amply available and large distances may need to be overcome through pipelines.

[58] Based on IPCC (2005); table TS3.

Table 8.10 Rough calculation of the mitigation costs over an 8-year crediting time of the TOA without taking into account cost reductions through learning, transport and storage costs

Country	Yearly additional capital costs	Cumulative additional capital costs	Cumulative CO_2 emission reduction 2013-2020	Average mitigation costs
	Billion US$	Billion US$	$GtCO_2$	US$/$tCO_2$
COAL				
China	9	71	2,7	26
EU	11	88	2,2	41
India	4	29	0,8	35
Russia	1	7	0,2	35
USA	14	115	2,8	41
Total	*39*	*309*		
GAS				
China	1	5	0,2	29
EU	3	24	0,5	46
India	0	2	0,0	38
Russia	2	12	0,3	38
USA	3	21	0,5	46
Total	*8*	*63*		

Political feasibility of the CCS-TOA

In table 8.11, the actor constraints of a CCS-TOA are outlined. It should be born in mind that CCS is a costly technology, and the economic constraints will therefore be substantial. The investment flows that have to be realised to comply with the agreement, both domestically and internationally, are very large. The negative consequences for competitiveness, however, are restrained by the level-playing field that is created by the agreement. Table 8.11 shows the actors and the constraints.

Table 8.11 Actor-specific constraints on a CCS-TOA

Constraints	*Actor*			
	China/India	*EU*	*Russia*	*USA*
Economic	The costs of the TOA are high, but not if compared with the big competitors: USA and EU.	The treaty will have high costs for the EU, but this might be counteracted by first-mover advantage perceptions.	Costs are high, but Russia can use its ample storage capacity to store CO_2 from neighbouring countries and can thus potentially achieve economic benefits.	The treaty will have high costs for the USA, but this might be counteracted by first-mover advantage perceptions.
Physical/ technical	China and particularly India may encounter storage capacity constraints	CO_2 storage capacity is likely to be sufficient over the whole EU, but may be constrained locally. CO_2 storage reservoirs may compete with other underground functions.		
Legal/ contractual		If the EU wants to continue the EU ETS in this period, measures need to be taken to avoid double-counting of the CCS obligation in the case of non-100% auctioning.		
Social/equity	The risks and public acceptance of CCS may become a problem at the scales of implementation.			
Institutional	There is a need for an international set of guidelines for CCS projects, which might be enabled by such a TOA.			

Although in terms of resources, the lower availability of resources in China and India is partially covered by a fund and by technology transfer through a flexible mechanism, and this will compensate for the difference in both financial and technical resources between Annex I and non-Annex I countries, the absolute cost burden on all countries involved is substantial. For timing of the agreement, the planned construction of power plants may be taken into account, as well as a scheme to allow for further development of the technology.

Costs are high for the CCS agreement, but leverage points may be important. The agreement will ensure a level-playing field among the participating countries. Technological development and progress, and export potential, may be a big asset for the countries that have heavier targets. The first-mover advantages will be greater for those countries with stricter targets, which may compensate for the costs. The technology of CCS is one of the few low-carbon technologies that is compatible with the vested interests of the fossil-fuel industries in countries like the US, China and Russia.

8.3.6 Carbon efficiency in cars

Scope of the technology
The technology addressed in this agreement applies to all personal vehicles (petrol and diesel) and includes all measures that reduce CO_2 emissions per km[59]. Some of the measures relate to the engine, but also efficiency gains can be made in transmission, weight, aerodynamics, additions, and tires (IEEP/TNO/CAIR, 2005). Also, because this is not a fuel economy agreement but a CO_2 emission agreement, the fuelling with sustainably grown biofuels or low-carbon hydrogen, as well as the switch to electric vehicles, could be used to reach the target. The adoption of other fuels would depend on the engine and the provisions therein, which the car manufacturers control, but also on the fuels available at the pump and upstream emissions of hydrogen and electric cars. The agreement therefore contains commitments of both car manufacturers and countries.

Contents of the Cars-TOA
The type of TOA that is relevant for the technology at stake depends on the maturity of the technology. When it is still in the research phase and needs to proceed to demonstration, a Type 2 agreement might be best suited. When the technology is technically feasible but still faces economic or institutional barriers, a Type 4 agreement, targeted at overcoming those barriers, might be best suited.

It is clear from a number of studies that the technologies required for the improvement of fuel efficiency in cars are largely mature. The fuel economy of cars in Japan, for instance, is almost a factor 2 better than that of the United States (Sauer, 2005) – as an indication of the emission reduction potential that is there just by bringing the entire world on the level of the current best available technology. It also seems, by comparison of Japanese, European and US programmes, that mandatory standards are more effective than voluntary ones (Kuik, 2006; Dings, 2006). Strict targets lead to higher innovation levels in industry, so even acknowledging that deeper emission reductions would still need research and development, a Type-4 agreement seems most appropriate for an international agreement on fuel efficiency in cars.

The contents of the agreement that we examine might be as follows:
1. All car manufacturing industries agree that their new person cars on average emit less than 80 gCO_2/km in the year 2020[60]. The target is made with non-mandatory intermediate targets of 120 gCO_2/km in 2012 and 100 gCO_2/km in 2016;
2. All countries involved agree that, in addition to point 1, they will provide tax incentives for smaller and more efficient cars, and that they will promote the availability of low-carbon fuels at fuelling stations;
3. If a car manufacturer in a one of the participating countries does not comply with the mandatory provisions, the country's government will apply an appropriate CO_2-tax to each car that exceeds the target for that year. If a car manufacturer doesn't comply with the non-mandatory targets, it is left to the discretion of the government to stimulate the company to stay on track.

Cars are only produced in a small number of countries around the world. Since it is an agreement under the UNFCCC, the discussions should take place between Parties. However, the car manufacturing industry is highly globalised, and there are only a small number (<20) large car manufacturers worldwide. The number of actors to involve in the agreement is therefore small.

For the Cars-TOA, the following countries are relevant:
- China
- European Union

[59] In fact, according to our definition, this is not so much a technology-oriented agreement as an emission standard.
[60] This corresponds to a linear improvement according to the European Automobile Manufacturers Association (ACEA) schedule (120 gCO_2/km in 2012, 100 gCO_2/km in 2016 and 80 gCO_2/km in 2020).

- India
- Japan
- South Korea
- United States

Emission reduction potential of the TOA
The WBCSD (2004) indicates that about 45% of all global energy use in the transport sector originates from cars (or light-duty vehicles). According to the IPCC (2007c), a global 50% increase in energy efficiency in cars could reduce global greenhouse gas emissions by 0.7 to 0.8 $GtCO_2$ in 2030. Others indicate that a 50% energy efficiency increase in new light-duty vehicles would be achievable by 2020.

A simple calculation can shed light on the assumptions and emissions reductions as a result of the Cars-TOA. If we assume, based on data in the IPCC Fourth Assessment Report, the IEA World Energy Outlook data, and incorporating some assumptions on replacement rates of cars, that a reduction of CO_2 emission per passenger-km from current levels to 80 gCO_2/km in 2020 corresponds to a 50% reduction, given that presently, emission levels in the EU-15 are around 160 gCO_2/km. Bear in mind, however, that emission levels in developing countries but notably in the US, are significantly higher, but that they are lower in Japan (Kuik, 2006). Given the weight of the US demand on worldwide car sales, it is likely that the emission reductions are an underestimation of the actual emission reductions.

Table 8.12 Calculation of emission reduction as a result of the Cars-TOA

	2004	*2010*	*2015*	*2020*
CO_2 emission transport sector worldwide ($MtCO_2$)[61]	5289	5900	6543	7111
Share of LDV[62]	45%	46%	47%	48%
Total CO_2 emissions by LDVs worldwide ($MtCO_2$)	2380	2708	3063	3396
Number of LDV (billion)[63]	0,7	0,8	0,9	1,1
Vehicles added to the fleet, plus those replaced	-	-	0,2	0,5
Cumulative emission reduction through 50% efficiency improvement ($MtCO_2$)	-	-	255	695
Resulting worldwide CO_2 emissions from LDVs ($MtCO_2$)	2380	2708	2808	2701

It is clear from Table 8.12 that the Cars-TOA realises a small decline of total emissions in a sector which is normally on the rise, and a significant diversion from the baseline scenario emissions. The treaty can therefore be regarded as environmentally effective.

Expected costs
The costs of this TOA at this point cannot be estimated. The IPCC (2007c) argues that a 50% reduction of carbon emissions from cars can be achieved by 2030 at a cost of less than 100 US$/$tCO_2$. This excludes possibilities of biofuels, which might result in reductions of a similar magnitude, also below 100 US$/$tCO_2$. Costs are therefore significant, but are not exorbitant compared to other options. In addition, because the costs of cars will increase, there might be a decrease in car sales, which would enhance the emission reductions further, and make alternatives such as mass transit more competitive.

61 Numbers are based on the IEA World Energy Outlook 2006 Reference Scenario: page 81.
62 Number in 2004 is based on WBCSD (2004), assuming a 2% per year increase in share.
63 Numbers from IPCC Fourth Assessment Report Final Draft (2007): Figure 5.5.

Costs distribution among the different countries involved will most likely not be equal. Countries with a large portion of their LDVs in heavier classes, notably in the United States, might have difficulties changing the sales to smaller types of cars, and will have to rely on further technological advancements, and make more costs, to reach the targets. On the other hand, costs are not only made on the country level, but will, due to the level-playing field, burden those consumers that have a preference for large cars more. In that sense, the agreement does right to the polluter pays principle.

Apart from the benefits in terms of greenhouse gas emission reductions, there are several co-benefits to this type of agreement. One major benefit in terms of economic effectiveness compared to national regulation (which has been the case so far) is that there will be a global level playing field if all countries participate. Another benefit, particularly in developing countries with increasing urban air pollution problems, is the effect on the emissions of health-damaging air pollution. In terms of energy security of supply, and the conservation of hydrocarbon resources, the agreement would have benefits as efficiency improvements reduce oil use.

Political feasibility of a Cars-TOA

It appears that the carbon efficiency of cars could be improved significantly by implementing an international agreement with a limited number of countries (those that manufacture cars), which is environmentally effective and has a number of co-benefits. The costs are substantial, but mainly fall to those consumers with the most carbon-intensive preferences, and the level-playing field ensures that country's industries are not disadvantaged.

The agreement is flexible in the sense that new countries can enlist easily without extra costs to the car industry. The compliance check could be simple and straightforward, although there are potential barriers in terms of agreement on testing procedures for cars (An, 2006). The likelihood of enforcement is enhanced by keeping the punishment on the domestic level. Although a country can decide not to enforce, this will probably not help its own industry much as the requirements still goes for the other participating countries. The free-riding incentive of the agreement is therefore not very large.

One note should be placed here – the treaty discussed here is not a technology-oriented agreement according to the definition used in this report, as it does not prescribe a technology. It can better be classified as a sector-based carbon efficiency agreement.

The political constraints for a number of actors are addressed in Table 8.13.

Table 8.13 Political constraints for a selection of actors in the Cars-TOA treaty

Constraints	*Actor*		
	EU and Japan	*United States*	*India*
Economic		High costs because of larger reductions	Difficulties in freeing development costs for domestic car industry.
Physical/technical	The treaty is a technology-forcing treaty, which means that there is uncertainty on whether the goals will actually be achieved.		
Legal/contractual			
Social/equity		Employment issues may be at stake	
Institutional	There is a tendency that technology-forcing agreements are later weakened for protectionism reasons. This is most likely to apply to the US. Also, the compliance mechanism is not particularly strong and there are likely to be issues with testing procedures.		

The other factors that have been identified as relevant for the political feasibility of agreements are resources, time frame and timing, and leverage points. The resources that companies will have to spend in case they will need to make profound adjustments to the cars they produce will likely be substantial. The time frame allows for sufficient time to implement the agreement, and seems appropriate given the literature around this issue. In terms of leverage points, the co-benefits for consumers and ample possibilities for first-mover advantages is hopefully driving both car manufacturers and countries towards an ambitious solution.

8.4 Conclusion on the proposed TOAs

Table 8.14 summarises environmental effectiveness, costs and political feasibility in a qualitative way. The environmental effectiveness (i.e. the emissions reduction the agreement is to achieve) depends on the type of agreement. If the agreement is certain to lead to emission reductions (because inherent in the agreement), the environmental effectiveness is described as "guaranteed". However, if the agreement only aims to take away political or legal barriers to deployment of the technology, the environmental effectiveness cannot be guaranteed. The emission scope of the agreement is also assessed here; as the ammonia agreement only covers a small amount of greenhouse gas emissions, its effect is small, whereas the scope of a CCS agreement is much larger, and its effect is large.

Cost burden is partly dependent on the scope of the emission reductions, especially if they cannot be achieved at low or negative mitigation costs. Sometimes, such as in the case of bioethanol, the costs depend on domestic policies (biofuels obligation in EU) or on oil and gas commodity prices. Although the cost effectiveness is not comparatively assessed in this report, and cost effectiveness of TOAs is almost certainly significantly lower than the cost effectiveness of a global cap-and-trade agreement, the likelihood that emissions reductions are complied with in areas where they are relatively cheap are estimated to be higher in the case that a TOA is agreed on them.

The outcome of the political feasibility assessment is also summarised in the below scheme, where in most cases it is a diffuse balance between positive and negative aspects.

Table 8.14 overview of political feasibility of the hypothetical TOAs

	Environmental effectiveness	Cost burden	Political feasibility
Bioethanol	Large and guaranteed	Medium	High, although concerns on social/equity constraints should be taken into account
Nuclear energy	Potentially large but not guaranteed	Small	High as agreement is in place; low if NPT problems is considered
Cement	Large and guaranteed	Small	High because of low cost burden; low for large number of actors
Ammonia	Small but guaranteed	Small	High
CCS	Large and guaranteed	Large	Low because of cost burden, may be medium because of positive technology perception and high for good compatibility with vested interests in fossil-fuel sector
Cars	Large and guaranteed	Large	High because of small number of actors; low as technology forcing agreement meet resistance

The study concludes that a number of TOAs could be explored and might be politically feasible as well as environmentally effective in the context of the factor-constraint framework used here.

Costs can be high, and can pose barriers to implementation. In addition, various TOAs would have social and legal consequences that need to be addressed. In reality, other considerations will play a role. For instance, developing countries have resisted the use of sectoral approaches based on moral and sovereignty arguments. Many developing countries reject the notion of taking on any obligation whatsoever based on principles of equity and per-capita emissions, which are very low for a major emerging economy like India.

Appendix: Data relevant to bioethanol TOA

Table 8.15 Sugar Cane production in 2004 in SADC and selected other countries (from Johnson and Matsika, 2006)*

	Area harvested	total production	average yield	Shares of total production	
	1000 ha	*1000 tc***	*tc/ha*	*share of SADC total*	*share of world total*
Angola	10	360	38	0,8%	
Congo DR	43	1786	42	3,9%	
Madagascar	69	2460	36	5,4%	
Malawi	20	2100	105	4,6%	
Mauritius	72	5199	73	11,4%	
Mozambique	30	400	13	0,9%	
South Africa	326	20419	63	44,8%	1,5%
Swaziland	48	4500	93	9,9%	
Tanzania	17	2000	118	4,4%	
Zambia	17	1800	106	4,0%	
Zimbabwe	45	4533	101	10,0%	
SADC total	**696**	**45557**	**65**		**3,4%**
Australia	448	36995	83		2,7%
Brazil	5371	396012	74		29,1%
India	4608	281600	61		20,7%
Thailand	1139	74259	65		5,5%
World	**20822**	**1359120**	**65**		
Sources: FAOSTAT 2005					

*SADC: Southern Africa Development Community (SADC)
** tc: tonne cane

Table 8.16 Land Use summary for SADC countries and other selected countries (from Johnson and Matsika, 2006)

Country/ Region	*Total Land Area*	*Forest Area*		*Agricultural Areas (a)*		*Cultivated Area (b)*	
UNITS:	***Million ha***	***Million ha***	***share of total land area***	***Million ha***	***share of total land area***	***Million ha***	***share of total land area***
Angola	124,7	69,8	56%	57,6	46%	3,6	2,9%
Botswana	56,7	12,4	22%	26,0	46%	0,4	0,7%
Congo	226,7	135,2	60%	22,8	10%	7,8	3,4%
Lesotho	3,0			2,3	77%	0,3	11,0%
Madagascar	58,2	11,7	20%	27,6	47%	3,6	6,1%
Malawi	9,4	2,6	27%	4,4	47%	2,6	27,5%
Mauritius	0,2			0,1	56%	0,1	52,2%
Mozambique	78,4	30,6	39%	48,6	62%	4,6	5,8%
Namibia	82,3	8,0	10%	38,8	47%	0,8	1,0%
South Africa	121,4	8,9	7%	99,6	82%	15,7	12,9%
Swaziland	1,7			1,4	81%	0,2	11,2%
Tanzania	88,4	38,8	44%	48,1	54%	5,1	5,8%
Zambia	74,3	31,2	42%	35,3	47%	5,3	7,1%
Zimbabwe	38,7	19,0	49%	20,6	53%	3,4	8,7%
Total SADC	**964,1**	**368,3**	**38%**	**433,2**	**45%**	**53,4**	**5,5%**
Brazil	845,9	543,9	64%	263,6	31%	66,6	7,9%
China	932,7	163,5	18%	554,9	59%	154,9	16,6%
India	297,3	64,1	22%	180,8	61%	169,7	57,1%
United States	915,9	226,0	25%	409,3	45%	175,5	19,2%

Sources: FAOSTAT 2005; World Resources Institute 2005

Note: (a) Agricultural areas include temporary and permanent pastures, permanent crops, and temporary crops. The figures do not provide any indication of the suitability or availability of the land for particular purposes.

Note: (b) Cultivated areas includes permanent crops and temporary crops

Chapter 9 Technology in the climate regime: fatal fragmentation or enhanced cooperation?[64]

9.1 Introduction

Chapter 8 has discussed political feasibility and environmental effectiveness of several hypothetical TOAs separately. To address the whole of the climate regime, we examine the institutional options for co-existence in this chapter. We will discuss three variants of cap-and-trade regimes, and two hypothetical examples of TOAs. We distinguish between four levels of integration of TOAs and cap-and-trade regimes. These four levels range from no integration ('Separate'), to full institutional, organizational and operational integration ('Joined'). In-between these extreme levels of integration is a level of partial (operational) integration ('Linked') (see Section 9.2.3).

Apart from the organization and embedding of the treaty, there are different ways of co-existence of agreements. We make a distinction as to whether the TOA and cap-and-trade agreements are *instrumentally* or *geographically* additional. With instrumentally (or sectorally) additional we mean that the TOA is applied in the country where also a cap-and-trade agreement is implemented. This thesis will not focus on that case, but it has been addressed in the report on which this chapter is based (Coninck et al., 2007), taking a game-theoretic approach.

The analysis in this qualitative game-theory exercise is based on the fact that coalitions have to be profitable, stable and credible in order to survive. To address a global public good problem, which notoriously suffers from free-riding problems, the issue area could be linked with another issue area that has a different benefit profile. Issue linkage has first been suggested as a strategy in international economic and military negotiations (Tollison and Willett, 1979; Sebenius, 1983). Cesar and Zeeuw (1996) have demonstrated that it can also be applied to international environmental agreements. For climate change, issue linkage is most commonly used to solve the public-good related free-rider effects by linking membership of the for some parties unprofitable climate change agreement to membership of a profitable club-good coalition. This club good coalition could be a TOA. Some analysis has already been done linking research-related TOAs to cap-and-trade agreements (Buchner et al., 2002), but the result was that the threat to not agree to a TOA if another country does not agree to the cap-and-trade agreement is not credible. It all depends, however, on whether the different countries can see through other country's strategies – game theory based on the Nash equilibrium principally assumes perfect information and foresight with all participants in the game. In reality, participants in negotiations do not know the profitability of the agreements for themselves and for other participants, and although game-theoretic analysis can provide a useful framework for analysis, it is not a realistic representation of the actual situation.

Geographically additional agreements represent the case that country A pursues a TOA whereas country B pursues a cap-and-trade agreement, as well as the TOA. This will be examined based on institutional analysis, where the consequences of various modes of co-existence will be assessed based on the effectiveness and functioning of the institutions (Section 9.3). A conclusion is in Section 9.4.

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9.2 Approach and starting points

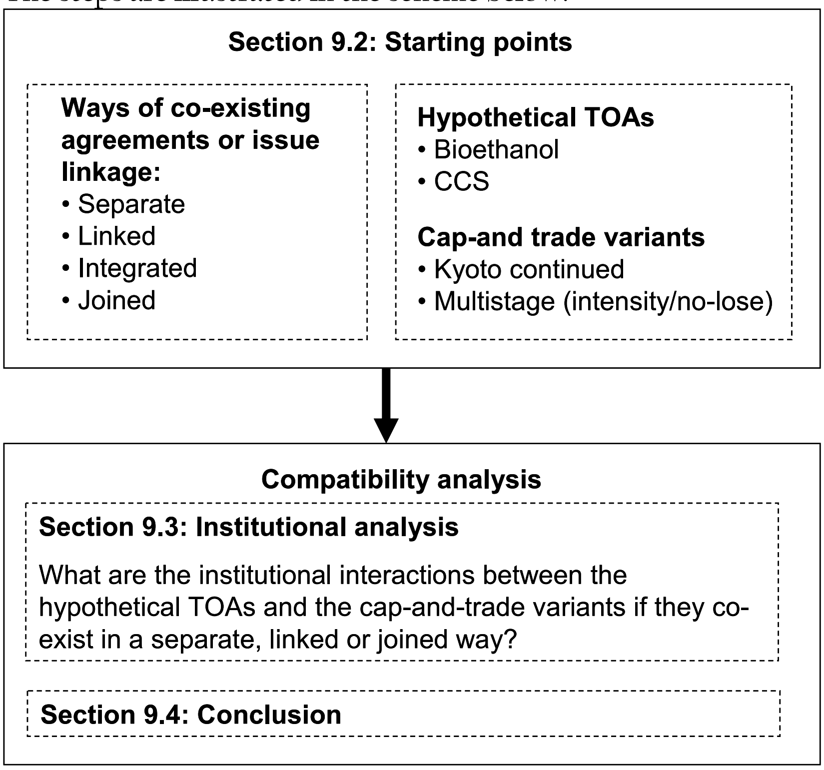
9.2.1 Methodology: subsequent steps taken in the analysis

We established that the compatibility of various approaches for international climate policy has several aspects: the approaches can co-exist in the same or in different countries, and the extent of linkage can vary greatly. In order to shed light on the interactions, we have identified a number of concrete cap-and-trade and TOA approaches (see sections below).

For each of the possible combinations of these approaches, we will discuss the formation of the agreement in the different contexts, as well as the institutional consequences of co-existence. The coming about of a treaty is examined through game-theory analysis, and the co-existence through analysis of institutional interaction.
This chapter will go through the following steps:

- Identification of cap-and-trade agreements and hypothetical TOAs
- Explanation of ways of co-existence
- An institutional issue linkage discussion, the consequences of having the different TOAs and the various cap-and-trade approaches in different countries will be discussed in the case that they are completely separate, institutionally linked, or institutionally joined.
  - In the separate case, interactions only take place because the mere existence of the one treaty influences the outcome of the other.
  - In the linked case, institutional challenges for linking are addressed.
  - In the joined case, the treaties would have to be negotiated in parallel, and there is interaction between the two in terms of the negotiated outcome.
- The discussion will be framed in the context of advantages and disadvantages of fragmentation in the international institution area, and in the context of political feasibility of Parties under different conditions.
- Lastly, the mere situation of more regimes on one issue area might have consequences, and these will be discussed in a conclusion, based on literature on fragmentation, and linked to the earlier outcomes on separate, linked or joined regimes.

The steps are illustrated in the scheme below.



9.2.2 Description of the technology and cap and trade agreements

For the cap-and-trade agreements we selected three different approaches: a 'Kyoto-continued', where the Annex I countries and the treaty design remain the same, and only deeper targets are agreed; and two multi-stage approaches with an intermediate stage for emerging economies that is either an intensity target or a no-lose target.

Chapter 8 outlined six potential technology-oriented agreements and evaluated them for costs, environmental effectiveness and political feasibility. The TOAs were agreements on ammonia production, bioethanol from sugarcane, carbon efficiency in cars, the cement industry, CO_2 capture and storage (CCS) in the power sector, and nuclear energy. From these TOAs, we selected the bioethanol and CCS cases. Before going into the compatibility of the agreements, this section will describe the proposals based on their most important characteristics.

The agreements will be described in general terms, and not in terms of quantitative targets, although we would like to emphasise that the legal nature of both the cap-and-trade and the technology-oriented agreements is assumed to be binding. The TOAs can therefore be regarded as 'technology-pull' rather than 'technology-push' agreements. Because in that sense they serve the same purpose as a cap-and-trade agreement (which also aims to provide a technology-pull), the activities in the TOA could in one way or another be credited in a similar way as the cap-and-trade efforts.

The reasons for not going into the details regarding quantitative targets in the cap-and-trade variants here are twofold. First, we would like to steer clear of the discussions around the exact percentage of emissions reductions required to comply with the UNFCCC, i.e., "to prevent dangerous anthropogenic interference with the climate system", and the allocation of allowable emissions to countries. We will however assume that the agreements lead to reductions of emissions relative to the baseline, and therefore that the reductions come at some cost (economic cost or investments into realising no-regret options). Second, as we will assess the interactions between the agreements in a qualitative way and no single TOA has the potential to fully meet the assumed cap on its own, the outcome will not change fundamentally if the emission reductions or technology implementation levels are small or large; the result depends on whether there is implementation taking place.

Cap and trade: Kyoto-continued

The 'Kyoto-continued' agreement is included as a representation of a continuation of the mindset that let to the current state of affairs around Kyoto. Although times have changed since 1997, and doubts can be expressed around whether a treaty like Kyoto would be achieved again, we assume that there is a possibility that the current situation will continue. Kyoto-continued represents no divergence from the design of the Kyoto Protocol, and assumes essentially the same ratifying countries in Annex B and the same rules for international emissions trading and CDM. The only difference with the current Kyoto Protocol is that the emission targets will be stricter, and the commitment period will be stretched to 2013-2020. The Kyoto-continued agreement is likely to offer the same benefits and difficulties as the present Kyoto Protocol. Although doubts can be cast on whether the same countries that have currently ratified the Kyoto Protocol will also ratify its successor, and the same countries that have not participated so far will not, we will assume for this case that this is the case.

Cap and trade: Multi-stage with intensity or no-lose targets

The multi-stage variant of a post-2012 regime is extensively described in various publications (Berk and Elzen, 2001). Recognising the unlikelihood that emerging economies will participate in a system with fixed and binding caps, a Kyoto-type of agreement is proposed with more differentiation. In addition to the two stages that Kyoto has, i.e. fixed caps for Annex-B countries, and voluntary participation through the CDM for non-Annex-B countries, the multi-stage approach is extended with an intermediate category. This intermediate category might be linked to the targets of the original Annex-B countries through emissions trading.

In this variant of the multi-stage approach, the intermediate stage would comprise intensity targets (in terms of CO_2 emission per GDP or unit of product) that show some diversion from the baseline (which already includes an endogenous reduction of energy use per GDP). The reason why emerging economies, with rapid economic growth, are thought to be more inclined to agree to intensity targets than to an absolute emission reduction target is that an intensity target is more amenable to uncertainty on future economic growth – and related changes in emissions. It remains to be seen if emerging economies, such as China, India, Brazil and South Africa, are willing to agree to such an agreement. Some countries have indicated that they might sign up to such an agreement, whereas others have not shown any interest. It is also uncertain whether the commitment of a country like China to comply with intensity targets is enough to make the United States agree to an absolute target. However, for the sake of this analysis, we assume full participation.

In the second variant of multi-stage agreements, the intermediate level receives a no-lose target (or non-binding target, or 'emission budget'). Each country signing up to a no-lose target negotiates a target (allowed amount of emissions, or assigned amount), very likely above current emission level and probably close to a baseline scenario of emissions. If it emits more than the target, it will not be punished. If it emits less, it can sell the credits on the international market; i.e. to Annex-B countries (Philibert, 2000).

The no-lose targets don't punish economic growth, which is important, but it is likely that the establishment of the target scenario is a very difficult and highly politicised action. The permits generated by the no-lose system can be easily integrated with the international carbon market, although there might be concerns that the additionality check for CDM projects is currently more easily implemented and stronger than the check for an economy-wide target such as in the case of no-lose targets. For example, 'windfall' emission reductions in some sectors could compensate for rising emissions in other sectors. In the case of the CDM, these would not be credited; in the case of no-lose targets, they would. Also here, we assume that all countries agree to the conditions of this agreement and that broad participation is achieved.

TOA: Sugarcane-based bioethanol in Africa
The first TOA that will be assessed for compatibility with cap-and-trade-based systems is an agreement between Brazil, the European Union and countries in the Southern African Development Community (SADC). The aim of the TOA is to utilize the Brazilian knowledge and the European biofuels targets and finance to set up a sugarcane-based bioethanol industry in SADC countries in order to supply Europe with sustainable biofuels. The time horizon for this TOA will be 2020.

Brazil will be the knowledge-supplying party. The knowledge transfer will include both expertise on the agricultural system (e.g. cane varieties for various soil types, pest control, use of vinasse as fertilizer) and on the industrial ethanol production system (technical assistance on building large-scale ethanol plants, infrastructure, etc.). The SADC will be the technology-receiving countries. As part of the TOA, Brazil and the SADC will sign a Memorandum of Understanding (MoU), in which they stipulate the intention to build up an ethanol industry. As third party, the European Union (EU) will act as financing party of projects. In return, supply contracts are signed for the ethanol production to be exported to Europe to meet targets for biofuels and GHG emission reductions, possibly coupled with a fixed price (or a price range with minimum and maximum boundaries depending on the oil price developments). The commitment by the EU could be expanded by the introduction of flex-cars on its market: cars that can use both ethanol and gasoline.

Even without carbon crediting in the EU, the TOA may be economically feasible at high oil prices because it provides the EU with guaranteed and affordable biofuels, which is good for energy security of supply, the African countries with a new source of income and Brazil with a market for the technology with which they have unique, decades-long experience. The SADC countries might also use part of the biofuels for own consumption, which would lead to emission reductions in African countries rather than in the EU. It is therefore essentially a win-win agreement which would only require minimal coordination. Drawbacks, however, include environmental and social consequences of large-scale sugarcane cultivation in Africa.

TOA: CO_2 capture and storage in large users of coal
A TOA on CCS might be relevant for all countries that depend heavily on fossil fuels for their electricity production. However, we have identified a small number of countries with fast-growing and substantial greenhouse gas emissions, ample national fossil fuel resources, growing gas- or coal-fired power capacity, and with much potential for CO_2 storage as the most likely candidates: China, the European Union, India, Russia and the United States. Other possible countries are thinkable, but we will restrict the analysis to these. The elements of the CCS agreement are explained in Chapter 8.

It is assumed that all countries involved have sufficient national CO_2 storage capacity. India appears to be the only country for which this may be problematic as there are no reliable capacity estimates for that country, and initial scans do not reveal a large area of suitable underground.

Incentives for participation are absent if there is no urgency for emissions reductions at all. However, what might convince some countries is that there are difficult targets for China as well as for the EU and the US, which would improve the level-playing field, and hence compliance. The US and the EU may perceive the enormous market for all aspects of CCS technology as an opportunity for technology export, e.g. of gasifiers, CO_2-separating membranes, and underground management services.

9.2.3 Ways of co-existence

It is our contention that under any future climate regime the current system of cap and trade will continue to form the foundation of the regime's architecture. We also believe that TOAs could in some capacity be part of that framework, either by supplementing cap-and-trade efforts in countries, or by having an environmentally effective policy in countries that have not signed up to the cap-and-trade agreement. The question then arises at what level and in what form TOAs could possibly co-exist with cap-and-trade. Could they fit, both institutionally and economically, within the framework of a regime such as the Kyoto Protocol? Or would they work better outside of the regime? Using Kyoto as our frame of reference we have identified four potential scenarios of co-existence for TOAs: Separate, Linked, and Joined.

Separate
As the name suggests in this scenario the cap and trade (CAT) regime and the TOA would operate in parallel and have no institutional or economic linkages. There would be separate unrelated secretariats and separate unrelated accountancy and reporting schemes. The only potential for overlap would be that countries might opt to be signatories to both the CAT and the TOA. Current examples of this can be seen in the relationship between the Kyoto Protocol and the Asia-Pacific partnership.

Linked
The Linked scenario can be characterized by two separate agreements operating under two separate institutional regimes (a TOA regime and a CAT regime) with two different reporting and ac-

counting schemes for emission reduction credits. The links between the CAT and TOA could exist in two forms. The first is that all projects or actions under one of the institutions, for example the TOA, would receive emission reduction credits under the CAT but not vice-versa. In the current Kyoto design, this is automatically the case for Annex-I countries but could also be made the case for non-Annex I countries through the CDM. The second form it could take is that only a certain number or type of projects under either the TOA or CAT would be mutually recognized and receive corresponding emission reduction credits. These would have to be agreed upon between the two institutions.

There is also a third way of establishing linkages between the regimes: in terms of fulfilment of capacity building, technology transfer, awareness raising and other means of achieving the 'softer' targets often included in cap-and-trade agreements, including the Kyoto Protocol. However, without denying the relevance of these activities, we do not regard this in this research as it is not central to emission reductions.

Joined

Under the 'Joined' scenario the TOA would be an integral part of a larger climate agreement that combines CAT elements. One could envisage a regime that has quantified and binding emission reduction targets and that the instruments to reach those targets would be a combination of the current 'flexible mechanisms' as well as the employment and/or transfer of agreed technologies. Institutionally then the TOA would not be an agreement as such but rather an article in a convention or a protocol and overseen by either an executive board or supervisory committee administered by the convention's secretariat, much the way JI and CDM are handled under the UNFCCC. The institutional oversight of TOAs in this form would serve to certify that technology 'implemented' was meeting its set goal. Economically, the specific parties undertaking the initiative would manage the TOA.

9.3 An institutional compatibility assessment of technology agreements and cap-and-trade approaches

A game-theoretic perspective on the co-existence of TOAs and cap-and-trade regimes primarily addresses the reasons why a country might be persuaded into agreeing to a cap-and-trade regime through issue linkage with technology. It therefore primarily examines shifting interests of various parties in the climate negotiations, in an instrumentally additional context; i.e., for a country to participate in the TOA, it has to participate in the cap-and-trade agreement as well (Coninck et al., 2007).

This chapter takes the notably different view of geographically additional agreements. It assumes that the treaties have already been agreed and discusses, for different ways of co-existence, how the TOAs and cap-and-trade agreements interact, and, contrary to game-theoretic approaches, doesn't speculate on the process of agreeing on the treaty.

The theoretical framework of the study is the situation of fragmented international regimes, and applies the insights resulting from that literature to the climate regime. First, therefore, the chapter provides a review of the existing, theoretical literature on the co-existence of international institutions. Secondly, it asks the question: what happens to the institutions involved if different countries sign up to cap-and-trade agreements and TOAs? How would such a landscape affect the entire climate regime?

9.3.1 Fragmented regimes for climate change

There is an ongoing academic debate on the consequences of the increasing density of organizations in the international institutional playing field. There seems agreement in the literature that this increasing density leads to fragmentation of the regime complex, in the sense that there is more overlap and specialization of international treaties, and less international coordination. There is, however, by no means a definite answer as to whether such large variety of partially overlapping treaties would decrease the effectiveness of reaching solutions. Whether centralization or fragmentation leads to a better outcome depends on the perspective taken; i.e. an international lawyer will look at the issue differently than a political economist. It also depends on the specifics of the issue area. Where for economic trade issues, a fragmented regime may be adequate, for a more fundamental issue such as human rights, a centralized regime may be regarded as more appropriate (Tahvanainen, 2004).

It is regularly argued for fragmentation that a plurality of regimes results in healthy competition for influence, resulting in the most effective means to reach a target (Charney, 1996). It is also seen as a logical symptom; an "institutional expression of political pluralism internationally" (Koskenniemi and Leino, 2002). Any problems caused by such plurality of international regimes, such as isolation and lack of coordination, would supposedly be solved by the increasing number of networks that impact the regimes and that would solve problems of coordination (Raustiala, 2002).

In response to these rather optimistic earlier publications, however, a number of political theorists started pointing at weaknesses in fragmented regimes. It started with highlighting a methodological problem: Keohane and Nye (2001) elaborate on the increasing difficulty of contemplating and studying single international organizations, as they should be seen in an increasingly important and complex context. Raustiala and Victor (2004) coined the term 'regime complex' as a substitute for an international organisation. They use the example of the various treaties impacting on plant genetic resources as an example of how changing insights in an issue area result in a dynamic regime complex with a host of different rules and a lack of legal consistency. This conveniently leaves room for all nations involved to interpret the rules as they like it, but it doesn't provide a consistent backdrop for a common solution. Benvenisti and Downs (2007), finally, even go beyond this and argue that fragmentation is detrimental for the interests of small states, and is even used by powerful states as a strategy to further their own goals at the expense of weaker others. Such purposeful use of fragmentation as a power-enforcing strategy, they argue, makes it resistant to reform by consistency-enhancing features such as networks, and moreover obscure implementation of treaties and reduce accountability.

In the light of the above, the move of the United States to found the Asia-Pacific Partnership on Clean Development and Climate (APP), as well as a number of one-issue technology-oriented agreements, could be interpreted as a deliberate strategy to pull Parties out of the Kyoto Protocol and even the UNFCCC context into a more attractive, because less 'deep' agreement. This inference is confirmed by some observers (Asselt, 2007). However, it is also clear that the APP falls short of providing a credible solution for the climate change problem and the reduction of greenhouse gas emissions.

A requirement of the TOAs we will discuss further on in this chapter is therefore that they should be environmentally effective (or: having a significant global impact on GHG emissions), which, we established in Chapter 8, is the case for the CCS and Bioethanol TOAs. This in itself reduces the chance that the TOAs are used as token agreements to divert attention from the cap-and-trade regimes, but it doesn't rule out the possibility that other negative impacts of the emergence of a climate regime complex manifest. This we investigate in the sections below.

9.3.2 Separate

As explained in Section 9.2.3 in the case of separate co-existence of the CAT and the TOA there are no institutional or economic linkages and the regimes operate in parallel. The main interactions are potential overlap when countries are signatories to both regimes, and a 'technology bias' introduced by the TOA compared to the more market-based approach in the CAT.

For countries that are part of both regimes there will be no possibility to transfer carbon credits generated in one regime to the other. They will have to achieve both their commitments independently. This could be less than optimal from an economic point of view, but prevents difficulties of finding ways to link the schemes (Philibert, 2005). A point of attention should be the long-term view: if it is envisaged that the regimes be linked in the future, it could be useful to stimulate some interaction between the bureaucracies so that GHG accounting and policies may become more easily linked in the future.

In TOA countries also having a CAT target, a technology bias is likely to be introduced by the TOA compared to the CAT-only scenario: higher diffusion of the TOA technology, and lower diffusion of other mitigation technologies, and thus, theoretically, a higher price of emission reductions. Although there is a theoretical possibility that a CAT agreement could push a technology so far to make the TOA on that technology obsolete, normally a TOA for such a technology would not be necessary so such a TOA would not be agreed. Also, if participation of the TOA does not fully overlap, the TOA would still have an effect in the country that has not signed up for the CAT agreement.

A new additionality question also needs to be answered: to what extent are GHG reductions created by TOA technologies implemented still eligible for trading? E.g. can India claim CERs for CCS implemented under the TOA to which it has signed up? This is a similar question as currently in the CDM additionality test, which says that reductions should go beyond current domestic policy in place. The presence of a TOA gives a new international context. In the 'separate' case it is not decided *a priori* that these reductions are non-additional, as it can be argued that there are no interactions between the regimes. If the reductions go beyond what was agreed under the TOA, all countries (under both regimes) should be able to claim carbon credits eligible for trading.

The interactions are for the bioethanol and CCS case are further specified in Table 9.1.

Table 9.1 Institutional interactions in separate TOA and cap-and-trade combinations

Cap-and-trade variants		TOA-variant	
		Bioethanol	CCS
Kyoto-continued		All countries in the TOA are also Kyoto countries. The **EU** will achieve their Kyoto target partly by using bioethanol (technology bias). In the case of own use of the biofuels, **African countries** could produce the biofuels both for export to EU and claim CERs, which introduces the possibility of double-counting (which could be difficult to resolve in the 'separate' case).	All countries except the **US** are covered by both regimes. A technology bias will be created in the **EU and Russia**. Also, demand for carbon credits may decrease as the required reductions are fulfilled through the TOA. The supply potential for CDM in **India and China** may or may not be reduced, depending on the outcome of the additionality debate.
Multi-stage	No-lose	No difference with Kyoto-continued as **Brazil** – with a no-lose target – is only technology supplier.	The **US, EU and Russia** have both an absolute GHG target and a commitment under the TOA which creates a technology bias. Whether signing up to the TOA will have an impact on the stringency of the no-lose target for **India and China** is an issue to be resolved. In one case, they are likely to achieve and go beyond their targets easily due to their TOA commitments, which will result in a larger supply of carbon credits to the international market. Double dipping is not an issue in the no-lose case
	Intensity	Similar to no-lose case	**India and China** are likely to achieve their intensity target with more ease, and will be able sell more carbon credits compared to the CAT-only case, assuming that the targets of the TOA and the CAT are set independently. If not, India and China may accept stricter targets in the CAT if they know they have to comply with the TOA.

9.3.3 Linked

In the case that separate institutions exist for the TOA and the cap-and-trade regime, but decisions on linking or integration of the two regimes are made, the TOA, similarly to the 'separate' case, would still introduce a technology bias in the (supposedly) otherwise perfectly competitive market of the cap-and-trade agreement, in the case that a country engages in both a cap-and-trade regime and a TOA. For the remainder, interactions would take place in the field of availability of technologies. This is a consequence of spill-over effects of technological change in the country implementing the TOA, which, if effective, brings down the costs of technologies needed to comply with the cap-and-trade regime.

For other effects, we first explore how links between the technology regime and the cap-and-trade agreement may look like. The next step is to determine the nature, scope and consequences of the linking or integration specifically for the selected TOAs and cap-and-trade examples, which is done in Table 9.2.

If there is to be a link between the institutionally separate regimes, it would mean that part of the TOA commitment of country can be met through buying credits in another country on the CAT-based carbon market. Conversely, it could mean that part of the commitment undertaken as part of a cap-and-trade agreement can be met through implementation of the TOA.

This might not be straightforward. In both of the cases above, one needs a metric that allows for conversion of the one target into the other. The first metric that comes to mind for this is emission reductions (tonnes CO_2-eq emissions reduced), although this is by no means unproblematic. The advantage is that the metric of cap-and-trade agreements is already stated in terms of tonnes of greenhouse gas emissions, or emission reductions, and that the technologies implemented also lead to reductions in emissions. It gets more problematic if the details are taken into regard. What baseline, for instance, for the emissions would need to be assumed in the country that only signs up for the TOA, and that wants to sell credits on the market of the cap-and-trade country? When can such credits be regarded as additional? And how do we deal with the fact that the bioethanol-TOA regulates supply or production of fuel, whereas the cap-and-trade agreement measures the demand or consumption?

The most likely outcome might be, in the case of the cap-and-trade variants, to treat the TOA obligation as a policy and apply procedures similar to the first, hesitant proposals for 'Policy CDM' as they are now discussed and might be implemented in the context of improving the Clean Development Mechanism (CDM). It could even be decided that the policy baseline would be the sectoral baseline of the country that signed up to the cap-and-trade agreement. In the specific case of the bioethanol-TOA, the reductions of emissions take place in the Annex-I countries, so they are automatically accounted for in their national inventories.

If the country that signed up to the TOA wished to achieve part of its agreement through the purchase of carbon credits from the cap-and-trade system, a similar operation would have to be done, although it could also be argued that the compensation would be one-way. Based on a baseline, the amount of credits required to compensate for the non-implementation of an action under the TOA would be calculated, and non-compliance with the TOA would only be established if the amount of carbon credits is insufficient. Creating a linkage in general means that part of the risk of signing up to a TOA or a cap-and-trade agreement is mitigated through allowing compliance through the other.

Both in the case of the TOA-country buying or selling into the cap-and-trade treaty, and the reverse, the TOA or the cap-and-trade agreement could include a limit to the amount of compliance that can be done outside of the agreement itself. If there is a limit, the agreements are linked. If there is no such limit, they qualify as integrated.

Table 9.2 Institutional interactions in linked/integrated TOA and cap-and-trade combinations

Cap-and-trade variants		TOA-variant	
		Bioethanol from sugarcane	CCS
Kyoto-continued		In this case, all countries in the TOA are also Kyoto countries. A policy-CDM type of arrangement could be agreed between **African and EU countries**, where the African countries would sell any emission reductions by using more biofuels in their own countries, as well as selling biofuels to the EU. The TOA introduces a technology bias in the EU Kyoto-continued-implementation, and possibly also a geographical bias in policy-CDM towards Africa, which can be perceived as correcting the current low representation of Africa. The agreement has no direct consequences for **Brazil**, except potential consequences for Brazil in selling less CERs to the EU.	The countries in the TOA are not all Kyoto-countries; the US is not. The question therefore is how to link with a non-Kyoto party. If **the US** would like to buy credits from, or sell them into the Kyoto-continued agreement, a baseline would have to be established which may be methodologically challenging. To guarantee environmental integrity of the Kyoto-continued agreement, the baseline of the **EU or Russia** could be adopted. A policy-CDM-type of agreement could be agreed between **China and India**, as Kyoto-ratifying countries without a binding target.
Multi-stage	No-lose	**African and EU countries** can trade similarly as in the Kyoto-continued case. The TOA introduces a technology bias in the EU Kyoto-continued-implementation, and possibly also a geographical bias in policy-CDM towards Africa. **Brazil** has a no-lose target under multi-stage but the TOA does not affect that as Brazil is only technology supplier in the TOA, and there are no consequences in its own emissions.	For the **US, Russia and the EU**, the treatment would be the same as in the Kyoto-continued agreement. **India and China** are subjected to a no-lose target, and sales of emission reductions below the no-lose baseline scenario would lead to double-dipping (or: double funding for the same effort) . This can be avoided through taking account of the TOA emission reductions in the no-lose baseline scenario. One could also decide to allow double-dipping to provide an extra incentive to sign up to the TOA and the multi-stage agreement.
	Intensity	Similar to the no-lose variant of multi-stage.	Similar to the no-lose variant of multi-stage. The accounting of carbon credits is likely more complex because of the use of relative (intensity) rather than absolute targets.

Recalling the factors and constraints used to determine the political feasibility of the stand-alone TOAs, the advantages of linked regimes in terms of political feasibility lie primarily in the flexibility regarding timing and number of actors. In terms of timing, the treaty agreed on first would be determining the linking rules laid down in the other treaty. (Would they be negotiated simultaneously, they would count as a 'joined' regime.) The number of actors in the TOA can be kept flexible as well (assuming that the participation of cap-and-trade regimes is broader), which allows for easier negotiations, but possibly also to equity constraints as late entrants would have to play by the rules of the club that initially started the agreement. This was also mentioned as one of the problems of fragmentation (Benvenisti and Downs, 2007).

9.3.4 Joined

It will be recalled that under the Joined scenario the TOA and the CAT are institutionally one and the same, as they form different but integral parts of the larger rubric of the climate agreement. It will also be recalled that countries subscribing to this larger Joined agreement have the option to employ, as with the linked scenario, one or both means of emissions reduction strategies, CAT or TOA. Although this is not necessarily a simple task, for the sake of the argument we will assume here that the problem of the conversion metric encountered in the linked scenario is essentially solved. The issues of targets (either intensity or absolute) and baselines are also predetermined or pre-negotiated as well as the manners in which those targets will be achieved; either through CAT or TOA. This though is also the main political and technical drawback of this Joined scenario.

Whereas with the linked approach, baselines and targets are agreed upon by the parties under the framework of either a TOA or CAT agreement, within the joined scenario a commonly agreed upon set of targets, baselines and deadlines would have to be negotiated before the joined regime could begin. For example the USA would need to agree to a specified baseline and target if it were to participate in the joined agreement.

Table 9.3 Institutional interactions in joined TOA and cap-and-trade combinations

Cap-and-trade variants		TOA-variant	
		Bio ethanol	CCS
Kyoto-continued		As all the countries under this scenario are Kyoto signatories this arrangement affects very little the actions of the countries. The only significant interactions to note is that since the TOA is an integral part of the climate agreement the accounting of carbon credits (if the African countries decide to use the biofuels itself) is made easier if compared to the linked scenario.	In this case, since the US is not a party to Kyoto and has no general baselines or targets but wishes to participate in the joined regime, a baseline and target would need to be negotiated on the amount of CO_2 that could be reduced by the use of the CCS-TOA. The **EU** and **Russia** still have their full range of commitments of which CCS will deliver a portion. The amount agreed upon by the US could be a correlated matrix of that which either the EU or Russia as Annex I parties believe can be achieved through CCS. Any 'extra' reduction stemming from CCS in the US could be 'sold' to third party Annex I countries, via a mechanism similar to JI. Alternatively, if the US were to aid **China** or **India** in implementing CCS through the flexible mechanism in the CCS-TOA, then the US itself could gain credit to be applied to their pre-negotiated emissions reduction target, similar to CDM.
Multi-stage	No-lose	Similar to the linked scenario, **SADC** and the **EU** can trade carbon credits; it is only made easier as the accounting scheme is under one regime.	For the **US**, **Russia** and the **EU** situation is as above. As with the integrated scenario, China and India have no-lose targets of which a portion can be achieved by the use of CCS. In this case however reductions below an agreed no-lose baselines would simply go into the common pot of credits for the Joined agreement, no double dipping could occur, resulting in a standard CDM-type arrangement, if the other sectors to which the no-lose target applies perform according to expectation.
	Intensity	This situation would not vary from the 'No-lose' above.	Again for the US and Annex I countries the situation remains as under KP. For China and India any credits gained by the use of CCS would be attributed to the common accounting scheme under the Joined agreement. The accounting of carbon credits may be more complex because of the use of relative rather than absolute targets.

Politically speaking, the Joined regime might be more feasibly implemented than the Linked regime, regardless of the actual TOA case involved, but assuming that the TOA is a technology-pull agreement (for a R&D agreement, linked or separate agreements are sufficient). One can postulate that the administrative and transaction costs of creating two institutionally separate yet compatible carbon accounting schemes might be prohibitively high thus making such an option unattractive, especially if participation in TOA schemes is low.

Referring back to Chapter 8, the discussion of political feasibility revolves around a discussion of key factors and constraints. What then are some of those factors and constraints associated with the implementation of a Joined regime? The first is that a convincing enough argument is made that TOAs are environmentally effective enough to be fully incorporated into the global climate regime, that their value added would be broadly applicable to a diversity of parties. This we have endeavoured to show by highlighting the technical additionality of TOAs as well as the range of actors that have the potential to participate in them. The second issue has to do with advocacy and timing. If TOAs are a path to pursue, the discussion of them in the post 2012 regime needs to be advocated or lobbied for by a coalition and must be brought to the negotiating table at the earliest opportunity.

It is conceivable that the discussion of TOAs emerges after an initial framework for a new regime is settled. This would in all likelihood lead to either the Separate or Linked scenario as discussed earlier. At present there have been no obvious, broad, policy windows to leverage the issue of a Joined regime. Nevertheless, the time and timing for engaging in such a discussion is opportune. The one main institutional constraint, as stated above, would be the necessity for defined baselines and targets to be associated to particular TOAs, especially for those countries that would still choose not to employ cap and trade mechanisms. Institutionally then there would need to be a strong body within the regime to oversee the accreditation of all potential TOAs. In which case, TOAs could be taking the route of policy-based CDM for CAT-parties without a target, or a means of participating in the same regime for non-CAT parties.

9.4 Conclusion

In this chapter, we discussed the compatibility of TOAs with a number of post-2012 cap-and-trade variants. Apart from the organization and embedding of the treaty, where we have distinguished separate, linked, and joined institutions, as well as different ways of co-existence of agreements. We have made a distinction as to whether the TOA and cap-and-trade agreements are instrumentally or geographically additional. Instrumentally additional agreements have been discussed elsewhere, and the focus in this chapter has been on TOAs and cap-and-trade variants that are geographically additional.

Geographically additional agreements represent the case that country A pursues a TOA whereas country B pursues a cap-and-trade agreement, as well as the TOA. This was approached based on institutional analysis, where the consequences of various modes of co-existence are assessed based on the effectiveness and functioning of the institutions. The argument for looking into this geographically additional option is that it is uncertain whether all relevant emitters are willing to sign up to a domestic or international emission reduction target.

The following results were found. When the TOAs and cap-and-trade agreements are institutionally completely separate, but there is overlap in participation, the interactions will be limited to 1) technology bias in the realisation of emission reductions under the cap-and-trade agreement, and 2) impacts on baseline setting and CDM additionality for non-Annex I countries in the Kyoto-continued case, and all countries that do not have an absolute target in the multi-stage case. When the TOAs and cap-and-trade agreements are linked or joined, there are will be challenges in agreeing on a metric for conversion of the achievements under the TOA into the achievements under the cap-and-trade variant. These challenges are likely to be greater in the case of the bio-ethanol-TOA compared to the CCS-TOA, as the implications of the bio=ethanol-TOA are on the demand-side and are inherently more uncertain than the CCS-TOA, which directly regulates emissions.

The interactions that have been identified can be readily solved by explicitly relating the cap-and-trade and the TOA, but the effort of making the full 'climate change regime complex' internally consistent with several TOAs, and varying membership, ambition and substance, would be significantly more difficult. In such a situation, the problems of fragmentation and the potential consequences in terms of accountability and increase of power of already powerful states could be severe.

Neither application of game-theory nor the institutional analysis in this chapter allows us to make firm predictions of behaviour of countries and regions with respect to TOAs in combination with cap-and-trade variants. For such predictions, we would need more information on costs and pay-off functions, we would need a deeper understanding of the strategic incentives of some of the options, and we would have to dive deeper into the detailed developments of the various TOAs. Moreover, we would also need to have a better understanding of the institutional challenges and constraints regarding the compatibility question. An additional challenge is understanding the role of the private sector. Technologies are often not owned by states (although states often represent the interests of their private sectors), leading to a different dynamic, including complicated IPR issues, than would be the case if states would be the proprietor of the technology. Although some scholars are looking into this problem of "multi-level decision-making", this has not yet resulted in usable recommendations for international agreements that have a bearing on company competitiveness.

What we can conclude, however, is that there can be conditions, in the case that the design of the TOA introduces a beneficial reciprocity in the cap-and-trade regime, the combination of both types of agreements can lead to a better environmental outcome than only a cap-and-trade treaty would through wider participation and a dual emission target and technology diffusion target, notwithstanding the less cost-effective outcome.

This potentially positive result should be weighted, however, against the possibility of regime fragmentation and the threat that might entail to consistency and accountability of the international institutions. Responsible linking, although potentially costly in terms of administration and transaction costs, would be essential to safeguard that adding TOAs to the climate change regime would constitute a credible solution.

Chapter 10 Conclusion: Technology rules?

This thesis addresses the general research question: Can technology-oriented agreements provide greater reciprocity and thus improve the effectiveness of the international regime for climate change mitigation? The research brought together in this thesis suggests that specific technology-oriented agreements indeed provide greater reciprocity, although for a robust conclusion data currently do not suffice. After starting with an overview of recent developments in the international political field is, this concluding chapter discusses the outcomes of this thesis following the research questions in Chapter 1.

10.1 Current international climate politics

While the various chapters of this thesis were written, developments around climate change have moved rapidly. In some sense, the question addressed is a moving target; as research emerges, negotiations proceed in certain directions, new issues arise, and country positions change as a consequence of economic and political developments. As the ideas in this thesis took shape over the course of 2006, technology-oriented agreements and even sectoral agreements played no significant role in the climate negotiations. After the flood of critiques immediately following the Kyoto Protocol agreement in 1997 (e.g., Cooper, 1998; Ott, 1998; Victor, 2001), the attention turned to implementation, such as through the Marrakesh Accords of 2001 and the Joint Implementation mechanism. When the Kyoto Protocol entered into force, the greatest interest was in whether its signatories would comply, how the carbon market both in the CDM and the European Union Emissions Trading Scheme would develop, and how the private sector would respond to the carbon price (Grubb and Neuhoff, 2006; Michaelowa and Jotzo, 2005). Although various scholars continued model calculations around long-term commitments, costs, regional impacts, and burden sharing (e.g., Elzen and Meinshausen, 2006), proposals for post-2012 policy options continued to be generated (Bodansky, 2004) and widening the impact of the Clean Development Mechanism received much attention (e.g., Samaniego and Figueres, 2002), the political process leading to a post-2012 treaty had come to a stand-still.

The situation completely changed in only one or two years. Three main publications seem to have contributed most to this: The 2006 Stern Review, Al Gore's 2006 “An Inconvenient Truth”, and the IPCC Fourth Assessment Report, published in 2007, followed by a Nobel Peace Prize for Gore and the IPCC at the end of 2007. It also became clear that emissions have been rising faster than expected until 2007, particularly because of China's rapid development, and are surpassing some of the highest estimates of the IPCC in its Emission Scenarios report (Raupach et al., 2007), although the rate of emission growth has been moderated in the past year due to economic fluctuations. In addition, results for the Kyoto Protocol impacts became available; for various reasons, it had a discernable but insufficient impact on global emissions (IPCC, 2007a; Prins and Rayner, 2007). Consequently, the sense of urgency rose to unprecedented levels, and literature on post-2012 climate agreements became less academic and more inspired by reality.

In thinking on post-2012 climate policy, one major thing changed: the single focus on emission reductions by industrialised countries that had such a prominent role in the Kyoto Protocol has disappeared. A myriad of possibilities for post-2012 architectures emerged, and mitigation through emission reduction, building on the Kyoto Protocol elements, was not the only concern anymore. Adaptation had been on the political agenda for a long time, but got a boost when the Conference of Parties met in Kenya in December 2006, with attention focussed on least-developed countries needs (Mueller, 2006). Sectoral agreements, both voluntary industry initiatives and binding agreements, have been reviewed by several institutes, scholars and governments (e.g., Schmidt et al., 2006; Baron and Reinaud, 2007). Technology innovation and diffusion also became one the issues under exploration. Discussions on the role of technology in climate policy started emerging (Grubb, 2004; Sugiyama and Sinton, 2005; Aldy and Stavins, 2008), focussing primarily on incorporating a technology innovation component alongside a cap-and-trade or emission-reduction agreement. This diversity of directions for international climate policy was reflected in the Bali Action Plan, which features four negotiation tracks: mitigation, adaptation, technology and finance (UNFCCC, 2007). The technology track in the Bali Action Plan clearly opens up possibilities for incorporating technology innovation and diffusion in a future climate treaty.

The thinking on the role of technology in the climate regime also seems to have changed. Increasingly, technology policy is seen as a goal in itself, rather than a policy support to correct specific carbon market failures and reduce transaction costs of (a cap-and-trade-based) climate policy. This change in thinking was provoked by mostly US researchers, claiming that commercialisation of a number of promising technologies is needed (Hoffert et al., 2002) and that currently available technologies can reduce emissions substantially (Pacala and Socolow, 2004). The modified role of technology in the climate debate is also demonstrated by the way the Expert Group on Technology Transfer (EGTT) under the UNFCCC now approaches the issue. In their proposals, as well as proposals for technology transfer/climate funds and the like by developing-country Parties, the innovation, adoption and diffusion of technology has become a distinct objective. A telling example is the G77 and China submission for a "Technology Mechanism under the UNFCCC" (UNFCCC, 2008a). This proposal talks exclusively about technology, and proposes a diverse menu of policy options including aspects of enabling environments and reducing barriers, such as addressing intellectual property rights and capacity building, and "meeting incremental costs" – i.e. funding the difference in costs between conventional and low-carbon technology – of mature low-carbon technologies, such as wind energy and CO_2 capture and storage (CCS).

Not only in emerging economies can a rising interest in innovation and diffusion of technology be observed. In industrialised countries, industry and technology policies have existed for decades, but climate policymaking has shifted towards market-based instruments since the Kyoto Protocol was agreed. There is now a growing recognition that clean industry and low-carbon technology policies provide opportunities for expanding markets and innovation. This recognition is confirmed by market data: investments in renewable energy have almost doubled between 2005 and 2007 (REN21, 2008), innovative car companies producing cleaner and more efficient cars have been commercially successful (OICA, 2008), the solar energy export industry in China and Taiwan has grown rapidly, and wind turbine manufacturing in Germany and Denmark has continued to prosper (Dorn, 2007). Numerous private-sector initiatives have sprung up, and billionaire philanthropists such as Richard Branson have attracted media attention by making available funds for "winning" technologies. A coalition of banks, industry and policymakers with a keen interest in low-carbon technology, fortified by recession- and financial-crisis induced stimulus packages could lift low-carbon technologies to a next level (HSBC, 2009).

United States domestic politics have also changed considerably. There have been calls in influential journals for technological leadership and strong domestic pushes for technology to address climate change and help the competitive position of US industry (Bales and Duke, 2008), contrary to earlier papers that defended the US climate policy scepticism. Where scholars used to argue that US involvement will be extremely difficult due to the two-thirds majority required in the US Senate for the ratification of international treaties (Bang et al., 2005; Ueno, 2007), Purvis (2008) argues that the option of congressional–executive agreements, which require a simple majority in Congress and a presidential consent only might be legally feasible. In addition, the mood of Congress is changing towards allowing for domestic climate policy. Barack Obama, after his inauguration as 44th President of the United States, has signalled both a willingness to address climate change multilaterally and has sought to use the financial crisis aid package to make significant domestic investments in low-carbon technologies. The American Clean Energy and Security Act contains a greenhouse gas reduction target, for the first time in American history, and a number of technology-oriented provisions.

10.2 Can technology-oriented agreements provide greater reciprocity and thus improve the effectiveness of the international regime for climate change mitigation?

Climate change is a global collective action problem. Providing a stable climate is a public good and no country can solve the problem by itself. This calls for international cooperation in interventions to provide the public good. In addition, the climate change problem structure is characterised by deep distributional imbalance: The vulnerability to climate change impacts is highest in countries which do not hold responsibility for the problem, while the cost of addressing the problem is highest in those countries which are least affected by it. This structure leads to the central barrier that this thesis addresses: a specific agreement to reduce emissions is not in the interest of those countries that should most urgently reduce their emissions. What treaty design and which mechanisms for compliance should be chosen in such a situation?

The problem would be ease to solve if it were a symmetric coordination problem, for which cost-benefit analyses, such as Stern (2006), show that it pays to coordinate solving the problem. For separate countries, however, the interest structure is different. A review of international environmental agreements and their problem structures reveals that the mechanism to ensure compliance in asymmetric externality problems is through provisions for either coercion or positive exchange (reward or "transfer") in the design of the international agreement (Mitchell and Keilbach, 2001).

In the case of a "strong victim", coercion is an option (Mitchell and Keilbach, 2001). In the case of a rich victim, the victim can use rewards to provide reciprocity to the perpetrator, usually in the form of side-payments to compensate for the costs of addressing the problem. In the case of climate change, however, the victims are not strong, nor are they rich. Coercion or rewarding between countries are therefore no options. In international environmental agreements, there is no institution that can enforce compliance. The agreement will therefore have to be set up in such a way that it is self-enforcing, i.e., "attractive for countries to want to sign, and want to carry out the terms of agreement" (Barrett, 1994). For climate change, it means that the inherent structure of the agreement provides reciprocity to all signatories, but particularly those that face high costs and low benefits (Barrett; 2003). It has become clear over the past years that although the Kyoto Protocol has been successful on some accounts, its design is not suitable for providing sufficient participation, compliance and technological effectiveness (Aldy et al., 2003; IPCC, 2007c).

One way of providing countries with high mitigation costs with incentives to reduce emissions is to provide them something in return; in other words, to provide reciprocity – a method often applied in international agreements to make their terms acceptable to all involved (Keohane, 1986). Credible reciprocity could provide compensation for those parties with low climate change impacts and high mitigation costs. This should be reciprocity in all directions – every party should perceive reciprocity, whether it is a developed or a developing country. In addition, reciprocity provided by a climate agreement should minimise uncertainty as much as possible, be as specific as possible, and Parties should trust each other. Only in that way, concessions can be valued and compliance can be expected (Larson, 1988).

What might be the reciprocity that could be provided along with mitigation actions? Many mitigation actions inherently imply innovation and diffusion of technology (IPCC, 2007c; IEA, 2008b). Here, technology is broader than installations alone and comprises "know-how, methods, procedures, experience of successes and failures, physical devices and equipment" (Dosi, 1982) to reduce greenhouse gas emissions. The hypothesis of this thesis is that technology can provide reciprocity. Innovation and diffusion of technology are assumed to be institutionally implemented in so-called technology-oriented agreements (TOAs).

The work reported in this thesis suggests that, whether replacing or complementing an emission-reduction agreement, TOAs could provide for reciprocity more than emission reduction agreements in three ways: enhanced innovation, concrete export opportunities and the positive “vibe” associated with technology compared to emission reductions. On the first source of reciprocity, economies that invest in innovation are more competitive in the international arena. Their productivity and the quality of employment are higher than in other countries (OECD, 1997). This concerns all aspects of technology, including human capital and regulatory experience (Lall, 1992). Second, countries that have or expect a strong market position for their industry in the field of the technologies that will be implemented as a result of the agreement are unlikely to free-ride. Recent literature calls for technological leadership with Parties that are unlikely to embark on an emission-reduction agreement (Bales and Duke, 2008), reflecting the conviction that technological leadership and innovation will deliver economic, political and environmental benefits. Last, countries are more likely to sign up to an agreement that makes positive investments in a more sustainable and innovative economy, through making use of the first-mover advantages (developed countries) or through enhanced technology transfer (developing countries) (Bazilian et al., 2008). Many Parties perceive an emission reduction as limiting economic development and growth, whereas technological innovation is considered an opportunity and an essential economic stimulus (HSBC, 2009).

In addition, particularly on the R&D and demonstration side, international collaboration on technology can deliver more cost-effective technology development. For more mature technologies, it can facilitate technology transfer and diffusion. This is demonstrated by existing international TOAs in a variety of environmental topic areas, such as knowledge-sharing agreements on research and development, and technology mandates against marine oil pollution (Coninck et al., 2008a). TOAs could provide benefits for all Parties involved. An agreement on technology development, diffusion and transfer would provide for greater innovation and global markets for countries with an outlook on technological leadership. For Parties with a strong interest in technology transfer, TOAs with technology transfer components could fulfil their needs (UNFCCC, 2008a). Whether from those countries’ point of view the TOA would provide reciprocity depends on the conditions for technology transfer in the agreement as well as the committed funds. The arrangements around intellectual property rights could be a key factor (Ockwell et al., 2008).

Whether on balance TOAs would provide the sufficiently specific “deep reciprocity” that is required to improve the self-enforceability of a climate regime is hard to predict. More detailed studies could help clarifying the real value of TOAs. The general conclusion on reciprocity is that TOAs are likely to introduce a favourable dynamic in any climate regime.

10.3 What design characteristics define technology-oriented agreements?

A characterisation of technology-oriented agreements is introduced in Chapter 5 (Coninck et al., 2008a): “International technology-oriented agreements (TOAs) to address climate change are those international agreements that are aimed at advancing research, development, demonstration, and/or deployment of technologies. With respect to TOAs to address global climate change, these technologies would be aimed specifically at reducing GHG emissions.” TOAs have become part of negotiations language, and are currently mentioned in UNFCCC negotiation documents (e.g., most recently, UNFCCC, 2009). In the technology transfer literature and UNFCCC documents, this class of technologies is most commonly termed environmentally sound technologies (ESTs) or low-carbon technology. Some TOAs have broad participation of the lion’s share of countries around the world, but most existing TOAs engage a selected group of countries, consisting of only industrialised countries, or a combination of industrialised and developing countries.

Four types of TOAs are distinguished, each with their own features and effectiveness in various circumstances. Type-1 TOAs advance technology by sharing and coordinating knowledge between governments, research institutions or industries. Members of a type-1 TOA for instance align research and development programmes, exchange information on the latest research results and new directions, or agree on best practices for regulation of the new technology. This is the "shallowest" type of international technology cooperation and is generally low-cost and useful if information barriers are prevalent for the technology addressed. An example may be reduction of methane emissions, which in various circumstances can be done cost-effectively and only needs lowering of awareness barriers. Generally, however, for ESTs, information is one of many barriers and more than a type-1 TOA would be needed to significantly advance the technology.

Type-2 TOAs focus on research, development and demonstration of technology, and involve some degree of cost-sharing. For instance, if various countries invest in an international research fund, or a collaborative programme to demonstrate large-scale Concentrated Solar Power applications, this would be a type-2 TOA. Type-2 TOAs can help advancing technologies that are not yet commercialised in any market, that is, technical problems have not been fully resolved, they remain to be demonstrated at full scale, or costs could be reduced through further collaborative technology development. In such cases, international coordination can be a cost-effective way to further develop the technology, and particularly get over the "valley of death" around demonstration of large-scale technologies (Murphy and Edwards, 2003). This could be useful, for instance, for getting a technology like CCS through the demonstration phase. Another example is nuclear fusion, of which the technological and economic risks, and demonstration costs, are so high that pooling of resources pays off for the participating countries. ESTs that are technologically mature but remain more expensive than conventional technology, however, would not benefit much from a type-2 TOA (Aldy and Stavins, 2008). For wind energy, for instance, a type-2 TOA will not make any difference – the technology is too advanced and structural implementation is required in order to reduce costs further by learning by doing and economies of scale.

Type-3 TOAs are agreements that explicitly aim for technology transfer and adoption by firms and consumers in developing countries. This type would normally employ elements of the other TOA types, but technology transfer has specific features that require an additional strategy and justify a separate category (see e.g., UNFCCC, 2008b). Elements relevant to technology transfer include knowledge sharing, capacity building, transfer of regulatory experience, as well as demonstration and adjustment of the hardware to the specific social and infrastructural circumstances in the recipient country. In addition, type-3 TOAs could provide for intellectual property rights transfer, modifying technology to fit local circumstances, and creating an enabling environment for the technology. One way of defining and analysing enabling environments for technology is through the Technological Innovation System (TIS) approach (Bergek et al., 2008; Hekkert et al., 2007). Bergek et al.'s approach links "structural components" of the TIS, such as actors, networks and institutions, to "functions", such as market formation and entrepreneurial experimentation, and defines a step-wise approach of specifying key barriers and policy issues. A type-3 agreement could be designed to take account of such functions. Often, technology-transfer agreements are not technology-specific, but include a list of "positive" technologies, such as in the Global Environment Facility which supports a broad range of ESTs. Type-3 agreements may be especially appropriate for technologies that are commercial in industrialised countries but that need an enabling environment or some modification to be appropriate in other countries (Bazilian et al, 2008).

Finally, Type-4 TOAs include standards, mandates or incentives that explicitly aim for deployment or diffusion of an environmentally sound technology. As the cooperation required in such agreements could be rather deep, involving considerable concessions, there are few examples of type-4 international agreements in the history of international technology cooperation. However, the few examples that have been agreed have been rather successful in addressing environmental problems, such as for marine oil pollution. Some of this type of TOAs do not prescribe a technology, but could exclude a technology, such as single-walled oil tankers, or coal-fired power plants without CCS. Such a design would take away some of the concerns of governments picking winner technologies, or using technology standards to promote their own interests (see e.g., Jacobsson and Lauber, 2006; Jho, 2007). Type-4 TOAs are closest to regulatory, command-and-control agreements and can help particularly if the new technology is already technologically mature, can be implemented globally, and is not responding well to market-based incentives because of barriers that still need to be overcome. An example is an agreement in the personal vehicle transport sector, in which a range of mature technologies can be implemented to increase efficiency of personal vehicles and reduce emissions (IPCC, 2007c), firms compete in an international market, market-based mechanisms, particularly the Clean Development Mechanism, have shown ineffective (Wright and Fulton, 2005), and numerous barriers play a role.

The assessment of the characteristics, taxonomy and past performance of TOAs leads to the conclusion that the design of international TOAs should reflect specific technology characteristics and promote those technologies of which an objective assessment has shown that they are required to address climate change and have significant global emission reduction potential. In reality, however, TOAs also have specific problems. First, assessments of future emission reduction potentials will have uncertainties; an "objective" assessment hard to make. Countries that dominate negotiations might be in a position to promote those technologies that are in their specific interest, which could lead to a suboptimal technological or economic outcome in general (Benvenisti and Downs, 2007). Current proposals to address that include technology expert panels analogous to the Montreal Protocol Technological and Economic Assessment Panel (UNFCCC, 2009). Second, although there are examples where parties have agreed on and adhered to a TOA, those involving deep levels of cooperation would have to provide deep levels of reciprocity. As costs of the TOA may be high, while benefits are uncertain, this is a significant concession of countries that has not been tested for climate change.

The question remains what TOAs would look like in practice if they were designed specifically to be deep and climate-focused. Chapter 8 presents six hypothetical designs of TOAs for different technologies with participation limited to countries that are relevant to the technology or the industry: ammonia production, sugarcane-based bio-ethanol, cement production, CCS, nuclear energy, and carbon efficiency in cars. A review of factors and constraints for those hypothetical TOAs bring the review of past international TOAs in Chapter 5 a few steps further. First, the typology of TOAs will probably not be applied rigidly. Rather, a combination of elements of various types of TOAs will be used. The TOA on bio-ethanol, for instance, combines type-3 and type-4 elements which complement each other and makes the totality of the TOAs more tailor-made to what the technology requires – an advantage discussed in Chapter 3. This is also confirmed by the above-mentioned G77 and China proposal on a UNFCCC "Technology Mechanism" (UNFCCC, 2008a) and by various other recent proposals for technology frameworks that have been done (Bazilian et al., 2008; Tomlinson et al., 2008; Tirpak and Childs Staley, 2008).

Another observation is that participation could be restricted to those countries that would likely comply, as their interest structure matches the aim of the TOA. Allowing for flexibility on who might join the agreement could make it self-enforcing. This can be done while the coverage in terms of greenhouse gas emission sources of the agreement and its environmental effectiveness remain large. An agreement on the manufacturing of cars, for instance, could be agreed by a limited number of countries, as the lion's share of cars are manufactured in only six or seven countries (OICA, 2008). The emission impacts, however, would have a global scope as the companies from these countries produce for the rest of the world. The conclusions in Chapter 8 are further confirmed by both qualitative and quantitative recent studies in this field (see e.g., Tomlinson et al., 2008; IEA, 2008b).

10.4 How do TOAs compare to the current climate regime?

Based on converging critiques of the Kyoto Protocol, Chapters 1 and 2 identify a number of shortcomings that would have to be improved in a new regime. The extensive literature on the Kyoto Protocol (e.g., Sathaye et al., 2006; Victor, 2001; Ott, 2001; Cooper, 1998; Barrett, 1998) converges on five main areas of criticism: (1) Incentives for participation (particularly the United States and large, fast-growing developing countries); (2) Compliance and enforcement (preferably the new regime would be self-enforcing); (3) Environmental effectiveness and technological change; (4) Provisions for technology transfer and (5) Predictability of economic consequences and costs. Chapter 6 investigates how TOAs compare to the Kyoto Protocol. On some aspects, TOAs could improve on the Kyoto Protocol, but this answer is contingent on a number of important details.

The first Kyoto criticism relates to *participation*: the United States did not ratify, and large emerging economies, increasingly contributing to global greenhouse gas emissions, were not given emissions targets. Chapter 3 analyses the interest structure around an emission targets-based approach and shows that a rational-actor IR analysis provides an explanation of why the United States reneged from the Kyoto Protocol. Two reasons were given by the United States for not participating: that economic impacts would be too high, and that developing countries did not get targets (US Senate, 1997). The first can be explained by studies showing very high costs for the United States compared to other Annex-I parties (see e.g. Murkowski, 2000). The second argument seems to reflect especially the concern with China challenging US industry (Rice, 2000).

Both arguments for US defection from the Kyoto Protocol can be related directly to the lack of *reciprocity*: the returns of the agreement are low compared to the costs, and developing countries' absence of commitments is seen as damaging US competitiveness, thus magnifying the negative economic impacts even further. Participation of the United States in a future regime is considered essential for any effective post-2012 climate mitigation agreement. However, participation of high emitting and economically strengthening developing countries, particularly China, is also becoming more important: while emissions trajectories develop according to higher baselines, the required emission reductions grow, and all countries with substantial emissions will have to make efforts to reduce them (IPCC, 2007c). If this is done in an international climate agreement, it needs to provide reciprocity to both the United States and to China to make participation attractive, and keep in mind that each country might require something else out of the climate agreement than the other. Moreover, this reciprocity would have to be greater as emissions rise faster.

In addition, although assessment studies have been done (e.g., Nordhaus, 2001), the economy-wide targets in the Kyoto Protocol made the quantification of costs and benefits highly uncertain. This relates to another criticism: that the lack of *predictability of costs* of an agreement, or more in general information, is a major barrier to participation. Both the United States and developing countries hold back on targets, fearing that their economic development will face constraints by the high costs of complying with a climate agreement. Scholars from developing countries argue that they get too few “carrots” in return for commitments (e.g., Zhang, 2008).

Various models project costs of climate policy measures, but have always had to cope with uncertainties in selecting policy strategies (Lempert et al., 1996; Weyant, 1999; 2004b; IPCC, 2007c). Chapter 2 introduces instruments such as marginal abatement cost curves, and top-down and bottom-up economic models for estimating costs and benefits of climate change mitigation. Marginal abatement cost curves and bottom-up models have the advantage of detailed sector and technological cost estimates, but offer less information on substitution effects and economy-wide impacts (e.g., Bakker et al., 2007; McKinsey, 2009; Vuuren, 2007). Top-down models reflect substitution effects, but lack the technology and sector detail, as well as disaggregated learning effects, of bottom-up models (Goulder and Pizer, 2006). The interactions of various sectors in the economy, as well as assumptions on optimalities of the energy system (Grubb et al., 1993) add to large uncertainties on economy-wide costs.

The performance on the cost predictability criticism, relative to the economy-wide target of the Kyoto Protocol, of a group of TOAs that would collectively be environmentally effective is difficult to determine, certainly in the absence of empirical data. Although considerable cost uncertainties remain, the cost uncertainty of any single TOA is generally smaller than for an economy-wide target. This is illustrated in Chapter 8, where straightforward calculations around concrete TOAs provide relatively exact numbers, albeit still dependent on assumptions. A group of TOAs, however, would still have uncertainties around costs that are probably on the same order of magnitude as the uncertainties of economy-wide emission reduction targets. The question is how the apparent cost predictability of single TOAs would affect the perception of agreeing to a group of TOAs and lower barriers to participation.

On the participation point, in Chapter 3, based on a theoretical analysis of the interest structure around the climate negotiations, the argument is made that the United States and several emerging economies might be willing to sign up to agreements that focus on a single technology in the event that they anticipate a leading market share in manufacturing the technology, exporting equipment, and selling expertise and intellectual property, producing the opportunity for monopoly rents and competitive advantage. The assumption here is that several countries expect to benefit from the agreement, although their expectations may not have become reality over the course of the implementation of the agreement as their information at the moment of agreeing on the treaty will be incomplete. If the expectations of benefits are high and certain enough, the treaty would become self-enforcing and *compliance and enforcement* mechanisms would be strengthened. The TOA-cases in Chapter 8 do show barriers in terms of costs, but also identify opportunities that economy-wide targets would not visualise so much. However, the chapter also explains that this outcome is not clear-cut, and makes assumptions that are surrounded with uncertainty. Notably, the dynamics of incomplete information is unclear; a nation state might be interested in pursuing a technology-oriented agreement if it believes it will benefit, but might defect if later on it turns out they do not benefit from it.

Another shortcoming that is sometimes linked with the Kyoto Protocol is *environmental effectiveness*, both in terms of reduction of greenhouse gas emissions and inducing *technological change* (Prins and Rayner, 2007). There is actually much disagreement on whether the Kyoto Protocol is sufficiently environmentally effective. Those criticising the Kyoto Protocol point out that the emission reductions as a result of the Kyoto Protocol are not going far enough and are also compromised by a number of concessions in the treaty, such as claiming of land use and certain types of projects under the CDM (Wara and Victor, 2008). Indeed, longer-term and deeper emission reductions than those in the Kyoto Protocol are required to prevent dangerous climate change. Others point out that the emission reductions in the Kyoto Protocol were never intended to solve the climate change problem; they were intended as a first step to be followed by deeper emission reductions beyond 2012 (Jacoby et al., 1998; IPCC, 2007c). They argue that the emissions caps inherent to the Kyoto Protocol would guarantee emission reductions, if there would be general compliance.

The environmental effectiveness of TOAs is also contested. A number of researchers, based on multi-criteria analysis or game theory, questioned environmental effectiveness of technology agreements (Höhne, 2005; Buchner and Carraro, 2005). However, those studies focus on type 1 or type 2 agreements, involving the earlier phases of the technology development and innovation chain and leaving diffusion solely to market mechanisms. Chapter 8 introduces a number of TOAs with elements of type 3 and 4 that are explicitly designed to achieve diffusion of technology, also towards developing countries, rather than development alone. Such TOAs could create a market for a technology through subsidies, mandate and standards, or through lowering barriers and fortifying the technological innovation system in a country. TOAs in the type-4 category could be designed in a way that they are environmentally effective, e.g. by fixing targets for low-carbon technologies (Coninck et al., 2008a).

Chapter 5 and 6 show that for TOAs, similar to the Kyoto Protocol, the environmental effectiveness depends on the details of the target-setting; i.e., how much financing would be provided, or how much technology would be deployed. A well-chosen group of technology-oriented agreements, possibly following recommendations from the IEA (2008b), and accounted for in a consistent and transparent way, can arrive at similar emission reductions as an emission reduction agreement, and thus be as environmentally effective. Again, however, not every type of technology-oriented agreement can be expected to have such performance: only type-4 agreements could perform as well. A threat to environmental effectiveness in a patchwork of specific TOAs is the lack of coordination between the various TOAs. Firm guarantees on preventing fragmentation of the climate regime into many separate elements, operating independently and not striving to reach a common goal, need to be put in place. For an emissions-targets approach, however, the threat of non-participation and non-compliance, which also leads to reduced environmental effectiveness, is greater.

A last point of criticism relates to the specific issue of *technology transfer* to developing countries. The claim that the Kyoto Protocol facilitates technology transfer was investigated in Chapter 7 for the CDM (Coninck et al., 2008b). Here we compared market-based approaches with technology-based approaches for technology transfer, mainly from industrialised to developing countries. These results are consistent with results in more extensive and recent studies (Haites et al., 2006; Schneider et al., 2007; Dechezleprêtre et al., 2008). They demonstrate that (for the sample of CDM projects investigated) the market-based CDM uses new or improved technologies that originate from outside of the host country in about half of projects, usually with knowledge transfer and capacity building as well. However, the CDM was not effective in all sectors; projects in end-use sectors such as transportation and energy efficiency are a small part of its project portfolio, even though theoretical studies indicate that they would be cost-effective even without a price on carbon (e.g., Bakker et al., 2007; McKinsey, 2009). For technologies in these sectors, a specialised technology mechanism or fund that would address institutional aspects of technology – including the development of technological innovation systems and enabling environments – may be more effective. The characteristic of a market-based mechanism is that it prices an externality and thus directly addresses the cost barriers, but only indirectly other barriers, such as lack of human capabilities, issues related to IPR, or the regulatory environment (e.g., Jaffe et al., 2005; Coninck et al., 2008a; UNFCCC, 2008a). A mechanism that addresses those barriers might be more effective than a price signal.

Summarising, TOAs appear to provide some improvement in the field of participation and compliance, technological change, and technology transfer; areas where the Kyoto Protocol underperforms. They are particularly effective where free-rider incentives, market failures or extensive transaction costs hinder cost-effective implementation of a market-based regime. If applied in other situations, they may reduce cost-effectiveness of the climate regime as a whole (Coninck et al., 2008a) as technology choices will need to be made based on incomplete and imperfect information, and the benefits over global coordination in a single emission-target approach would be lost. A similar conclusion could be drawn for sectoral approaches, although the loss in cost-effectiveness might be lower (Bradley et al., 2007), as sectoral approaches are less prone to governments picking the wrong winners.

10.5 How would technology-oriented agreements interact with the climate regime?

The possibility of including TOAs in the climate regime leads to new questions of an institutional nature. How would TOAs be embedded in the current climate regime context? And if the international climate regime would continue to be cap-and-trade-based, but would include technology-oriented features, how would they influence each other's performance and the notion of reciprocity? On the first question, Chapter 3 argues that there are institutional windows to accommodate TOAs within the UNFCCC regime, notably since the Bali Action Plan, but also outside that regime. Incorporating TOAs in the UNFCCC allows for better and more consistent oversight, and could prevent double-counting of actions under various obligations.

For this, however, the UNFCCC would have to develop clear standards of what is “measurable, reportable and verifiable”, even for actions that are not emission reductions. The specific nature of TOAs means that many are needed to cover the wide range of sectors that emit greenhouse gases and the most important abatement technologies. Chapter 9 notes that fragmentation is a real threat, as it may lead to powerful states furthering their interests disproportionally and a reduction of equity, transparency and accountability (Benvenisti and Downs, 2007). A multitude of TOAs, whether along-side or substituting an emissions-targets regime, could lead to fragmentation of the climate regime. The rules might have to make provisions against powerful states exploiting their position and putting their economic interest in a specific technology above the general interest of environmental effectiveness. An independent, impartial and UNFCCC-based Technology Assessment Panel is one of the proposals to address this concern (UNFCCC, 2009).

To be effective the various TOAs would have to be coordinated and linked institutionally. Victor and Raustiala (2004) introduced the concept of “regime complex” – a range of separate agreements with overlapping issue areas and that have often evolved in an uncoordinated way. A coordinated “climate regime complex” might be diverse by design to reflect the different interest structures of parties and could have centralised oversight, for instance under the UNFCCC. Although such institutional linking in a regime complex would be necessary for environmental effectiveness, it would also result in higher transaction and administrative costs, and considerably complicate the climate negotiations. Three possible scenarios of institutional linking have been explored: “functional complementarity”, “geographical complementarity” and “full replacement” of emission reduction targets with TOAs.

Several chapters in this thesis arrive at the conclusion that combining TOAs and a market-based agreement on emission reductions (such as a follow-up of Kyoto) could provide the best result, in the light of the economic perspective of TOAs as reducing transaction costs and correcting market failures (Coninck et al., 2008a). In such a case, we speak of a “functional complement” of an emission reductions-based regime. The types of TOAs in this case would primarily be type 1, 2 or 3, depending on the specific technology characteristics and needs. However, such a complement is unlikely to provide much reciprocity as the cost of the emission reduction target remain, the gains of only including the TOA are long-term technological effectiveness and reduction of transaction costs and market failures. To make full use of what type-4 TOAs have to offer on specific reciprocity, TOAs can also be viewed in a way other than “functionally complementary”.

The theoretical analysis on rational design of institutions in Chapter 3 shows that defection is likely in a emission reduction-based regime (such as a cap-and-trade agreement). Even if not all industrialised Parties defect, some may drop out, as we have seen in the Kyoto Protocol. The more specific reciprocity of the TOAs may make it more attractive for those countries to agree on a number of strong and specific Type-4 TOAs than to sign up to an economy-wide target with unclear economic consequences. Some countries might sign on to an emission reduction-based regime, while others comply with a series of TOAs. In such a situation, TOAs would be a “geographical complement" to an emission reduction-based international climate regime, even though seen on the country level, they would serve as a replacement of an emission-target regime. Formalisation in the UNFCCC context could take two forms: An environmentally effective combination of Type-4 TOAs could be recognised as a commitment comparable to an emission reduction target, or it could serve as a backstop option (as first suggested by Edmonds and Wise, 1998) for defectors of an emissions reduction agreement and could be integrated in the compliance and enforcement mechanism.

The last possibility is that TOAs would fully replace the international and all domestic emission target-based regimes. Currently, this is unlikely as several countries have already shown determination to continue a cap-and-trade-based regime (EC, 2008). In theory, however, even countries with a domestic emissions trading scheme could sign up to Type-4 TOAs on an international level – the loss of sovereignty might be limited, as the deployment of technologies that is achieved in a Type-4 TOA would contribute to achieving the emission target. There are no real additional barriers to the "replacement" scenario, apart from that the current political situation in various parts of the world render it unlikely.

10.6 Back to theory and further work

Chapter 1 and 2 have reviewed the literature related to technology and innovation in various disciplines. The following chapters contributed to the theoretical work around international institutions, technology and climate change in a couple of ways. To theory in particular, this thesis made three small contributions, which I would like to discuss here.

First, Chapter 3 extended the framework for rationally designing international environmental agreements with an additional dimension determining the treaty design outcome if negotiated by rational actors. Earlier work had predicted the rational outcome of institutional design on whether there was a possibility of "symmetric externalities" (where several states both cause and experience damage), and when there were "asymmetric externalities", based on whether the victims were either strong or weak. In the case of weak victims, the option of coercion is not available so rewarding the perpetrators for reducing the damage, also called "exchange", "transfer" or just "side-payments", is the only solution (Mitchell and Keilbach, 2001). This model, however, did not solve the question of the choice between coercion and rewarding for asymmetric externalities and strong victims. Chapter 3 adds to this by introducing another dimension: that of the rich or poor perpetrator and the rich or poor victims. In the case of a strong victim and a rich perpetrator that does not accept side-payments, coercion would be the rational outcome. In the case of strong victims and poor perpetrators (Financial Mechanism in the Montreal Protocol), rewards would work best, but coercion would work better for the case of weak and rich victims (whaling in Iceland). However, for weak and poor victims, no clear outcome could be identified as those stakeholders lack the ability to coerce or to reward. In very simple terms this represents the climate change interest structure between some of the important national players: the rich and strong perpetrators (the industrialised countries) and weak and poor victims (the developing countries). It provides a fundamental explanation for the absence of a clear rational outcome for an institutional design for the climate change regime and for the deadlock in the negotiations. Moreover, it provides a more robust connection between the game-theoretic literature on cooperation games and institutional design. Rationally acting nation states, given the interest structure of climate change, could be expected to generally follow this framework, and not reach agreement.

A second contribution is an attempt to make steps towards a better understanding of the role of technology in international institutions in general, and climate change in particular, within IR-theory. Understanding how the perception of benefits accruing from technology innovation and diffusion in the minds of rational-actor nation states is challenging. Some studies (e.g. Jacobsson and Lauber, 2006) suggest that in some countries particularly those with an explicit industry policy, low-carbon technology interests play a role that could modify the interest constellation of individual nation states towards the problem structure of climate change, and therefore the outcome of the "rational institutional design" for climate change. There is a need to take into account vested (but dynamic) interests and bounded rationality. Perceptions of nation states can be based on correct or incorrect information, is impacted by uncertainty about outcomes, and all this can change over time. This thesis, in Chapter 3, has not done more than flagging the positive role that particularly incomplete information and uncertainties about future markets may play in negotiating a technology-oriented agreement. A limited discussion was offered on perceived first-mover advantages, but other areas, notably perceived comparative or competitive advantages, would be worth looking into as well. As in IR there is an ongoing discussion between neo-rationalists and constructivists (Fearon and Wendt, 2002) on a model for incorporating bounded rationality in nation state behaviour into rational design of international institutions, the role of perceptions of technological advantages and innovation may be a place to look for clues. The National Innovation Systems literature (Lundvall, 1992) and the discussion of Cardwell's Law on the interaction between technological innovation, political competition and the success of economies (Mokyr, 1994) could provide useful theoretical concepts to develop further in an international context. The Technological Innovation System (Bergek et al., 2008 and references therein) and the literature based on Lall (1992) on technology transfer could provide practical policy recommendations for international institutions on low-carbon technology diffusion and transfer.

Third, the policy instrumentation of technology transfer in international institutions is an area where this thesis makes a contribution, particularly in Chapter 7. In international climate negotiations, the technology transfer debate suffers from different perceptions of stakeholders – roughly, developing countries see industrialised countries financing the transfer of technology as a moral duty, whereas industrialised countries tend to treat it more like as a side-payment for engaging developing countries into mitigation actions. In this case, perceptions of the situation are inhibiting an outcome of the negotiations (Larson, 1988). Much of the literature has been written from either the donor or the recipient country perspective (Ockwell et al., 2008; Haites et al., 2006), and an empirical analysis of effective technology transfer is much needed. This thesis made a first attempt at this, attempting to incorporate both the industrialised and the developing country viewpoints in the technology transfer definition and criteria.

Only some areas around the potential role of technology innovation and diffusion in international institutions have been explored here. The conclusions allow for setting out some directions for further research. There are three areas which this thesis has left insufficiently addressed to draw robust conclusions. These areas are 1) explicitly resolving the theoretical question of rational-actor nation states behaviour towards international institutions in the context of many other issues that relate to the subject of the institution; 2) a quantification of the interest structure of countries for agreements on the most important low-carbon technologies; and 3) the role of private actors in technology-oriented agreements.

The first area concerns what the role of innovation is in changing rationally acting nation states' point of views on a certain institutional outcome given their domestic political economy and interests. If relevant factors, such as technology in the climate regime or a changing world order, are weighed in the bounded rational actor views, would countries be willing to leave the conventional self-interested path? Various authors have provided more theoretical work on this issue (e.g., Slaughter, 2004, argued for the greater role of informal networks rather than formal institutions), but the linkage to innovation and climate change has not yet been made.

The second relates to the constellation of interests informed by country-specific perceptions on pay-off functions, their competitiveness, and future global markets for single technologies that could be the subject of a technology-oriented agreement. For instance, a country could be taken as a case study and the impact of specific TOAs could be investigated for every relevant sector, including the business community. More detailed studies, including game theory experiments for specific sectors or technologies, that allow for repeated simultaneous decision-making on parallel issues with incomplete information (Bolton and Ockenfels, 2000), and better insights in the costs of potential TOAs, could help clarifying the real value of TOAs.

The third area is an interesting question as the holders and implementers of technology are often not the governments which take seat at the negotiation table, but national and multi-national companies. This brings along a wholly different dynamic – potentially more rational and supranational. Vested interests, as well as interest structures, will change. A model to simulate this was not provided by the current IR work, although much literature exists in the management studies field, which includes work on strategic behaviour of firms (Lichtenthaler , 2008) and on potential deal-enhancing and deal-inhibiting roles of the business community (Raustiala and Bridgeman, 2007). Issues to be addressed on the intersections of IR and management studies could include specific and general aspects of reciprocity, the value of first-mover advantages, and protection of intellectual property in the global context.

10.7 An outlook for the climate negotiations

I would like to end this thesis with some words on the recent developments in the post-2012 climate literature and the international negotiations, and the way the results of this thesis could be used. In the recent past, and parallel with the work reported in this thesis, sectoral agreements have become a much-mentioned add-on to a potential cap-and-trade regime. Chapter 3 goes into the differences between sectoral agreements and TOAs and reviews some of the literature on sectoral agreements. The differences are subtle. TOAs should probably be seen as a sub-group of sectoral agreements (Bodansky, 2007), as TOAs necessarily aim at one sector, but sectoral agreements could cover several technologies. They are however often used interchangeably, and in this thesis the distinction is not always maintained clearly: the automobile-TOA in Chapter 8, for instance, is technically not a TOA according to Chapter 5's definition, but a sectoral agreement. Most of the conclusions for TOAs in this thesis could also apply to sectoral agreements. However, sectoral agreements tend to focus more at mitigating international competitiveness concerns, and TOAs are more tailored towards mobilising interests in the innovation and diffusion of specific technologies.

A number of conditions that TOAs need to fulfil can be identified based on the above. First, TOAs should reflect the characteristics of the technology they address and be aligned with the (vested) technological interests that prevail in the sector, to ensure a positive payback function of the agreements to important parties. Second, a smart combination of market-based and technology-oriented agreements would work best both for climate change in general and for technology transfer to developing countries. Third, if indeed market-based and technology-oriented instruments are combined, there co-existence under one regime is recommended over a fully fragmented regime. This is necessary to prevent problems of fragmentation, lack of transparency and sketchy accountability that would all comprise environmental effectiveness of the climate regime. And last, if TOAs are applied as a replacement or as a geographically or functionally complement, they should be designed to be effect-based, to ensure environmental or technological effectiveness.

My forecast for future international climate policy is that we will need geographically complementary TOAs or sectoral agreements; so that a range of TOAs would in some countries replace the ideal-case of an emission target-based regime. This might apply in particular in emerging economies for which emission targets are not acceptable, and an emissions trading scheme would be institutionally challenging anyway (Bell Greenspan, 2005). However, potentially also the United States and Canada, as part of a compliance mechanism for an emissions-trading based agreement, might prefer a range of multilateral and bilateral type-4 TOAs. In addition, there is potential for type 1, 2 or 3 TOAs to complement other international mechanisms. This thesis suggests that it is possible to improve reciprocity in climate treaty design if such provisions were included.

Finally, I would like to emphasise a last argument of why technology rules may create a positive dynamic in the international climate negotiations. Over the past years, emission caps have been associated with constraints and costs; they signal restraint and control, especially in countries with an allergy to excessive government interference. Technology and innovation, however, is associated with progress, with opportunities, indeed, even with civilisation. The associations and beliefs with negotiators can potentially contribute or inhibit international agreement. In climate change, years of difficult negotiations have fed mistrust between the state parties. The presidential election in the United States and the new sense of urgency, combined with the economic optimism that a technology brings, have the potential to change the international relations in climate change for the better, which is much needed to provide for an atmosphere of trust in which concessions are valued and duly reciprocated.

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Abbreviations

APP	Asia-Pacific Partnership on Clean Technology and Climate
CAT	Cap and trade
CCS	CO_2 capture and storage
CDM	Clean Development Mechanism
CER	Certified Emission Reduction (under the CDM)
CERN	European Organisation for Nuclear Research
CH_4	Methane
CO_2	Carbon dioxide
CSD	Commission on Sustainable Development
CSLF	Carbon Sequestration Leadership Forum
EC	European Commission
ECN	Energy research Centre of the Netherlands
EGTT	Expert Group on Technology Transfer
EU	European Union
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gas
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
IEA	International Energy Agency
IEA-IA	IEA Implementing Agreements
IPCC	Intergovernmental Panel on Climate Change
IPHE	International Partnership on the Hydrogen Economy
IPR	Intellectual property rights
IR	International Relations
IVM	Institute for Environmental Studies, VU University of Amsterdam
JI	Joint Implementation
kWh	kilowatthour
LHC	Large Hadron Collider
MARPOL	International Convention for the Prevention of Pollution from Ships
MDG	Millennium Development Goal
MLF	Multilateral Fund (of the Montreal Protocol)
Mt	Megatonne
MW	Megawatt
N_2O	Nitrous oxide
ODA	Official Development Assistance
ODS	Ozone-depleting Substance
OECD	Organisation for Economic Cooperation and Development
PAMs	Policies and measures
PDD	Project Design Document (for the CDM)
PRSP	Poverty Reduction Strategy Paper
R&D	Research and development
RD&D	Research, development and demonstration
SADC	Southern African Development Community
TC	Tonne cane (sugarcane)
TIS	Technological Innovation System

TOA	Technology-oriented agreement
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
US	United States
WBCSD	World Business Council on Sustainable Development
WTO	World Trade Organisation

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