



**Estimates of Future Supply
of International Greenhouse Gas Offsets:
A Critical Review**

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ABSTRACT

Greenhouse gas offsets, or credits, are a central feature of most proposed or enacted national and international cap-and-trade systems. U.S. policymakers have relied on offsets from developing countries as a primary form of cost containment in proposed legislation. These legislative proposals allow for emitters to use up to 1.5 billion tons CO₂e of offsets from developing countries to meet their annual compliance obligations. In this paper, we review estimates of the projected availability (*i.e.*, supply) of international offsets, and evaluate the various methods used. We find that (1) Estimates of supply of international offsets to global markets vary widely, with estimates differing by billions of tons CO₂e annually in 2020; (2) Despite the variation, existing studies suggest that by 2020 gross international offset supply will likely exceed U.S. demand for international offsets under current Congressional cap-and-trade designs; (3) Competition with governments and entities with emission reduction obligations (*e.g.*, the EU), as well as with policies and measures undertaken by developing countries as part of their own mitigation contributions, could reduce the net offset supply available to U.S. entities; and (4) Several important offset program design and market factors that are central to future offset markets and credit issuance (*e.g.*, sources of offset supply, program stringency and crediting methods, establishment of international governance and market structures) have yet to be systematically considered in offset supply assessments. This paper outlines factors that should be incorporated into future analyses of international offset supply and quality. Such analyses could prove particularly germane as policy makers continue to deliberate on the role of international offsets, including whether and how to recognize credits from the Clean Development Mechanism (CDM), develop new sectoral crediting mechanisms, and consider offsets for reduced deforestation.

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EXECUTIVE SUMMARY

Cap-and-trade legislation recently authored by U.S. policymakers relies heavily on offsets to contain the price of emission allowances and the overall economic costs of the program. Offsets represent emissions reductions from projects or actions implemented in sectors or regions not subject to an emissions cap. As a mechanism to achieve compliance with the emissions cap, offsets offer an alternative to reducing emissions in regulated sectors and regions. Offsets provide “where” flexibility to emitters covered by a cap-and-trade system; if offsets are abundant and available at marginal costs lower than reductions in regulated sectors and regions, then their direct economic benefits could be significant.

Studies by the U.S. Environmental Protection Agency (US EPA) and other analysts suggest that the availability of abundant low-cost domestic and international offsets can lower allowance prices in a U.S. cap-and-trade program by a factor of two or more. In addition, US EPA projects that international offsets may be considerably more abundant at lower cost than domestic offsets, which would be sourced from uncapped sectors within the U.S., largely in agriculture and forestry. However, the development of, and reliance upon, international offset markets presents significant uncertainties and risks as well as opportunities. This paper reviews available estimates of international offset supply and identifies a set of key issues affecting supply that have yet to be adequately explored.

International offsets are expected to provide significant cost containment to capped entities under a U.S. cap-and-trade program. US EPA analysis of the *American Clean Energy and Security Act* (HR 2454, as approved by the U.S. House of Representatives in June 2009) indicates that if no international offsets were allowed, allowance prices could be 89 per cent higher than otherwise projected.¹ Recent Congressional cap-and-trade bills – including the *American Clean Energy and Security Act* (HR 2454) passed by the House of Representatives in June of 2009, the *Clean Energy Jobs and American Power Act* (S 1733) reported out of the Environment and Public Works committee in U.S. Senate in November 2009, and the *American Power Act* introduced as a discussion draft in the Senate in May 2010 – include the same overall limit on the use of offsets. Each allows for the use of up to 2 billion tons

of offset credits annually, an amount that is roughly a third of total capped emissions in the U.S. in 2020. As a point of reference, offset usage of 2 billion tons would represent nearly all of the reductions required by the bills in 2020, and nearly 40 per cent of total U.S. GHG emissions under regulation (5.1 billion tons CO₂e).² The bills differ, however, in their limits on international versus domestic offsets. Both Senate bills allow for offsets from developing countries (the only international offsets allowed in any of the three bills) to comprise one-quarter (500 million tons) of the limit; and the House bill, up to one-half (1 billion tons). However, all three bills permit the share of developing country offsets to be higher should the supply of cost-competitive domestic offsets be lower than expected, an outcome that many analysts consider likely.³ In such a case, the allowable usage of offsets from developing countries could rise to as much as 1.5 billion tons annually.⁴

Given the possibility of competition with other developed countries for access to developing country offsets – as well as the considerable uncertainty regarding international climate negotiations and the extent and form of international offset mechanisms in a post-2012 climate agreement – will international offsets be available at the scale of 1 to 1.5 billion tons to U.S. entities, and at prices competitive with U.S. allowances? U.S. government analyses of the bill differ markedly in the quantity of international offsets projected to be available in the near term – with some analysts (e.g., the Congressional Budget Office) indicating that fewer international offsets will be available than the prescribed limits allowed in the House and Senate bills.

In this paper, we review studies of GHG abatement potential and methods used to translate these into estimates of future supplies of offset credits globally or as provided to capped entities under a U.S. cap-and-trade

1 Comparing Scenario 7 (No International Offsets) with Scenario 2 (Core HR 2454 scenario) in US EPA (2009).

2 Including emissions caps and complementary measures, both bills require emission reductions of about 2,200 MMT CO₂e relative to business as usual in 2020 per Larsen, J. (2009).

3 In particular, the US EIA (2009) and CBO (2009) analyses predict constrained domestic offset supply.

4 All three bills allow for the stated limits on international offsets to be exceeded if the usage of domestic offsets falls below a particular threshold. In addition, the three bills discount international offsets by 20 per cent in or after 2018. Limits and discounts in the two bills are detailed further in Table 2.

program. Among the studies reviewed, including those by U.S. government analysts, international research institutions, and carbon market actors, we find that approaches and results differ markedly. In particular:

1 Studies that use marginal abatement curves as offset supply curves yield estimates of international offset supply that are highly optimistic.

For example, when used as estimates of offset supply, US EPA's marginal abatement curves suggest that about 6.4 billion tons CO₂e of offsets could be available annually in 2020 from developing countries. By contrast, studies by carbon market observers that consider how past trends in offset markets might develop in the future yield estimates of 1.5 to 2.5 billion tons per annum. All of these estimates are much higher than the supply of Clean Development Mechanism (CDM) credits in recent years of about 0.3 billion tons (300 MMT) CO₂e annually (UNEP Risoe Centre, 2010).

2 Existing studies suggest that by 2020 gross international offset supply will exceed the U.S. demand for international offsets under current Congressional cap-and-trade designs.⁵

Estimates of potential offset supply range from 1.5 to over 6 billion tons CO₂e, which indicate that gross international supply is expected to exceed demand from U.S. entities, estimated at between 0.4 billion tons CO₂e (CBO) to almost 1.3 billion tons CO₂e per annum (US EPA) for the Waxman-Markey bill, before accounting for the legislation's requirement that U.S. entities would need to surrender 5 tons of international offsets for every 4 tons of emission after 2018.

3 Competition with other national governments and entities with emission reduction obligations (e.g., in the EU), as well as with policies and measures undertaken by developing countries as part of their own mitigation contributions, will likely reduce the net offset supply available to U.S. entities.

The ambition of other country's climate programs will be a key factor influencing offset supply, and is likely to continue as a major area of international negotiation and uncertainty for some time. Existing analyses of potential supply and demand balances differ widely – with

some predicting a large oversupply of international credits, which, in the absence of limits on the use of offsets in industrialized countries, could lead to a collapse in carbon market prices (Carbon Trust 2009; Parpia, 2009). Yet as an increasing number of industrialized countries make GHG reduction commitments (including the U.S.), estimates of demand from industrialized countries have consistently been upgraded, such that some analysts – particularly those that have been pessimistic on the supply of offsets from sectoral crediting and REDD – have suggested that demand may instead actually far outweigh supply (Point Carbon, 2009). Additionally, in the event that major developing economies (e.g., China, India and Brazil) take on either voluntary or binding emission reduction commitments and targets, competition for GHG reduction credits is likely to increase and the major sources of international offset credits to date could be severely constrained.

4 Offset program design and market factors are critical drivers of offset supply and quality, but have yet to be systematically considered in offset supply assessments.

Studies differ markedly in their treatment of offset mechanism design and market factors. Based on our review, key factors that merit more explicit treatment include: potential sources of offset supply (e.g., offset project types, sectoral crediting mechanisms, REDD), stringency of crediting methodologies and related emissions benefits (instead, most existing analyses assume instead that a “ton is a ton”), establishment of international governance structures and agreements to enable supply from developing countries, and lag times needed for technical and administrative scale-up of crediting infrastructure.

As policymakers in U.S. Congress grapple with efforts to provide cost containment to capped entities while ensuring that climate legislation meets its intended purpose of reducing emissions, better understanding the costs, quantities, and net emissions benefits of international offsets under leading policy proposals is critical. For example, the global balance of supply and demand for offsets will substantially affect what quantities of offsets will be available to U.S. entities at what cost, yet relatively little research has explored the question of global supply and demand balances. Similarly, decisions yet-to-be-made regarding which activities will be eligible as offsets and how those offsets will be credited – both within the U.S. and through post-2012 international agreements – will hold substantial sway over both the emissions benefit and marketable supply of international offsets.

⁵ By *gross* offset supply, we mean supply before consideration of alternative mitigation actions (e.g., uncredited country NAMAs), competing demands from other countries, or legislative design factors (e.g., discounts) that would affect the net offset supply available in the U.S.

1 INTRODUCTION

Greenhouse gas offsets, or credits,⁶ are a central feature of most proposed or enacted national and international cap-and-trade systems. Greenhouse gas (GHG) offsets represent emission reductions from projects or actions implemented in sectors or regions not subject to an emissions cap, and offer an alternative to reducing emissions in capped sectors as a means to achieve emissions reduction goals. Offsets are generally envisioned as a means to provide increased flexibility, economic efficiency, and cost savings to U.S. entities and countries required to reduce their emissions. Policymakers have focused attention on offsets from both domestic and international developing country sources. The expectation embodied in recent U.S. cap-and-trade legislation is that up to 2 billion tons of emission reductions from offset projects could be available annually, with up to 1.5 billion of these tons from developing country sources,⁷ an amount 5 times greater than current global offset supply, which come largely through the Clean Development Mechanism of the Kyoto Protocol.

Various U.S. legislative proposals introduced to date include offsets sourced internationally through a variety of crediting mechanisms, including:

- **Sectoral crediting mechanisms**, where GHG offsets could be generated from developing countries that reduce emissions in certain sectors (e.g., power production, cement industry, iron and steel industry) below prescribed, negotiated levels.
- **Internationally recognized offset crediting programs**, such as programs established by the United Nations Framework Convention on Climate Change (UNFCCC) or a protocol or treaty that succeeds that convention. Such programs are generally understood to include the evolution

and subsequent iterations of the current Clean Development Mechanism (CDM).

- **Bilateral domestic crediting recognition**, Several countries are considering or actively pursuing the development of unilateral regulatory domestic offset crediting programs for uncapped sectors of the economy, including the U.S., Japan, Australia and South Korea. Countries implementing domestically governed and enforced greenhouse gas reduction programs (as opposed to being a party to a binding multilateral GHG reduction treaty) could bilaterally establish an agreement for mutual recognition of each other's offset credits for compliance use.
- **Offsets from reduced deforestation**, often referred to as RED, or if emissions avoidance from reduced *degradation* were to be included, then as REDD.⁸

All four of these potential sources of international offsets are actively being discussed in international negotiations, as potential means of recognizing, supporting, and, in some cases, crediting developing countries' Nationally Appropriate Mitigation Actions (NAMAs) and assisting developed countries in meeting their emission reduction goals more cost effectively.⁹ To the extent these approaches introduce new sources and types of market-based credits, the potential supply of offset credits to the U.S. could be greatly increased. Conversely, as these other mechanisms scale up and/or developing countries undertake unilateral or supported actions outside of carbon markets, these options could reduce the role of offsets over time as they, in effect, target some of the same sources of reductions that might otherwise have been used as offsets.

A sound understanding of the economics of offsets – in particular, of the potential supply of offsets under future market and policy conditions – is critically

6 We use the term “offsets” as shorthand here to refer to various forms of tradable emission credits that are based on voluntary participation and that could conceivably be used to fulfil compliance obligations under a cap-and-trade system.

7 In both ACESA and CEJAPA, the 1 billion and 500 million ton limits (respectively) on allowance-equivalent international offset usage can be exceeded (up to 1.5 billion and 1.25 billion tons, respectively) if usage of domestic offsets is less than 900 million tons. A similar provision exists in the discussion draft of the Kerry-Lieberman *American Power Act*.

8 HR 2454 allows credits from reduced deforestation but not from reduced degradation, where degradation is negative changes to the forest cover that reduce its productive ability.

9 NAMAs, as agreed in the Bali Action Plan, would be undertaken by developing countries as emission reduction measures, with technology, finance, and capacity building support from developed countries, subject to measurement, reporting, and verification (MRV).

important for policymakers as they craft climate policy. Indeed, some market observers have called the lack of analysis concerning the interaction of offset supply with future demands (as implied by future emission targets) “the greatest single weakness in the current negotiating process” (Carbon Trust, 2009). This point is underscored by the dramatic decline in the volume of credits transacted Clean Development Mechanism / Joint Implementation (CDM/JI) offset market in 2009 due to reduced demand stemming from the global economic downturn (Kossoy and Ambrosi, 2010) and corresponding continued declines in projected development of new CDM/JI projects (UNEP Risoe Centre, 2010).

This briefing paper summarizes methods used to generate estimates of the supply of international offsets, whether from traditional, project-based sources or from alternative mechanisms such as sectoral crediting. The paper has three sections:

- 1 A review of estimates of economically feasible GHG abatement based on existing analyses conducted by a variety of research firms,** both in Annex I and (especially) non-Annex I, developing countries. These estimates are typically represented in the form of marginal abatement curves (MACs) that suggest where emission reduction opportunities may exist – across technologies, sectors, and regions – at various marginal costs per ton of CO₂e reduced. These MACs, in turn, represent “runs” of techno-economic energy and/or land-use models under a suite of assumptions regarding future growth, resource costs, and technology costs and availability. While the studies provide useful insight on what the economic or technical potential of GHG abatement might be in future years, these estimates do not consider whether and how this potential might be translated into creditable offsets, in light of how offset markets and mechanisms work in practice. Not every abatement opportunity will respond to the price and other signals of an offset program, and for those that do, it can be difficult to accurately quantify the reductions or removals.
- 2 A review of methods to project future offset supply,** considering methods that adjust the marginal abatement curves to account for offset market factors, such as quantification methodologies and decisions about project-type eligibility, as well as those that extrapolate future offset supply based on existing offset market experience.

- 3 Preliminary findings,** in which we summarize available offset supply projections to date and suggest areas for further work to contribute to the ongoing discussion on the role of international offsets in U.S. climate policy.

Our intent in this paper is to identify a set of factors that future analysts may wish to consider in assessing the supply, cost, and economic and emissions impacts of international offsets as used in domestic cap-and-trade programs. We hope that this paper and subsequent analyses may help inform the ongoing debate in the U.S. and internationally regarding the role of international offset instruments in U.S. and international climate policy.

2 REVIEW OF ESTIMATES OF ECONOMICALLY FEASIBLE GHG ABATEMENT

Most studies that assess future offset supply rely on marginal abatement cost curves (MACs). MACs are the output of techno-economic models and present estimates of GHG abatement potential across technologies, sectors, and regions at a range of costs. In this section, we review the available MACs for different sectors or specific abatement measures in world regions through 2030 and the varied methods used to construct each of them.¹⁰ We present this review in three subsections, reflecting three sources of GHG emissions and removals: energy-related carbon

dioxide (CO₂); land-use, land-use change, and forestry (LULUCF); and non-CO₂ gases.

Figures in this section will be presented in millions of metric tons of carbon dioxide equivalent (MMT CO₂e) or, in some cases, billions of metric tons CO₂e. For reference, global greenhouse gas emissions are projected to exceed 50,000 MMT CO₂e (50 billion tons CO₂e, or GTCO₂e) in 2030, with most of those emissions occurring as CO₂ from energy production. Figure 1, below, presents several projections of global baseline emissions in 2030.¹¹

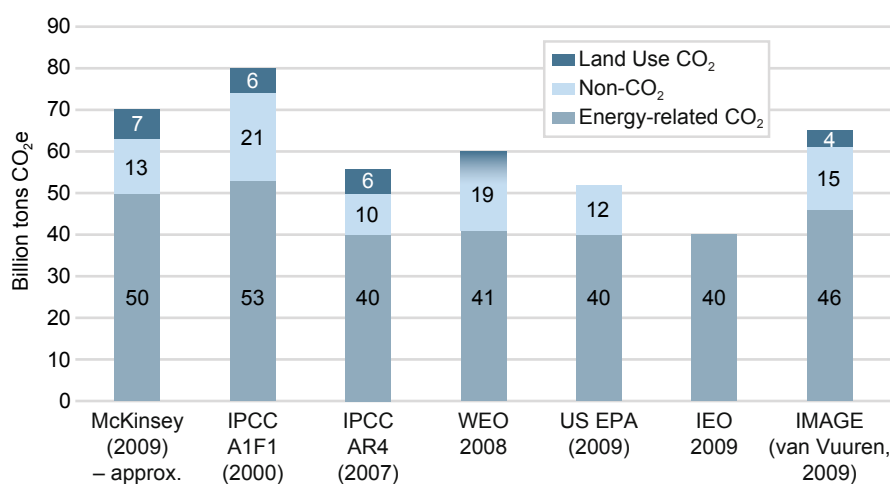


Figure 1: Comparison of global baseline 2030 emissions projections¹²

10 MACs exist beyond 2030 – with some extending through 2100 – and are valuable in understanding the long-term costs and options of abating greenhouse gas emissions. We choose the time period 2030 because we find it extraordinarily difficult to make projections about market activities in longer time periods. In addition, please note that dozens of MACs exist from numerous models. We have attempted to summarize here some of the leading MACs in the literature while referring readers to other published meta-analyses for further consideration of the full range of MACs available.

11 For a review of baseline projections of greenhouse gas emissions, see Annex 1.

12 McKinsey does not report energy-related CO₂ emissions distinct from all GHGs. To approximate energy-related CO₂, here we report McKinsey’s baseline 2030 estimates for the power, industry, transport, and buildings sectors less 40 per cent of their chemical industry emissions (assumed to be non-CO₂ process emissions per a note in their text) and emissions they note as associated with natural gas piping, which we assume to be largely methane. Other non-CO₂ and non-energy related emissions are certainly included in the estimate here attributed to energy-related CO₂, but we were not able to disaggregate them any further and they are not likely large enough to make up much of the difference between the McKinsey baseline and other baselines reported.

ENERGY-RELATED CO₂

Abatement of greenhouse gases from energy-related sources, including electricity production, transportation, buildings, and industry, are often interrelated because abatement activities are impacted by both supply and demand-side measures. These interactions must be carefully considered, as GHG abatement can take place through both efficiency measures that reduce power demand as well as measures to de-carbonize energy generation, such as renewable electricity.

Dozens of models have been used to estimate the costs of energy-related CO₂ abatement globally. As indicated by a recent meta-analysis (Kuik, Brander *et al.*, 2009), most of the models used to generate MACs employ a “top-down” structure characteristic of general equilibrium and integrated assessment models.¹³ Top-down models assess the interactions between energy supply, energy demand, and the larger economy, and tend to have limited technological detail. They are therefore well-suited to generating MACs that span all energy-related sectors (including power production, transportation, industry, and buildings).¹⁴ As an alternative to top-down models, bottom-up approaches assess the abatement potential of particular technologies or practices. Abatement potentials and costs from individual technologies can then be aggregated into broader sector- or economy-wide MACs. McKinsey’s *Global Greenhouse Gas Abatement Curve* (McKinsey & Company, 2009) is a bottom-up MAC, as is the aggregated sector-wide MAC presented in IPCC’s *Fourth Assessment Report* (Metz, Davidson *et al.*, 2007)¹⁵ and several other international efforts (Hoogwijk, Can *et al.* 2008; Bole, Saïdi *et al.*, 2009). Although care must be taken to use consistent assumptions (*e.g.*, consistent baseline scenario of economic growth, energy prices, etc.) and avoid double-counting,¹⁶ the greater sectoral and technology resolution provided by bottom-up MACs

can make them well-suited to assessing the potential supply of offsets in the carbon market.

One recent review of global top-down and bottom-up approaches found no systematic differences in the GHG abatement potentials resulting from the two approaches (van Vuuren, Hoogwijk *et al.*, 2009). Another recent study by the International Institute for Applied Systems Analysis (Amann, Rafaj *et al.*, 2009) found that models (largely top-down) that include measures to mobilise demand adjustments through behavioral and structural changes to the economy show twice as much abatement potential as models (largely bottom-up) that do not (Amann, Rafaj *et al.*, 2009).

Figure 2, below, presents differences in approach by displaying US EPA’s two recent developing country energy-related CO₂ cost curves,¹⁷ which were developed using the top-down MiniCAM model (now called GCAM), alongside the equivalent developing country portion of McKinsey & Company’s and IPCC’s (Metz *et al.*, 2007) bottom-up cost curves. Many other global energy-related MACs exist, however, but relatively few (at least in published form) report non-Annex 1 mitigation potential separately from global potential and so they are not individually summarized here.¹⁸ The comparison is displayed here for 2030 because results were most available for that year.

At abatement costs in the range of \$50–\$75 per tCO₂e, the McKinsey and US EPA analyses suggest a remarkably similar level of energy-related abatement potential in developing countries in 2030: approximately 15 billion tons (15,000 MMT CO₂e). Though remarkable, such congruence is not necessarily surprising: at these marginal costs and time frame several large-scale mitigation technologies, such as carbon capture and storage, nuclear and various renewable energy sources, are widely expected to be economic and capable of achieving significant market penetration (at least in modeling studies). Less ambitious in its assumptions

13 Models can also be hybrids, which typically include bottom-up technology detail in the electricity sector.

14 Many of the studies of abatement cost in the literature run top-down models to generate cost estimates of a particular stabilization target (*e.g.*, 450 ppm CO₂e) or emissions pathway (*e.g.*, 20 per cent reduction compared to 1990 levels) rather than generate costs over a range of abatement potentials. We report here on model runs that generate full MACs.

15 The IPCC also reviews results from top-down models, but the sector-wide MAC presented in Chapter 11: Mitigation from a Cross Sectoral Perspective (Barker, T., I. Bashmakov, *et al.*, 2007) is bottom-up.

16 For example, both end-use electricity efficiency and renewable electricity technologies can reduce emissions from electricity generation.

17 The US EPA’s “Group 2” cost curve (non-Annex 1 plus Russia) is used in its analysis of recent cap-and-trade bills, including the American Clean Energy and Security Act (HR 2454), to help assess potential international offset supply in future years.

18 For recent summaries of other MACs and models, see: van Vuuren, D., M. Hoogwijk, *et al.* (2009), Kuik, O., L. Brander, *et al.* (2009), and Amann, M., P. Rafaj, *et al.* (2009).

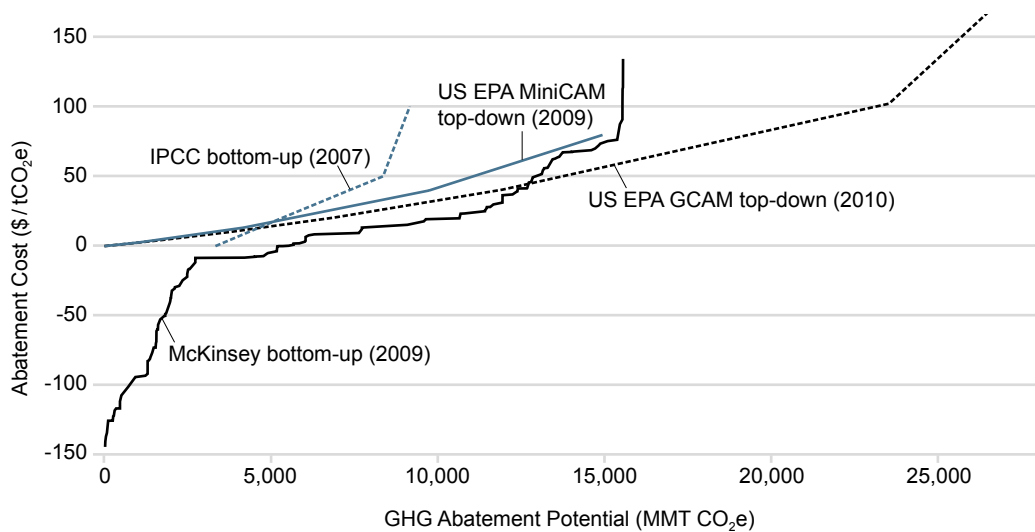


Figure 2: US EPA, UNFCCC, and McKinsey developing country energy-related GHG abatement curves for 2030¹⁹

regarding the penetration of mitigation technologies, the IPCC (Barker *et al.*, 2007) analysis shows lower potential in this cost range: approximately 9 billion tons of CO₂e abatement potential (9,000 MMT CO₂e).

Where the top-down US EPA analysis and the bottom-up McKinsey (and IPCC) analyses differ most markedly is in the potential for “negative cost” abatement opportunities, as shown on the left side of Figure 2. Whereas the McKinsey and IPCC analyses suggests that 3 billion tons (3,000 MMT) CO₂e of abatement could come at net economic benefit, largely from improved energy efficiency, US EPA curves, derived from the MiniCAM (now GCAM) model, shows no potential at negative costs.²⁰ This difference reflects a longstanding debate in the modeling community: some argue that bottom-up models do not give adequate weight to the opportunity and transaction costs of overcoming

market and social barriers to energy efficiency (Jacoby, 1998), while others argue that experience with energy efficiency programs and standards demonstrate that significant cost savings can be realized (Ackerman, DeCanio *et al.*, 2009).²¹

Some analysts have remarked that the presence of potential economic gains from negative cost abatement options, most notably energy efficiency, suggests that these options may be less responsive to price signals. As a result, some observers and parties (*e.g.*, the EU) have argued that offset markets may be inappropriate for negative cost options, due to these market barriers that a carbon price may not alone resolve, as well as

¹⁹ Sources: the EPA curve is the international “Group 2” (Non-Annex I countries plus Russia) energy-related abatement curve attributed to the MiniCAM model as documented in the data annex to US EPA (2009). The McKinsey curve is approximated by summing potentials in the power, industry, transport, and buildings sectors less options specifically noted as being non-CO₂ gases (*e.g.*, those associated with natural gas piping or process gases in the chemical industry) for the approximate same countries. The UNFCCC curve is the sum of the UNFCCC’s mid-range abatement potential estimates for the power, buildings, transport, and industry sectors for all non-OECD countries.

²⁰ The part of the IPCC curve below \$0/tCO₂e is not shown here. The IPCC analysis merely characterizes this first 3,000 MMT CO₂e of potential as having a cost of “equal or less than \$0/tCO₂e”.

²¹ This illustrates a common distinction between bottom-up and top-down studies: since most top-down models define the reference case to be a \$0 carbon price, and abatement is measured relative to this reference case, no abatement potential exists at \$0 (since any potential that did occur at \$0 would be, by definition, in the reference case). In contrast, bottom-up methods typically calculate the economic potential of efficiency measures, many of which are strongly cost-negative, even if social and market barriers may limit their adoption. For a summary of the limitations of bottom-up MACs, particularly with respect to social and market barriers, see Jacoby, H. D. (1998).

to the potential for significant rent generation when the price of offsets significantly exceeds the marginal cost of reductions (Commission of the European Communities, 2009).

Other differences between MACs generally arise from the following:

- **Different projections of baseline emissions**, or the future emissions trajectories expected to occur in a “business-as-usual” scenario. Projections of baseline emissions are in turn dependent on assumptions regarding future baseline economic growth and what mitigation measures are assumed to be included in the baseline. Even if studies show similar findings regarding what relative reduction is possible, since abatement potential is measured relative to an emissions baseline, a higher projected baseline will result in a higher abatement potential (Amann, Rafaj *et al.* 2009; Clapp, Karousakis *et al.* 2009; US EPA 2010b; van Vuuren, Hoogwijk *et al.*, 2009).
- **Time window assumed for mitigation implementation**, or the start year that mitigation action can begin. Some models assume that mitigation implementation begins as early as 2005 (or even before), while others do not assume beginning of mitigation measures until 2013. This eight-year (or more) variation in starting year has a significant influence on abatement potential in future years: delays in action reduce potential and increase costs (Amann, Rafaj *et al.*, 2009).
- **Availability and costs of abatement options included**, such as the growth in penetration rates of carbon capture and storage (CCS), accelerated retirement of inefficient capital stock, nuclear power, and demand responses to behavior change and structural adjustments (Amann, Rafaj *et al.* 2009; Clapp, Karousakis *et al.*, 2009).

Other factors that can help explain differences in MACs include how well the model is calibrated to base year emissions (*e.g.*, as reported by countries the UNFCCC), whether the model uses a social planner or private investor discount rate, and whether the model includes transaction costs.

ENERGY-RELATED CO₂ IN PARTICULAR SECTORS

Efforts to develop an international offset framework – whether as an enhancement to CDM or through the design of a new sectoral crediting or carbon bank mechanism²² – can benefit from a more detailed understanding of CO₂ abatement potential within individual energy producing and consuming sectors. Sectoral breakdowns also help provide insights on how sectors may differ in terms of their potential to supply offsets.

Figure 3 below presents the sector-related offset potentials from two of the bottom-up studies cited above (Barker, Bashmakov *et al.* 2007; McKinsey & Company, 2009). Top-down models, such as MiniCAM, also generate sector-based potentials, but extracting the sector-based results and presenting them in a form comparable to these bottom-up results is a challenge.²³ And, as was true of the differences in the energy-sector-wide MACs displayed in Figure 2, variation in potentials in individual sectors arise in part from variations in assumptions about baseline, start date of implementation, technologies included, and other factors described above.

Additional sectoral detail is needed for estimating the potential for specific project types (*e.g.*, thermal power plant energy efficiency) or crediting mechanisms (*e.g.*, sectoral crediting baseline for a country’s cement sector). Several bottom-up MACs provide this detail (Bakker, Arvanitakis *et al.* 2007; McKinsey & Company, 2009) as do estimates by international agencies such as the IEA (IEA 2008; IEA, 2009) or UNFCCC (UNFCCC, 2007). Additional estimates are also starting to emerge in reference to particular sectoral mechanisms envisioned for the power sector and specific industrial sectors such as cement or iron/steel (Amatayakul 2008; Schmidt, Helme *et al.* 2008; Baron, Buchner *et al.*, 2009). Estimates of possible offset generation or abatement potential associated with sector mechanisms will be discussed further in Section 3.

22 Several observers, including the Project Catalyst policy initiative, have proposed the creation of a single offsets aggregator that would charge purchasers a price per ton close to the price of emissions allowances, and use the funds collected to acquire reductions at a lower price (closer to actual incremental costs), thereby leveraging greater emission reductions (Metz, 2009).

23 For a summary of the sector-based results of top-down versus a bottom-up method similar to the IPCC’s, see van Vuuren, D., M. Hoogwijk, *et al.* (2009).

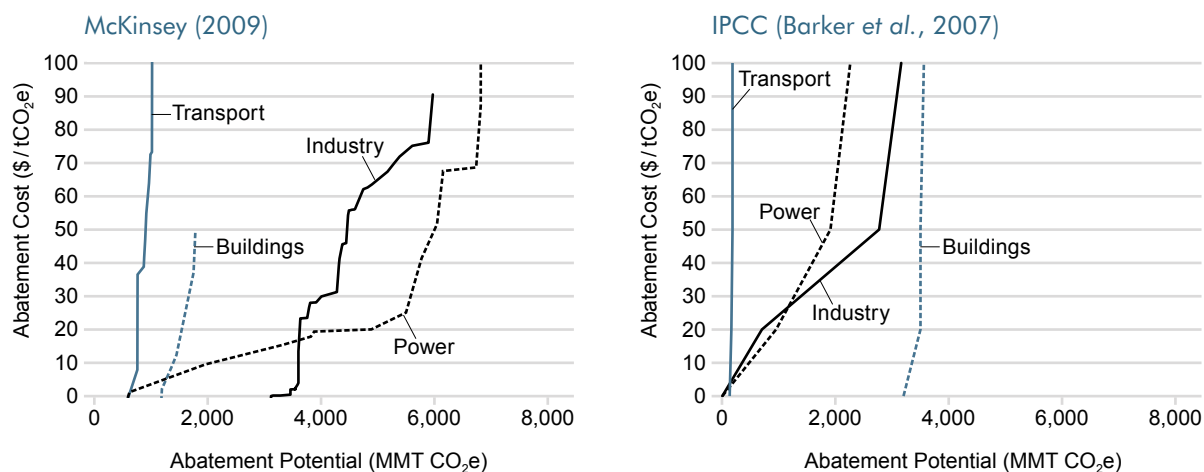


Figure 3: Developing country energy-related CO₂ abatement potential by sector in 2030
(At \$0/tCO₂e and above)²⁴

LAND USE, LAND USE CHANGE, AND FORESTRY

Land use practices can sequester or minimise the loss of carbon by growing trees on land not currently forested (afforestation and reforestation), increasing the carbon stock on existing agriculture and forest lands (*e.g.*, soil sequestration or forest management), and reducing emissions from deforestation and forest degradation (REDD). Of these categories, REDD generally, and avoided deforestation specifically, offers the greatest abatement potential in developing countries and is the focus here. Avoided deforestation is also one of the most controversial options, and as a result, unlike afforestation and reforestation, was not included in the Clean Development Mechanism of the Kyoto Protocol. Offset projects involving avoided deforestation have thus far been limited to voluntary offset markets, and even there, accounted for only one per cent of total transactions in 2008 (Hamilton, Sjardin *et al.*, 2009).

Several sources exist for marginal abatement curves for avoided deforestation – and, as in energy-related CO₂, both top-down and bottom up approaches exist. Bottom-up approaches include McKinsey and CSERGE (Strassburg, Turner *et al.*, 2009), and top-down approaches include those of the global land use models DIMA, GCOMAP, and GTM.

Differences in the three top-down models (DIMA, GCOMAP, GTM) largely arise due to differences regarding assumed carbon density per hectare, land area in forests, baseline deforestation rate, and discount rate (Boucher 2008; Kindermann, Obersteiner *et al.*, 2008). GTM results (Sohngen and Mendelsohn, 2007), used in U.S. government agency studies, generally yield the highest abatement potentials (of top-down models), and are driven largely by lower assumed land opportunity costs and higher carbon densities per hectare (Kindermann, Obersteiner *et al.*, 2008).²⁵

24 Note that both the McKinsey and IPCC curves include building and industry electricity efficiency measures in those respective sectors, not in the power sector. Also, note that since the IPCC did not distinguish potentials at negative costs (reporting only the potential up to \$0/ton), we use that same convention here to facilitate comparisons between the sector potentials rather than make the point, already stated, that McKinsey shows strong negative costs for a large number of options. A 2008 update to the IPCC cost curves – Hoogwijk, M., S. de la Rue de Can, *et al.* (2008) – was not included here because a comparable mid-range scenario for non-OECD countries was not included in that paper.

25 Note that the US EPA, CBO, and EIA have all used MACs from the GTM model – those attributed in Sohngen, B. and R. Mendelsohn. (2007) – in their analysis of international offset supply under Waxman-Markey. In addition, note that parameters for some of the models were updated for the Eliasch Review on *Financing Global Forests* commissioned by UK Prime Minister Gordon Brown (Eliasch, 2008): for example, carbon densities in the GCOMAP model were updated and resulted in a greater potential at any given cost (Sathaye *et al.*, 2008) compared to previous runs of the model. However, it is not clear whether these updates were made to the model for the IIASA review (Kindermann, Obersteiner *et al.*, 2008) or were made afterwards and only for the Eliasch review.

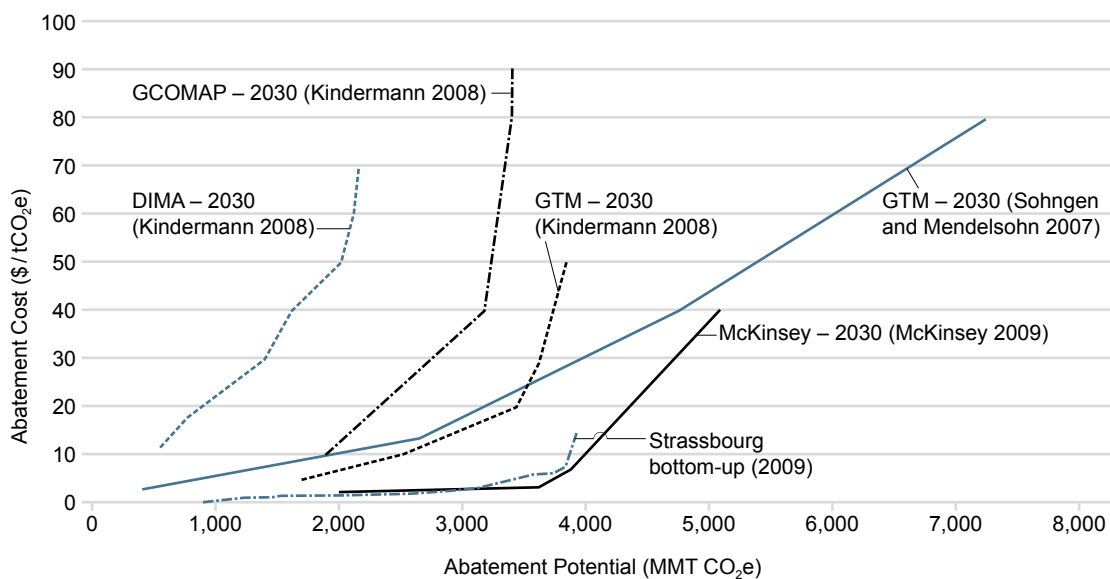


Figure 4: Avoided deforestation GHG abatement curves for 2030²⁶

Note: Studies of offset supply under U.S. legislation rely on the GTM model (Sohngen and Mendelsohn, 2007)

From the limited sample of MACs presented in Figure 4, there is a systematic difference between top-down and bottom-up approaches: as with energy sector MACs, the bottom-up analyses tend to show greater potentials at lower costs. Another review of MACs for avoided deforestation also came to this conclusion (Boucher, 2008) and recommended that a conservative approach would dictate using the top-down, rather than bottom-up, MACs, in assessing abatement potential. Given that the top-down models can generally account for supply and demand market interactions – crucial for avoided deforestation where transnational leakage can be substantial (Gan, 2007), we support this approach, but suggest that the bottom-up MACs (McKinsey and Strassbourg) may have utility in assessing the upper bound of offset potential – perhaps the potential associated with a offset crediting system that did not adequately address international leakage.

NON-CO₂ GASES

Opportunities to abate GHGs other than CO₂ arise in sectors as diverse as agriculture (*e.g.*, methane from livestock and nitrous oxide from fertilizer use), coal mining (*e.g.*, methane from mines), and a host of industrial sectors that produce or use highly potent fluorinated gases or nitrous oxide (*e.g.*, acid production and refrigerant manufacturing). Most global reviews and studies of non-CO₂ gases (including the IPCC) have cited the work of US EPA in this field, although select other estimates do exist for certain gases and regions (Smith, Pushpam Kumar *et al.* 2007; Amann, Isaksson *et al.*, 2008). Figure 5 presents US EPA's non-CO₂ abatement curves for 2030, which include methane, nitrous oxide and fluorinated gases. The total of abatement potentials for all measures included in this figure is on the order of 2,000 MMT CO₂e at prices above \$10 per metric ton of CO₂e, an abatement potential less than the developing country energy-related CO₂ and global avoided deforestation curves presented previously in Figure 3 and Figure 4. Note also the relatively high potentials at \$0 for some measures (*e.g.*, for CH₄, methane, project types). These results suggest that barriers other than economics are preventing the implementation of otherwise cost-effective actions (*e.g.*, the capture of methane for direct use as a fuel or to burn and generate electricity).

26 As pointed out by Murray, B. C., R. Lubowski, *et al.* (2009), the MACs from Sohngen, B. and R. Mendelsohn. (2007) are based on rising price scenarios, and are thus better suited to a policy scenario where a GHG cap becomes more stringent over time than the constant price scenarios reported in the MACs of Kindermann, G., M. Obersteiner, *et al.* (2008).

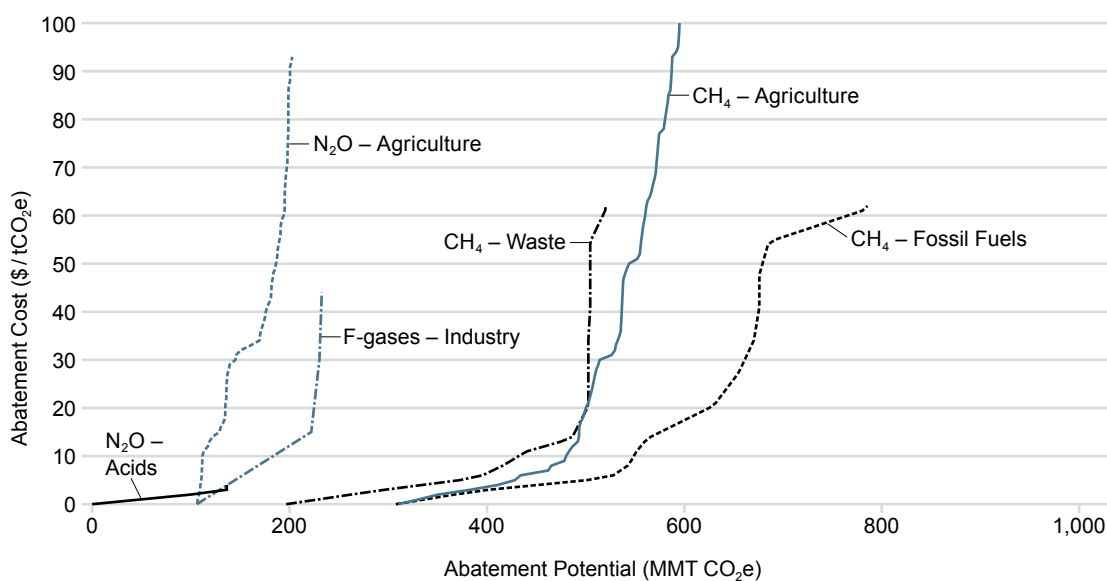


Figure 5: International (non-U.S.) non-CO₂ GHG abatement curves for 2030
(US EPA, 2006) – At \$0 and above²⁷

Other analysts have attempted to extend US EPA’s MACS to the middle and end of this century (Lucas, van Vuuren *et al.*, 2007) for the purpose of assessing offset supply, but US EPA’s upcoming revisions²⁸ are again expected to set the global standard for non-CO₂ MACs.

SUMMARY OF AVAILABLE MARGINAL ABATEMENT CURVES

Marginal abatement curves (MACs) depict estimates of what quantity of GHG abatement is projected to be available at different costs in future years. This section has summarized MACs in sectors and world regions that could potentially supply international offsets to capped entities in a U.S. cap-and-trade program. Key findings concerning MACs include the following:

²⁷ In their 2006 report, EPA reported Group 1 country abatement potentials for “2020+” and Group 2 country potentials for “2025+”. We adopt the sum of those two curves here for 2030, understanding that the EPA’s upcoming extension of these curves will supersede the EPA’s 2006 work cited here.

²⁸ The US EPA is reportedly updating both their projections of baseline non-CO₂ gases (US EPA 2006a) and estimates of abatement potential (US EPA 2006b) with updated methodologies and assumptions, as well as extending them more precisely to at least 2030.

- **Available MACs can differ widely in their underlying assumptions and, in turn, estimated abatement potentials and costs.** Key factors contributing to differences between MACs include projections of baseline emissions (and the abatement measures included in the baseline), availability and costs of abatement options included, the time window assume for mitigation implementation, the discount rate assumed, and whether the model used considers demand-side responses to behavior change and structural adjustments in the economy such as changing energy or forest product prices (Amann, Rafaj *et al.* 2009; van Vuuren, Hoogwijk *et al.*, 2009). In the energy sector, a recent MAC comparison study found that models that include behavior change can display twice as much abatement potential as models that do not (Amann, Rafaj *et al.*, 2009).

- **Few comprehensive energy-related MACs are available specific to developing countries,** countries that would be the source of offsets supplied to cap-and-trade systems in industrialized countries (including the U.S.). Only some of the available global MACs (*e.g.*, those of McKinsey, US EPA’s MiniCAM model, and the IPCC) report separate developing-country abatement potentials, although other models could certainly be configured to provide such MACs as indicated by some recent meta-analyses (Hoogwijk, Vuuren *et al.*, 2009). Several individual country

studies do exist for large developing countries (La Rovere, Pereira *et al.* 2006; TERI 2006; Tsinghua University of China 2006; Winkler, 2007). Since these studies do not generally use common methods and consistent assumptions across countries, and often consider only a subset of potential abatement options, they are of limited utility for the purposes of this analysis.

- **The use of MACs for assessing abatement potential presents several limitations.** Among them:

- **MACs derived from top-down models typically lack the sector or technology-specific detail** needed to assess where mitigation opportunities exist and how potential offset mechanisms or other funding sources might credit emission reductions. However, they can excel at reflecting economic inter-relationships among products, regions and sectors, as well as the indirect impacts of offset activities such as emissions leakage across countries or sectors.
- **MACs derived from bottom-up models tend to be more useful for offset supply analysis, as they can more readily distinguish among technologies and sectors in a manner that better corresponds to how offset mechanisms and crediting methodologies tend to apply** – that is, discrete project, technology, and/or sector-specific actions rather than economy-wide transformation. However, bottom-up MACs are weak in terms of capturing economic relationships and indirect effects (*e.g.*, leakage), and may understate transaction costs and thus overstate abatement and offset supply potential.
- **All MACs are subject to path dependence and significant uncertainty.** A MAC for any given year assumes (whether implicitly or explicitly) a global policy and technology pathway taken between now and the year in question. Actions and policy choices in early years greatly affect abatement potentials and costs in later years. One means of addressing this path dependence (as well as the inherent related uncertainty) is to use a range of potential policy scenarios in early years to generate alternative MACs for scenario analysis (Lazarowicz 2009; US EPA 2010b).

- **The use of MACs in reduced-form (*e.g.*, spreadsheet) models can yield results that depart from the parent models.** MACs represent only a particular slice of a model's results, but analysts have often used them to generate other, reduced-form models for specialised and extended applications. Using MACs in this way, such as to illustrate likely CO₂ prices and potential offset supply and usage, can generate results that depart substantially from results that would be obtained from the parent model (Morris, Paltsev *et al.*, 2008).

In addition, when MACs are used to project future offset supply, several other factors become important, including transaction costs, administrative infrastructure, and methodologies for generating credits. The next section reviews methods to generate estimates of offset supply, including how existing analysts adapt MACs to assess offset supply.

3 REVIEW OF METHODS TO PROJECT FUTURE OFFSET SUPPLY

Several existing studies estimate the supply of GHG offsets from international (largely developing-country) sources. This section provides a brief overview of these studies (further detail is provided in Annex 2), discusses the factors considered in estimating offset supply, and summarizes quantitative estimates of offset supply in the year 2020.

OVERVIEW OF EXISTING STUDIES

Most studies that project future offset supply start with MACs, which are then adapted to include consideration of administrative and market factors (e.g., transaction costs) to serve as estimates of offset supply. Alternatively, a few studies instead utilise historical experience with the GHG offset market and project past trends into the future (Carbon Trust 2009; Parpia 2009; Point Carbon, 2009).²⁹

Table 1 lists over a dozen studies of offset supply according to the regions and sectors they address. As the table indicates, most studies of offset supply

focus on supply from a global perspective (gross offset supply), not on net supply (i.e., net of other demands) to the U.S. or to other particular source of demand, such as Europe). Of particular relevance to policy dialogues in the U.S., however, are the US EPA, EIA, and CBO studies, which focus on the supply of international offsets to capped entities under HR 2454, the Waxman-Markey bill passed in the U.S. House of Representatives in 2009. As discussed below, the global studies can help offer particular insights not considered in the U.S. analyses and help suggest a framework for future assessments of potential international offset supply under U.S. cap-and-trade legislation.

The variation in assumptions among the three U.S. government analyses lead to divergent estimates of international offset supply through 2020. Figure 6, below, summarizes estimates of net international offset supply to capped entities in the US EPA, Energy Information Administration (EIA), and Congressional Budget Office (CBO) studies. In this case, the diverging estimates of offset supply do not

Table 1: Landscape of studies of international (global or developing country) offset supply

	Studies from a U.S. Policy Perspective	Studies from Global Perspective
Multi-sector	<ul style="list-style-type: none"> US EPA (2009 and 2010) US EIA (2009) CBO (2009) 	<ul style="list-style-type: none"> Energy Research Centre of the Netherlands (Bakker, Arvanitakis <i>et al.</i> 2007; Bole, Saïdi <i>et al.</i>, 2009) Netherlands Environmental Assessment Agency (den Elzen, Beltran <i>et al.</i>, 2009) UNFCCC (Haïtes, 2007) New Carbon Finance (Parpia, 2009) Carbon Trust (2009) Point Carbon (2009)
Specific industries only (sectoral approaches)		<ul style="list-style-type: none"> OECD/IEA (Baron, Buchner <i>et al.</i>, 2009) CCAP (Schmidt, Helme <i>et al.</i>, 2008) UNEP (Amatayakul, 2008)
Avoided deforestation only		<ul style="list-style-type: none"> Centre for European Economic Research (Anger and Sathaye, 2008) McGill University (Isenberg and Potvin 2009 – in review) ONF International (2008)

²⁹ Given the high degree of uncertainty regarding the future of the global carbon market and the role that existing institutions and programs are likely to play, basing future projections of offset supply on historical trends and institutional performance is uncertain at best.

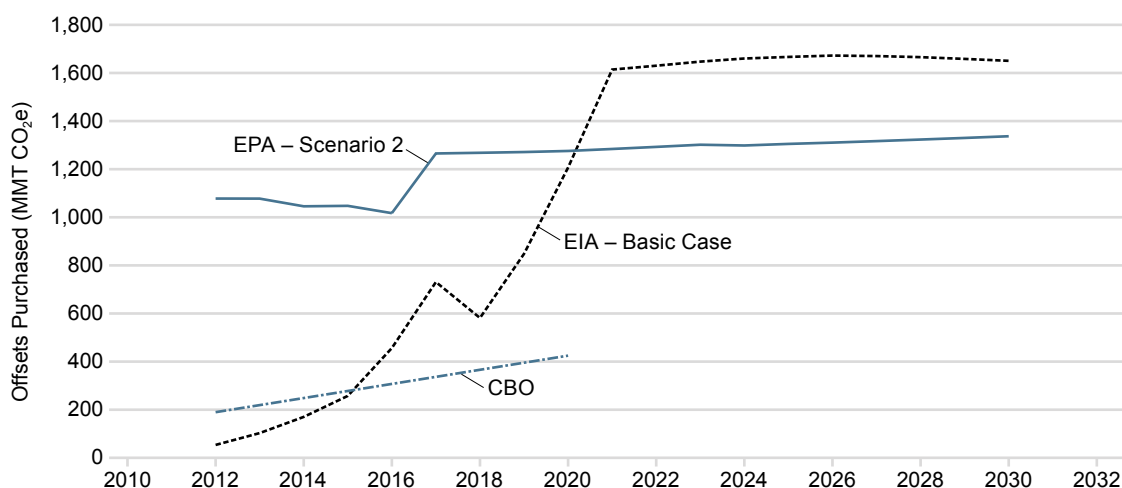


Figure 6: Estimates of international offset purchases in the U.S. under the Waxman-Markey Bill (HR 2454)

Before 20 per cent discount to yield allowance-equivalent offsets³¹

result from the underlying MACs, since all three use the same curves (US EPA 2006; Sohngen and Mendelsohn, 2007; US CCSP, 2007), but instead from each agency's assumptions regarding market update, timing and stringency of country commitments, and other factors.³⁰

FACTORS AFFECTING ESTIMATES OF INTERNATIONAL OFFSET SUPPLY

Several factors influence estimates of international offset supply, including not only abatement potential (as assessed, for example, by a MAC) but also offset mechanism design *e.g.*, crediting methods and stringency, offset market factors (*e.g.*, transaction costs, country risk), alternative mitigation actions (*e.g.*, developing countries' own mitigation actions,

or NAMAs), and competing demands from other countries. Figure 7 displays these factors and the general sequence of their consideration in translating a MAC to an offset supply curve and subsequently to net offset supply in a particular country (in this case, the U.S.). Each of these factors is discussed in greater detail below.

As the reader might deduce from Section 2 of this report, the choice of marginal abatement curve (for those estimates that rely upon them) can be one of the most significant determinants of projected offset supply (den Elzen, Beltran *et al.*, 2009). The results of these MACs are a function of two principal factors:

- **Mitigation model design and assumptions:** Choices regarding top-down versus bottom-up model structure (and corresponding treatment of demand-response and other behavioral options), projections of future baseline emissions, time window assumed for mitigation implementation, discount rate, and technologies considered (*e.g.*, CCS) can all substantially affect the range of projected abatement potentials and costs (a MAC) (Amann, Rafaj *et al.* 2009; Clapp, Karousakis *et al.*, 2009). Most studies to date have focused on the supply of offsets to an international market and used a single set of MACs, although some (den Elzen, Beltran *et al.*, 2009) use alternative MACs to test sensitivity, with wide swings in resulting estimates of project offset supply. Furthermore, as discussed previously, use of MACs in reduced-form (largely spreadsheet-based) economic models bring its own limitations – namely, that results

30 Another factor separate from the MACs is each analyst's assumptions or findings regarding future carbon price trajectory. However, since the differences in the price trajectories of the EPA, EIA, and CBO are not great enough to explain the large differences in offset usage displayed in this figure, we focus instead on the explanations more directly related to adapting the underlying MAC for use as an offset supply curve.

31 The Waxman-Markey bill requires capped entities to submit 1.25 international offsets in lieu of one allowance in 2018 and beyond, with a maximum of 1,000 MMT CO₂e of such allowance-equivalent offsets allowed, although this limit may be extended if domestic offset usage is less than 900 MMT CO₂e.

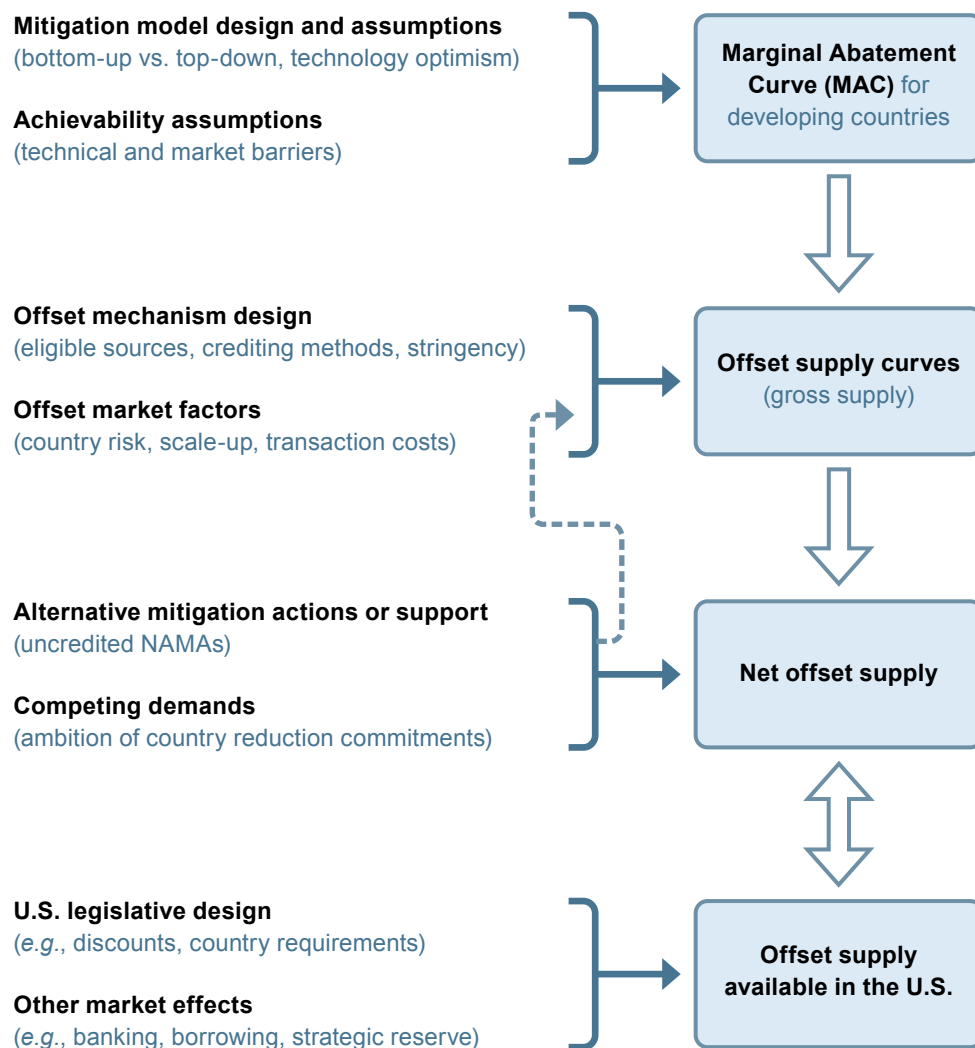


Figure 7: Factors to consider in projecting future international offset availability in the U.S.

obtained from applying the stand-alone MACs in a reduced-form model can differ markedly from what would be obtained from the original model (Morris, Paltsev *et al.*, 2008).

- **Assumptions about the “achievability” of the reductions:** A wide variety of social, market, or technical barriers can prevent the full technical or economic abatement potential in a MAC from being realized. Some analysts assume these barriers are addressed in the underlying MAC, while others discount the abatement potentials from MACs to further account for uncertainties regarding these barriers. For example, the EIA discounts US EPA’s developing country agricultural and forestry MACs by 50 per cent, one of the reasons the

EIA’s projections of international offset usage in Figure 6 are lower than those of US EPA.

Furthermore, to convert a MAC into an offset supply curve requires considering how offset mechanisms might work in practice, and thus:

- **Offset mechanism design:** Recent cap-and-trade legislation under consideration in U.S. Congress calls for international offsets from project-based mechanisms, sectoral crediting mechanisms, and efforts to reduce emissions from deforestation and degradation (*e.g.*, REDD) (Larsen, Kelly *et al.*, 2009). Yet most significant details – such as how these mechanisms would credit projects and what particular types of projects would be allowed to

generate offset credits – have yet to be decided. Choices regarding what sources are eligible and how reductions are quantified and credited will be critical both for offset supply and the emission reduction effectiveness of the enabling legislative framework.

While experience and insight into the supply of project-based crediting exists (in part, from the CDM) and modelers have begun to tackle estimates of potential credits under REDD (Kindermann, Obersteiner *et al.*, 2008), studies that focus on the potential of sectoral crediting mechanisms have only recently begun to emerge. Under sectoral crediting mechanisms, the choice of sector baseline or fixed sector target is critical, as “business-as-usual” is no longer the sole point of comparison in developing estimates of abatement potential (and associated MACs) and other means of sector-wide (as opposed to project-specific) crediting emerge. In particular, one leading sectoral mechanisms under consideration would define sector- and country-specific “no-lose” baselines (which would generally reflect some country emission reduction ambition and would therefore be lower than business-as-usual emissions projections) below which offsets could be generated for sale to developed countries (Baron, Buchner *et al.*, 2009). An analysis by Point Carbon suggests, however, that the potential for sectoral crediting is small – primarily because they conclude that sectoral crediting would so mute the price signal to individual firms that there would be little financial incentive to develop projects (Point Carbon, 2009).³² On the other hand, modeling conducted in the UK for Prime Minister Gordon Brown (Lazarowicz, 2009) suggests that sectoral crediting could yield greater abatement at lower cost than project-based (*i.e.*, CDM) mechanisms due to the ability of sectoral crediting mechanisms to more readily affect performance of entire industry sectors, not just individual projects. Regardless, analyses of sectoral crediting potentials are just beginning to emerge, and the potential supply of sector-based credits is far from certain (Baron, Buchner *et al.*, 2009). Most analysts have yet to address the topic directly, assuming implicitly that offset mechanisms will evolve or emerge to

realize the potential offset supply suggested by their analyses.

The potential supply of offset credits from sectoral crediting mechanisms in the future will also be significantly impacted by any other sources of financing directed towards these abatement activities. For example, under sectoral “no lose” crediting (Ward, Streck, *et al.*, 2008), a significant portion of the emission reductions below business as usual could be driven through either government funding or regulation (because the government has committed to drive reductions in a given sector below a certain point) or through the receipt of funding through multilateral, international development funds. In principle, these emission reductions – if counted toward of a country’s own emission reduction commitment – should not be eligible to receive offset credit. If a significant amount of the projected abatement from a given sector is supported through alternative financing mechanisms, then the supply of offsets sourced from these sectors could be relatively lower, and possibly only available at higher cost (if the lowest cost abatement opportunities were instead realized through the government regulation or funding). While such an outcome – the achievement of low cost reductions through other funding means – might increase the price of international offsets, it would also yield greater global emission reductions.

Perhaps more critically, regardless of offset sources, if rules and methodologies for crediting offset projects result in credit issuance greater than the actual emissions abatement attained, then, in effect, the U.S. cap on emissions would be breached and global greenhouse gas emissions would increase. For example, if rules allowed for an offset credit to be issued to an activity that would have occurred anyway (in the absence of the GHG offset payment), then the offset project would not result in a decrease in emissions.³³ In fact, since the U.S. entity that purchased that offset credit would be allowed to increase their emissions by a corresponding amount, the net effect would be that global greenhouse gas emissions would increase by an amount equivalent to the non-additional offset credits awarded. Few studies consider this possibility by assessing how offset mechanisms would treat assessments of

32 Furthermore, Point Carbon expects sectoral crediting to have a net negative effect on offset supply, as sectoral crediting begins to replace CDM but with reduced direct incentive to project developers to undertake projects, per Point Carbon (2009).

33 For summaries of concerns over additionality in the CDM, see Schneider, L. (2007) and Wara, M. W. and D. G. Victor (2008).

additionality, permanence, leakage, or other related factors, assuming instead that the underlying MACs inherently (and accurately) assess potential offset crediting.³⁴

- **Offset market factors:** The administrative infrastructure, financial resources and risks, social barriers, and transaction costs needed to translate abatement potential into saleable offset credits could be substantial. Analyst treatment of these factors can differ markedly and dramatically impact projections of offset supply. For example, a key distinction between the CBO and EIA analyses of offset supply under HR 2454 and that of US EPA is that EPA, in its core scenarios (e.g., Scenario 2 in US EPA, 2009), uses its marginal abatement cost curves directly as offset supply curves and assumes availability and implementation as early as 2012.³⁵ By contrast, the EIA assumes that the market penetration of the technologies and practices needed to generate GHG abatement ramp up following classic technology market penetration curves and that significant portions of the potential in some sectors can never be realized (US EIA, 2009). The CBO takes an even more extensive and nuanced approach by assuming transaction costs must be applied to realize the abatement potentials, that investment risks in certain countries can be substantial,³⁶ and that the actual availability of abatement potential would depart from US EPA-provided MACs by country and sector. (For a point-by-point comparison of the approaches, see Table 3 in Annex 2.)

In addition, few studies that project international offset supply based on marginal abatement curves consider the historical experience of carbon market development through the Kyoto Protocol's Clean Development Mechanism (CDM). Carbon market

analysts such as Point Carbon and Carbon Trust, on the other hand, have applied actual, historic build-up rates and lead times needed to develop GHG abatement projects in their projections of offset supply – assumptions that lead to significantly curtailed availability of offsets in early years as compared to most MAC-based approaches. In particular, estimates based on projections of past experience in the CDM indicate a potential global offset supply between 1,500 and 2,000 MMT CO₂e in 2020 (Carbon Trust 2009; Point Carbon, 2009). According to another carbon market analyst, New Carbon Finance, if forests are included in the carbon market, potential supply from forestry sources (both afforestation/reforestation and REDD) would add 2,000 MMT CO₂e in 2020 to these projections (Parpia, 2009) for a potential global total of over 3,500 MMT CO₂e.

Given that countries and regions (e.g., the European Union) other than the U.S. will be buyers of GHG offsets from developing countries, and that other commitments and mechanisms could address the same abatement tons that might otherwise yield offsets, the *net* supply of international offsets available in the U.S. (as in “net” of other demands) should consider:

- **Alternative mitigation actions or support:** In addition to engaging with the international carbon market through offset mechanisms, developing countries may also undertake Nationally Appropriate Mitigation Actions (NAMAs). In general, NAMAs may either be unilateral, supported and funded by developed countries, or credited as offsets and some industrialized countries have proposed that developing countries commit to some level of NAMAs unilaterally before receiving support or offset credits for further actions (Aasrud, Baron *et al.*, 2009). Accordingly, to the extent developing countries do undertake unilateral or supported NAMAs (or go further in future years and adopt binding caps), these actions should not be eligible for the carbon market and could therefore reduce potential offset supply. In other words, the more ambitious developing countries are in reducing their own emissions, and the more generous developed countries are in providing mitigation finance, the fewer offsets may be available to the international market, since those reductions could target the same emissions that otherwise could be supplied to the offset market (Bole, Saïdi *et al.*, 2009). Analysts differ in how they treat developing country actions, with very few (if any) distinguishing unilateral from supported NAMAs, yet most (including the

34 Several studies test simply whether or not certain project types (especially avoided deforestation) would qualify, but few assess alternative crediting methodologies / protocols.

35 The EPA does discount the technical potential in some of its curves, with a 90 per cent reduction applied to its energy-related CO₂ curve through 2015 and a 75 per cent reduction applied between 2015 and 2025.

36 Few studies include an assessment of country-specific investment risk, but those that do often use factors such as those by Böhringer, C. and A. Löschel (2008) who proposed country-specific factors but concluded the changes in overall abatement and distribution of that abatement was “rather small.”

US EPA, CBO, and EIA analyses) assume that developing countries adopt caps in some sectors (e.g., energy-related CO₂) in the future (e.g., in 2025), rendering those sectors no longer potential sources of offset credits, unless reductions exceed the targets set by the cap (the cap could become the new baseline).

- **Competing demands for offsets from other countries:** The ambition of other industrialized (and developing) countries in reducing emissions (and degree of reliance on offsets) will affect the supply of offsets to the U.S. The price of international offsets is dependent on both supply and demand, including demand from the U.S., European Union, and other countries (including any developing countries) that commit to binding reductions in emissions and allow use of offsets from developing countries. Country demand for offsets is determined by the ambition of each country's emission reduction target, the availability of abatement options within each country's capped sectors, the availability of domestically provided offsets, and both system-wide and entity-level limits on the use of offsets. Studies differ in assumptions regarding international demand. For example, US EPA's supplemental analysis of HR 2454 updated its Annex 1 country caps to be more stringent, based on the outcome of the July 2009 Major Economies Forum (US EPA 2010a), and finds that the expected price of international offsets increases by approximately one quarter, with significant reductions to the quantities of international offsets expected to be purchased in the U.S. Similarly, a recent assessment of the effect of alternative policy choices on carbon market supply and costs found that the level of ambition by Annex 1 and non-Annex 1 countries is one of the most significant impacts on international offset supplies and costs (den Elzen, Beltran *et al.*, 2009).

In addition to the factors discussed above, details of U.S. legislation would also need to be considered to determine estimated offset supply available to capped entities in the U.S. In particular:

- **U.S. legislative design**, including whether discounts on the use of offsets are applied (e.g., the 20 per cent discount on international offsets in 2018 and beyond in HR 2454) and whether offsets can only be supplied from developing countries that meet certain criteria (again as in HR 2454, which defined what countries were considered

“developing” and placed particular criteria on what types of countries were eligible for sectoral crediting). Of the leading U.S. government studies of HR 2454 (CBO 2009; US EIA 2009; US EPA, 2009), only the CBO study appears to make specific assumptions regarding how long it takes to negotiate and enact agreements with developing countries to supply offsets. US EPA's analysis of the American Power Act (US EPA 2010b) addresses the potential lag time in supply of international offsets by introducing several sensitivity scenarios that delay the availability of international offsets.

- **Other market effects** related to the cap-and-trade program design that affect demand for offsets, including provisions for banking and borrowing allowances that can smooth market prices and increase investor certainty, a strategic reserve of allowances, and other factors (Fankhauser and Hepburn, 2009). Assessing these factors requires modeling the decision by capped entities to make internal reductions versus the purchase of offsets, and typically requires a model of the broader economy (e.g., a computable general equilibrium model like US EPA's ADAGE or IGEM).

SUMMARY

This section discussed factors considered by analysts in assessing international offset supply. Analyst inclusion and treatment of these factors differ markedly, with some analyses (e.g., US EPA's core HR 2454 scenario) assuming that economic GHG abatement potential in developing countries can be rapidly realized as offset credits, while others (e.g., carbon market analysts) predicting a much more gradual increase in the offset market akin to trends observed to-date in the CDM. Varying treatment of these factors lead to diverging estimates of potential future offset supply, as indicated in Table 2, below. The table compares, for the year 2020, estimates of gross international offset supply (for which U.S. entities must compete) with estimates of expected purchase of international offsets under the Waxman-Markey bill and the limits of international offsets in current U.S. cap-and-trade bills.³⁷

³⁷ Estimates here are for 2020 because carbon market analysts more commonly focus on 2020 than 2030, the year discussed previously in this paper and which is more common for researchers, including the IPCC.

4 FINDINGS

As this paper illustrates, the future price and availability of international offsets is subject to a large number of highly uncertain factors, ranging from the future technology development and policy commitments to the practical considerations of offset markets. Based on our review, we find that:

- 1 Studies that use marginal abatement curves directly as offset supply curves yield estimates of international offset supply that are highly optimistic.** For example, estimates of offset supply embedded in the US EPA's marginal abatement curves suggest that about 6,400 MMT CO₂e could be available in 2020 from developing countries (US EPA, 2009), an amount far greater than estimates by other federal agencies (CBO) and carbon market observers such as New Carbon Finance, Point Carbon, and the Carbon Trust, whose estimates range between 1,500 and 2,500 MMT CO₂e, and who have considered past trends in international offset markets and how new offset mechanisms, particularly those addressing reduced deforestation and degradation (REDD), might develop over time. All of these estimates are much higher than the supply of CDM credits in recent years of about 300 MMT CO₂e annually (UNEP Risoe Centre, 2010).
- 2 Existing studies suggest that by 2020 gross international offset supply should exceed the U.S. demand for international offsets under current Congressional cap-and-trade designs.** As shown in Table 2, estimates of international offset supply range from 1,500 MMT CO₂e to over 6,000 MMT CO₂e in 2020, while projections of international offset purchases in the U.S. under a cap-and-trade bill range from around 400 MMT CO₂e (CBO) to almost 1,300 MMT CO₂e (EPA) for the Waxman-Markey bill, accounting for the legislation's 20 per cent discount on offset value (U.S. entities would need to surrender 5 tons of international offsets for every 4 tons of substituted allowances). Among Congressional bills, Waxman-Markey represents the high end of allowable international offset use with a limit of 1,250 MMtCO₂e, expandable to 1,875 MMT CO₂e should domestic offsets prove to be of limited availability (when taking into consideration the discount).
- 3 Competition with other national governments and entities with emission reduction obligations (e.g., in the EU), as well as with policies and**

measures undertaken by developing countries as part of their own mitigation contributions, will reduce the net offset supply available to U.S. entities. The ambition of climate policies in other countries will also be a key factor influencing offset supply, and is likely to continue as a major area of international negotiation and uncertainty for some time. Existing analyses of potential supply and demand balances differ widely – with some predicting a large oversupply of international credits, which, in the absence of binding limits on the use of offsets in industrialized countries, would lead to a collapse in carbon prices (Carbon Trust 2009; Parpia, 2009). Yet as an increasing number of industrialized countries make GHG reduction commitments (including the U.S.), estimates of demand from industrialized countries have consistently been upgraded, such that some analysts – particularly those that have been pessimistic on the supply of offsets from sectoral crediting and REDD – have suggested that demand may instead actually “far outweigh” supply (Point Carbon, 2009). Given these (and other) divergent viewpoints, the rapid evolution of country-level commitments in late 2009 and early 2010, and the large uncertainties concerning future supply, additional analysis is needed. In fact, the relative lack of analysis concerning this interaction of future demands with supply has been called “the greatest single weakness in the current negotiating process” (Carbon Trust, 2009). In the U.S., analyses of the availability of offsets to U.S. markets under cap-and-trade legislation could do more to account for dynamics of offset demand (e.g., potential for excess allowance supply, offset limits in Europe) and supply (e.g., unilateral or supported NAMAs). Further research on the interaction of offset supply and demand with other countries' climate policies could be particularly helpful.

- 4 Offset mechanism design and market factors are critical in affecting offset supply and quality, but have yet to be systematically considered in offset supply assessments.** Studies listed in Table 2 differ markedly in their treatment of offset mechanism design and market factors. Based on our review, key factors that merit more explicit treatment include:
 - Potential sources of offset supply (e.g., offset project types, sectoral crediting mechanisms, REDD);

- stringency of offset crediting programs and related emissions benefits (most existing analyses assume instead that a “ton is a ton”);
- establishment of international governance structures and agreements to enable supply from developing countries; and,
- lag times needed for technical and administrative scale-up of crediting infrastructure and technology uptake and implementation.

Clearly, much is unknown about the future supply (and demand) for international offsets. Analyses by U.S. government analysts – the most public and widely read analyses of offset supply under U.S. legislation – explicitly consider some of the significant factors likely to affect offset supply, but include little consideration of offset mechanism design and related offset quality issues. This paper has outlined many of these factors, as summarized in Figure 7, which can be incorporated into future analyses of international offset supply and quality. Such analyses could prove particularly germane as the Congress continues deliberation on the role of international offsets, include whether and how to recognize CDM credits, develop new sectoral crediting mechanisms, and consider approaches to awarding offsets for reduced deforestation.

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ANNEX 1: COMPARISON OF BASELINE EMISSIONS ESTIMATES

As discussed in the main body of this report, differences in projections of baseline emissions can directly affect estimates of abatement potential, which is assessed relative to that baseline. For example, McKinsey's projected global baseline emissions in 2030 are roughly 25 per cent higher than the IPCC's *Fourth Assessment Report* mid-range estimates (Barker, Bashmakov *et al.*, 2007), meaning that even if McKinsey and the IPCC made equivalent assumptions regarding the relative reduction potential in each sector (as they did for many sectors), McKinsey's estimates would be, on average, 25 per cent higher. McKinsey also assumed that power sector emissions could be abated at a greater rate than did the IPCC through much faster penetration of solar electricity (both PV and CSP) and carbon capture and storage (CCS) technologies.

Figure 8, below, compares the global baseline emissions estimates of several of studies, along with three other important baseline scenarios cited in the literature (IPCC A1FI, WEO 2008, and IEO, 2009). As the figure indicates, McKinsey's projected 2030 energy-related CO₂ emissions are roughly 25 per cent higher than many of the other studies listed except the A1 Fossil Intensive (A1FI) scenario of the IPCC (Nakicenovic, Alcamo *et al.*, 2000) and IMAGE-TIMER runs of the Netherlands Environmental Assessment Agency (van Vuuren, Hoogwijk *et al.*, 2009). A more detailed comparison of McKinsey's baseline to the others suggests it is particularly higher for China and the rest of developing Asia, as well as for the industry sector.⁴⁷

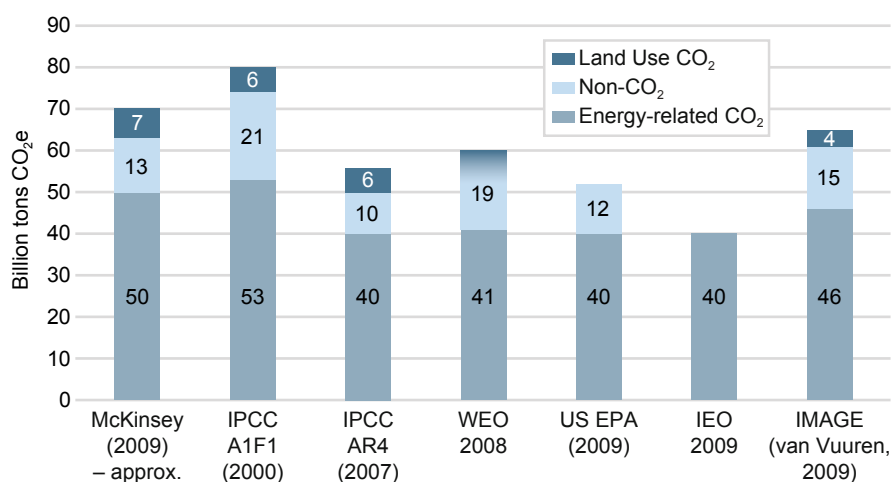


Figure 8: Comparison of global baseline 2030 emissions projections⁴⁸

47 As discussed in Levine, M. D. and N. T. Aden (2008), many of the global equilibrium models (including those covered in Figure 8) use data that is several years old and have largely not captured China's explosive growth in the mid-2000s. As a result, McKinsey's higher baseline – at least the portion for China – could potentially be a more realistic projection.

48 McKinsey does not report energy-related CO₂ emissions distinct from all GHGs. Here we report McKinsey's baseline 2030 estimates for the power, industry, transport, and buildings sectors less 40 per cent of their

chemical industry emissions (assumed to be non-CO₂ process emissions per a note in their text) and emissions they note as associated with natural gas piping, which we assume to be largely methane. Other non-CO₂ and non-energy related emissions are certainly included in the estimate here attributed to McKinsey, but we were not able to disaggregate them any further and they are not likely large enough to make up much of the difference between the McKinsey baseline and other baselines reported.

ANNEX 2: SUMMARIES OF MACS AND OFFSET SUPPLY ESTIMATES REVIEWED

TABLE 3: SUMMARY OF STUDIES OF INTERNATIONAL OFFSET SUPPLY

Study	Sectors	Region / country coverage	MAC curves used	Time scale	Offsets protocols / crediting methodologies	Scale-up (project type or country)	Transaction costs / other market factors included	International country GHG abatement commitments
Carbon Trust (Carbon Trust, 2009)	Those included in CDM (i.e., excludes forestry sector)	Developing countries	None (instead based largely on market trends)	To 2020	Implicitly assumes CDM-like methods for most of the supply and calls for CDM reforms (e.g., programmatic CDM, sectoral approaches)	Largely assumes continuation of current trends in CDM volume	Included implicitly since projections based on CDM volume; states that transaction costs are not major driver but "in combination with other factors... limit the kinds of projects for which the project mechanisms make sense."	Not specifically included in projections, but states that "lack of any internationally accepted process to analyze the interaction of supply... with the demand implied by future emission targets is the greatest single weakness in the current negotiating process."
Center for European Economic Research (Anger and Sathaye, 2008)	Avoided deforestation	Global	Own MACs derived from GCOMAP model	To 2020	Not specifically addressed	Not specifically addressed	Transaction costs (Antinori and Sathaye, 2007) CDM project risk factors (Böhringer and Löschel, 2008) Adaptation tax of 2% of CDM revenues	Caps: individual caps for Annex B countries; no caps for non-Annex B countries Abatement demand modeled using POLES BAU emissions from Netherlands Environmental Assessment Agency (Van Vuuren, Lucas et al., 2006)
Energy Research Centre of the Netherlands (Bakker, Arvanitakis et al., 2007)	Agriculture (CH ₄) CCS Energy Forestry Industry Waste	Non-Annex 1, Russia, and Ukraine	ECN's MAC from TETRIS project (Wetzelaer, Linden et al., 2007)	2020	Apply additional adjustment factors for select CDM project types ⁴⁹ Otherwise, assume that approved methodologies exist	Not specifically included, although partially addressed through market factors described at right	CDM project risk factors ⁵⁰ Discounting for social technology adoption barriers Correction factors to programmatic CDM to account for market vs. economic potential ⁵¹ Known alternative policies / technology trends in host countries that reduce offset supply	Scenario A: same Annex B targets as currently (e.g., 20% reduction target for EU) Scenario B: rapid roll-out of targets to include U.S. and China; 30% reduction in EU

49 Avoided deforestation, renewable electricity, cement blending, and waste fuel utilisation. In addition, select eligibility assumptions were applied for avoided deforestation, CCS, "clean coal", HFC-23 destruction foam, and HCFC-22 plants.

50 Per an earlier Bohringer study not fully cited in the report.

51 Correction factors were applied to energy efficiency projects in the buildings/industry/power sectors, biofuel consumption, transportation, and CH₄ agriculture sectors

Table 3: Summary of studies of international offset supply (continued)

Study	Sectors	Region / country coverage	MAC curves used	Time scale	Offsets protocols / crediting methodologies	Scale-up (project type or country)	Transaction costs / other market factors included	International country GHG abatement commitments
Energy Research Centre of the Netherlands (Bole, Saidi et al., 2009)	Agriculture (CH ₄) CCS Energy Forestry Industry Waste	Select non-Annex I	ECN's MAC (Wetzelaer, Linden et al., 2007) with updated baselines	2020	Same as previous ECN study (Bakker, Arvanitakis et al., 2007)	Same as previous ECN study (Bakker, Arvanitakis et al., 2007)	Same as previous ECN study (Bakker, Arvanitakis et al., 2007)	30% below 1990 for Annex I in 2020 (as in Bakker et al., 2007) 20% below baseline in select non-Annex I countries (Argentina, Brazil, Mexico, Korea, China, South Africa, India, Indonesia) that significantly curtail availability of credits to international markets
Netherlands Environmental Assessment Agency (den Elzen, Beltran et al., 2009)	Energy-related CO ₂ Non-CO ₂ Forestry	Global	TIMER model for energy-related CO ₂ (Van Vuuren, den Elzen et al., 2007) with alternate cases Other NEAA work for non-CO ₂ (Lucas, van Vuuren et al., 2007)	2020	Ran scenarios where REDD did or did not quality, but otherwise not addressed	Not specifically included	Explored 10% to 30% "CDM accessibility" factor	30% below 1990 for Annex I in 2020 15% below baseline for non-Annex I (20% for ADCs, 10% for ODCs and 0% for LDCs)
New Carbon Finance (Parpia, 2009)	Forestry (included avoided deforestation) Other project types aggregated but not specifically listed	Global	Own bottom-up MACs for avoided deforestation	To 2020	Addressed generally for afforestation, avoided deforestation	Ramp-up for afforestation beginning in 2010 and avoided deforestation beginning in 2013 Consider build rates and lead times based on analysis of existing programs	Include transaction costs for measuring/monitoring as well as administrative and implementation costs depending on region	Caps in EU, Japan, Australia, U.S. and Canada with supplementarity limits but no use of forestry credits in EU
ONF International (2009)	Avoided deforestation	Global	Kindermann (2008)	Through 2020	Not specifically addressed	Assume it would take 10 years to ramp up, leaving only 50% of the potential attained through 2020	Assume transaction costs of one-third (33%) of the opportunity costs	None – focuses on supply side only

Table 3: Summary of studies of international offset supply (continued)

Study	Sectors	Region / country coverage	MAC curves used	Time scale	Offsets protocols / crediting methodologies	Scale-up (project type or country)	Transaction costs / other market factors included	International country GHG abatement commitments
Point Carbon (2009)	All	Developing country	Not specified; analysis based mostly on market trends it appears	Through 2030	Not specifically addressed	Based largely on trends to date in the CDM	Assumes diverging "policy efficiencies" for CDM, sectoral crediting, and ETS systems	Assume Mexico and S. Korea have an ETS in place by 2015, Brazil in 2018, most others by 2020, and India in 2025, all with unspecified targets
UNFCCC (Haites, 2007) (UNFCCC, 2007)	CCS Energy Forestry (including avoided deforestation) Industry Waste	Global	EMF-21 (de la Chesnaye and Weyant, 2006)	Through 2030	Not specifically addressed	Looks at trends to date in CDM	Not addressed	Ambitious commitments by all current Annex I Parties including Australia and U.S. but no commitments by non-Annex I Parties based on results of EMF-21 (de la Chesnaye and Weyant, 2006) and World Bank (World Bank, 2006)
U.S. Congressional Budget Office (CBO, 2009)	Agriculture Energy Forestry (including avoided deforestation) Industry Waste	Non-U.S.	Same as EPA (US EPA, 2009)	2012, 2020	Not specifically addressed	Assumed agreements with other countries (as called for in HR 2454) would take significant time to negotiate such that only fraction of potential available in early years, increasing over time	Included fixed transaction costs across all project types and regions Adjusted MAC curves to account for market feasibility based on the Eliasch Review (Eliasch, 2008) and World Bank (Chomitz, Buys <i>et al.</i> , 2006) among others	Assumed unspecified commitments and targets for developed and developing countries, respectively
U.S. Energy Information Administration (US EIA, 2009)	Agriculture Energy Forestry (including avoided deforestation) Industry Waste	Non-U.S.	Same as EPA (US EPA, 2009)	Through 2030	Not specifically addressed	Applies gradual market penetration function to Group 2 country supply Discounted Group 2 avoided deforestation by 50% and applied lower penetration curve ⁵²	Applies discounts to EPA-generated MACs: 25% discount to industry/waste non-CO ₂ ; no discount to energy-related CO ₂ , and 25% and 50% discounts to Group 1 and Group 2 (respectively) ag/forestry MACs to account for technical, institutional, and market factors	"Stated or hypothetical" Group 2 country caps that are less stringent than in EPA (2009) and with adjustments to reference CO ₂ emissions in accordance with latest figures from EIA International Energy Outlook 2009. Crosses international demand (ex-US) with supply to calculate market-clearing floor price, below which no offsets provided to U.S.

52 EIA believes that due to substantial additional regulatory requirements in HR 2454 for avoided deforestation, the potential pool of countries available to supply such credits is likely limited. Accordingly, they apply a 50 per cent discount to the potential for avoided deforestation as well as the lower penetration curve.

Table 3: Summary of studies of international offset supply (continued)

Study	Sectors	Region / country coverage	MAC curves used	Time scale	Offsets protocols / crediting methodologies	Scale-up (project type or country)	Transaction costs / other market factors included	International country GHG abatement commitments
U.S. Environmental Protection Agency (US EPA, 2009)	Agriculture Energy Forestry (including avoided deforestation) Industry Waste	Non-U.S.	Bottom-up MACS (US EPA, 2006) GTM (Sohngen and Mendelsohn., 2007) MiniCAM (US CCSP, 2007)	Through 2050	Not specifically addressed	Applies graduated discount as discussed at right Otherwise, not addressed explicitly, but did include side scenarios (e.g., 7a, 7b) with international offsets delayed for 10 years	Applies sector-specific discounts in the construction of its MACs, particularly energy-related CO ₂ , where potential is reduced by 90% through 2015 and 75% between 2015 and 2025 in Group 2 countries based on assessments of market and institutional factors	Caps: Group 1 in 2010, Group 2 in 2025 ⁵³ Abatement demand modeled using MiniCAM: 10 billion tCO ₂ in 2030, 28 billion tCO ₂ in 2050
U.S. Environmental Protection Agency (US EPA 2010a)	[Same as above]	Non-U.S.	Bottom-up MACS (US EPA, 2006) GTM (Sohngen and Mendelsohn., 2007) MiniCAM (US CCSP, 2007)	Through 2050	Not specifically addressed	Graduated discount as above. Included scenario with no international offsets	[Same as above]	Caps: Group 1 in 2010, Group 2 in 2025, and more aggressive than in original analysis above ⁵⁴ Abatement demand modeled using MiniCAM: 15 billion tCO ₂ in 2030, 37 billion tCO ₂ in 2050
U.S. Environmental Protection Agency (US EPA 2010b)	[Same as above]	Non-U.S.	Bottom-up MACS (US EPA, 2006) GTM (Sohngen and Mendelsohn., 2007) GCAM (Calvin et al., 2009)	Through 2050	Not specifically addressed	Graduated discount as above. Included scenario with international offsets delayed, with no REDD, and with no international offsets	[Same as above]	Caps: Group 1 in 2010, Group 2 in 2025 Abatement demand modeled using GCAM: 19 billion tCO ₂ in 2030, 48 billion tCO ₂ in 2050

53 Group 1 regions are the Kyoto group less Russia, that is, Europe, Japan, Canada, Australia, and New Zealand. Group 2 regions are all others. These assumptions are based on MIT's 2007 analysis of cap-and-trade programs (Paltsev et al., 2007).

54 The assumptions in EPA's supplemental analysis are based on the outcome of the July 9, 2009 Major Economies Forum.

TABLE 4: SUMMARY OF SELECTED MARGINAL ABATEMENT CURVES – INTERNATIONAL AVOIDED DEFORESTATION

Model or method	Select studies using model	General model characteristics	Source of historic forest area data	Source of carbon density data	Projected base-line rate of deforestation	General approach to calculating opportunity costs	Discount rate assumptions	Other assumptions (feasibility, markets)
DIMA model	Kindermann, 2008 Eltis, 2008	Assess land use options in 0.5° grid cells across globe	JRC (2003) Global Land Cover Map	FAO Forest Assessment (FAO 2006; US CCSP, 2007)	Based on historical rates, 1990–2005 from FAO (FAO, 2006)	Calculated as ag land value based on an agricultural suitability index and projected population density	Used risk-adjusted discount rates of up to 30% (Benitez, McCallum <i>et al.</i> , 2004)	Transaction costs not included
GCOMAP model	Kindermann, 2008 Eltis, 2008 Anger and Sathaye, 2008	Dynamic partial equilibrium model 10 world regions total, 4 for avoided deforestation ⁵⁵	FAO (FAO, 1993; FAO, 2003)	Country-specific data from “F7 tropical forestry” and other sources (Kindermann, Obersteiner <i>et al.</i> , 2008) FAO (2005) Forest Resources Assessment (Sathaye, Chan <i>et al.</i> , 2008)	“FAO historical deforestation rates”	Estimated as “the value of economic activity on deforested land”, including timber that might be harvested during deforestation, annual crops, timber plantations, and/or cattle ranching	Private discount rates by world region: 12% to 30% for short-rotation forestry, 6 to 13% for long-rotation forestry	Transaction costs not included
GTM model	Sohngen and Mendelsohn, 2007 Kindermann, 2008	Dynamic optimization model 13 world regions ⁵⁶ Carbon rental payments made on total stock of carbon in forests	China: Ministry of Forestry, Beijing Rest-of-world: FAO Forest Resources Assessment (FAO, 2006)	Appears to be same sources as forest area, described at left	First 10 years of model projections use deforestation rates from previous 10 years (FAO, 2006); then decline over rest of the century (Kindermann, Obersteiner <i>et al.</i> , 2008)	Employs a rental function that remains constant over time in temperate regions and increases (the rental costs of maintaining forestland) over time in tropical areas to simulate future decline in baseline deforestation	Unspecified in Kindermann (2008)	Transaction costs not included

⁵⁵ The model estimates avoided deforestation for four regions: Rest of Asia (outside China and India); Africa; South America; and Central America. It assumes minimal or no deforestation for other regions.

⁵⁶ The regions are: United States, Canada, Central America, South America, Europe, Russia, China, Japan, Southeast Asia, Oceania, Africa, Central Asia, and Japan.

Table 4: Summary of selected marginal abatement curves – international avoided deforestation (continued)

Model or method	Select studies using model	General model characteristics	Source of historic forest area data	Source of carbon density data	Projected base-line rate of deforestation	General approach to calculating opportunity costs	Discount rate assumptions	Other assumptions (feasibility, markets)
Bottom-up estimates	Strassburg <i>et al.</i> , 2009	Bottom-up, per-area estimates Top 20 developing countries by forest area	FAO (2005) Forest Resources Assessment	FAO (2005) Forest Resources Assessment supplemented by three global/regional biomass models	Extrapolated based on average of 1990–2000 and 2000–2005 deforestation rates from FAO (FAO, 2006)	Two approaches taken: Field estimates from Stern review on economic return of alternative land activities Adjusted global map of economic rents from ag lands	Appears to use 10% discount rate	
Bottom-up estimates	Grieg-Gran, 2008	Bottom-up, per-area estimates	FAO (2005) Forest Resources Assessment	Did not include carbon density values. Other researchers (Boucher, 2008; Eliasch, 2008) have applied	Assumed continues at historical rate for next 10 years	Largely local-level estimates of returns on land (e.g., land types, soil/climate conditions, forested ag commodity prices)	10% discount rate	Includes transaction costs of \$4 to \$9/ha per year
McKinsey Global Cost Curve	McKinsey, 2009	Bottom-up estimates Limited documentation available	Unspecified Houghton (2003) research	Unspecified Houghton (2003) research	Historical (2000–2005) rate from FAO (FAO, 2006) through 2030 except for a few African countries where it stops when forested area reaches 15% of land base	Bottom-up estimates of compensation payments / opportunity costs for slash-and-burn, pasture-land conversion, intensive agriculture, and lost timber revenue	4% discount rate for avoided conversion to intensive agriculture; unspecified for others	Transaction costs not included Assume complete cessation of deforestation in Asia and Latin America and preventing 70% in Africa by 2025

TABLE 5: SUMMARY OF SELECTED MARGINAL ABATEMENT CURVES – INTERNATIONAL ENERGY-RELATED CO₂

Study	Model(s) used	General model characteristics	Geography coverage and resolution	Sector coverage and resolution	Other assumptions (feasibility, markets)	MAC availability
US EPA (US EPA, 2009)	MiniCAM (US CCSP, 2007)	Integrated assessment model, partial equilibrium Recursive-dynamic (“myopic”) Emissions mitigation policies prescribed exogenously	Global, 14 regions but not generally reported separately (US CCSP, 2007)	Power production, buildings, transportation, industry, agriculture, land use	Assumes efficient market mechanisms Unclear discount rate	From EPA website for every year through 2050 in 5-year steps. ⁵⁷ All sectors lumped and split into two world regions (US EPA, 2009)
US EPA (US EPA 2010b)	GCAM (Calvin <i>et al.</i> , 2009)	[Same as above]	[Same as above]	[Same as above]	Discount rate appears to be 5% per Clarke <i>et al.</i> (2009)	
McKinsey (McKinsey & Company, 2009)	McKinsey Global Cost Curve	Methods vary; generally bottom-up, engineering-economic estimates (10 sectors) but some top-down (3 sectors)	Global with 21 world regions / countries	Power, petroleum and gas, cement, iron and steel, chemicals, other industry, road transport, sea transport, air transport, buildings, agriculture	Transaction costs not included Uses social interest rate of 4%	Available in graphic, PDF form for 2015, 2020, and 2030, globally, and with limited country detail Spreadsheet versions not available
MIT (Morris, Matthews <i>et al.</i> 2007; Paltsev, Reilly <i>et al.</i> , 2009)	EPPA	General equilibrium Recursive-dynamic (myopic) Based on GTAP version 5 data	Global with 16 regions/countries	Energy (15 sub-sectors) and non-energy (including agriculture, services, energy-intensive products, other industries products, transportation, household transportation)	Unspecified discount / interest rate Transaction costs excluded	Available with country and region-level detail in spreadsheet form on MIT website (Morris, Paltsev <i>et al.</i> , 2008)
IIASA (Amann, Bertok <i>et al.</i> , 2009)	GAINS Mitigation Efforts Calculator	Bottom-up calculations Includes optimization of measures to reach given reduction target at least cost	Global but only Annex I is public (with detail for EU-27 as a whole plus other countries individually) ⁵⁸	Power plants, residential, commercial, industries (cement, iron/steel, pulp/paper, non-ferrous, chemicals), transport	Uses social interest rate of 4% (but with comparisons for results at a 20% rate) Transaction costs excluded	Available in PDF form for 2020 by Annex 1 country and (to some degree) sector and in interactive form by country (but not sector) on IIASA website. ⁵⁹

57 For example, in the Data Annex of the EPA’s June 2009 Analysis of HR 2454 at <http://www.epa.gov/climatechange/economics/economicanalyses.html>.

58 IIASA reports no specific plans to produce cost curves for non-Annex 1 countries in the near future.

59 <http://gains.iiasa.ac.at/gains/Annex1.html>

Table 5: Summary of selected marginal abatement curves – international energy-related CO₂ (continued)

Study	Model(s) used	General model characteristics	Geography coverage and resolution	Sector coverage and resolution	Other assumptions (feasibility, markets)	MAC availability
International Energy Agency (IEA, 2008)	IEA's partial equilibrium model	Partial equilibrium	Global. No country/region resolution in MACs	Power production, buildings, industry, LDV transport	Transaction costs excluded Discount rates vary by sector and country from 3% to 28%	Available in graphic, PDF form for 2050 with broad sectoral detail but no region detail
IPCC 4AR, Working Group III (Metz, Davidson <i>et al.</i> , 2007)	Compilation of various bottom-up and top-down estimates	Reviews and compares both top-down and bottom-up approaches to generate a composite MAC (Barker, Bashmakov <i>et al.</i> , 2007)	Global, with resolution for OECD, Economies-in-Transition (EIT), and non-OECD/non-EIT countries	Energy supply, transport, buildings, industry	Discount rates vary by sector Transaction costs excluded	Available in tabular PDF form for 2030 with broad sectoral and regional detail
ECN (Wetzelauer, Linden <i>et al.</i> 2007; Bole, Saidi <i>et al.</i> , 2009)	Compilation of various other researchers' bottom-up estimates	Aggregated from bottom-up country-specific abatement studies and scaled to entire non-Annex I region	Non-Annex I	Electricity, industry, household, transport, agriculture	Discount rate and other assumptions vary by source study Transaction costs excluded from MAC but included in separate analyses	Available in graphical and tabular form in source document; in spreadsheet from authors
Netherlands Environmental Assessment Agency (Van Vuuren, den Elzen <i>et al.</i> , 2007)	IMAGE/TIMER	Integrated assessment model Solves by assigning larger market share to low-cost energy options Can run with or without induced technological change	Global, 17 world regions plus land use at 0.5 x 0.5 degree resolution	Energy sector, transport, industry	5% discount rate used to calculate NPV of mitigation potentials? Energy-related investment decisions compared using 10% discount rate	Appears to only be available in tabular and graphical form for select years within articles but little sectoral / regional detail
Ecofys (Hoogwijk, Can <i>et al.</i> , 2008)	Bottom-up estimates	Bottom-up estimates intended as update to IPCC (Metz, Davidson <i>et al.</i> , 2007)	Global, with resolution for OECD, Economies-in-Transition (EIT), and non-OECD/non-EIT countries	Energy supply, transport, buildings, industry	Discount rate of 3% to 10% varying by sector	Available in tabular PDF form for 2030 with broad sectoral and regional detail

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