The Economics of Low Carbon, Climate Resilient Patterns of Growth in Developing Countries: A Review of the Evidence

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Steve Pye, Paul Watkiss, Matt Savage, Will Blyth

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Client	Department for International Development (DFID)
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Contact and correspondence	SEI
Authors	Steve Pye, Paul Watkiss (Email: paul_watkiss@btinternet.com, Tel: +44 797 104 9682), Matt Savage, Will Blyth
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Task Manager	Paul Watkiss
Quality Assurance	Tom Downing

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Executive Summary

The objective of this study is to review the evidence from the economics of climate change literature to assess to what extent developing countries can move towards low or lower carbon patterns of growth, without compromising economic growth. In addition, the study explores the impact of climate change on economic growth, and the investment needs for increasing climate resilience to ensure continued economic growth in future years.

The challenge of climate change is significant. In addition to stringent cuts by developed countries, reducing the risks of dangerous climate change also requires near-term action by developing countries.

Without action from the developing world, ambitious stabilisation targets towards limiting temperature change to 2ºC (400 to 450 ppm CO_2e) are impossible to achieve, and even relatively low levels of stabilisation (e.g. 550 ppm CO_2e) are unlikely.

This is because global emissions need to peak around 2020. However, a rapid increase in emissions over the next 10-15 years is projected, driven by growth in energy demand in developing countries. Decoupling emissions increases from ambitious economic growth targets is going to be challenging, and will require significant additional investment.

However, low carbon patterns of growth may also hold opportunities for developing countries such as improving efficiency and lowering energy costs, developing low carbon industries, improving technology, providing opportunities to raise carbon finance through international mechanisms and safeguarding natural resources, such as forests.

Developing countries will also need to invest in adaptation measures to ensure climate resilience against impacts that will inevitably arise. Such investment will need to ensure that the economy is climate resilient enough to withstand impacts and grow. However, the investment needs to ensure greater climate resilience could impact on growth in the nearer term; hence some complex trade-offs emerge.

The extent of the transition towards low carbon patterns of growth in developing countries will be dependent on the progress of an international agreement, political will and economic self-interest.

Differences in the level of ambition will emerge depending on national circumstances. Due to the level of current and projected emissions, Middle Income Countries (such as the G+5) will need to balance the risks of not adopting carbon reduction targets and incurring liabilities under a future global agreement against nearer term economic growth objectives.

Lower income countries, who have significantly lower emissions (e.g. <1 tCO_2/cap) and low levels of development could increase emissions in the near term. However, lower carbon patterns of growth may be in their self-interest in helping meet development objectives due to synergies across other policy areas (reflected by co-benefits), indigenous renewable energy resource potential, and opportunities for raising carbon finances.

The additional investment costs of low carbon patterns of growth in developing countries may not be prohibitive.

The broader literature on the economics of mitigation (as reviewed for example in the IPCC's 4th Assessment Report) suggests that significant levels of mitigation can be achieved whilst not significantly undermining growth objectives. Modelling suggest impacts on GDP to be in the region of 1-2% reduction in GDP (per annum) for stabilisation targets focused on restricting levels (or reducing the risks) of warming to 2°C.

Whilst the evidence base for developing countries is more limited, a range of studies (primarily using marginal abatement cost curve approaches) suggest similar conclusions, that significant potential exists at relatively low cost (<$20/t$CO_2$). These low abatement costs are driven by large amounts of energy efficiency potential, which is often negative cost i.e. introducing a measures results in cost savings.

In specific countries, such as Brazil and Indonesia, high mitigation potential in low cost sectors e.g. forestry and agriculture also drives down average abatement costs. For China and India the challenge is significantly greater due to the very fast growth of emissions observed in the last 5 years, and projected for the next 20 years and beyond. Consequently, the relative costs of comparable emission reductions are likely to be significantly higher.

For China and India, it is not clear from the literature how ambitious targets can be, and at different ambition levels what the costs will be. Further research is needed to fully understand what is achievable and at what cost, particularly for these countries which are so crucial in limiting greenhouse gas emissions over the next 10-15 years.

For all developing countries, additional investment levels are going to be significant and will require international cooperation (including agreement) to ensure long term certainty for investors, and robust mechanisms are in place to enable carbon trade and access to carbon financing.

The wider impacts on economic growth are less well understood although evidence that exists points to opportunities as well as challenges for economies in transition.

Few analyses have dynamically assessed the wider impacts of low carbon patterns of growth on the economy, using macroeconomic analysis. However, those that have (e.g. Mexico and South Africa) point to relatively small reductions in growth (<1%) and in some cases increased growth due to improved efficiency of the economy, access to carbon financing (subsidising investment) and new, emerging industries.

These analyses are all premised on significant cuts, back to and below base year levels. Therefore, we could conclude that for specific countries, less ambitious cuts should not undermine growth. However, extrapolating such findings to other countries and regions is problematic due to very different regional circumstances. Hence, the picture is incomplete.

These macroeconomic analyses also indicate that impacts are not uniformly distributed, with specific sectors, such as heavy industry, incurring higher levels of job losses and greater reductions in output. These impacts also filter down to society, with greater impacts on specific groups e.g. higher energy costs impacting on lower income classes. Again, the evidence base is limited on this issue; however the importance of this issue points to the need for significantly more research.

The co-benefits of low carbon patterns of growth are significant, indicating strong synergies with development objectives.

Co-benefits associated with low carbon options include reduced reliance on fossil fuels (air pollution and health, energy security, reduced foreign exchange payments), natural resource protection (ensuring sustainable livelihoods), dissemination of improved technologies (meeting energy needs) and improving urban quality of life.

Whilst usually recognised, such benefits are rarely quantified, remaining outside the analysis framework. This can result in economic costs being overplayed at the expense of wider policy benefits.

Implementation of policy remains the key challenge, the costs of which are not fully captured.

Without effective implementation, the necessary mitigation potential will not be realised and not at the costs highlighted in this research stocktake. Opportunities need to be pursued in a phased manner, reflecting their cost, technological maturity and ease of implementation. In addition to timing, having effective policies across all sectors is crucial, as is the capacity to access international financing opportunities (through donor funding, private investment and international carbon mechanisms).

It is also important to highlight that the economic assessments rarely capture those costs associated with implementation, often working from a perspective of perfect competition (not reflecting information failures, severe market imperfections e.g. fuel subsidies, behavioural issues) and not fully capturing transaction and policy costs.

Sectors for which significant levels of negative and low cost potential have been estimated are the most challenging from an implementation perspective. By definition, negative cost, energy efficiency opportunities exist because of the many barriers to realising them. Agriculture and forestry sectors are highly fragmented and involve many stakeholders, meaning that policy costs will be significant. They are also often premised on mechanisms that will provide adequate access to international financing e.g. REDD+ and at levels to provide the necessary incentives.

There is a need to consider climate resilient patterns of growth, in addition to the current economics of climate change and costs of adaptation.

The existing studies show that climate change will have major economic costs in developing countries. They also report potentially large costs of adaptation are needed. However, a new question is emerging on how to achieve climate resilient growth, considering the patterns of development that are likely to help build an economy's resilience in a future changing climate, both against future long-term trends and also changes in extreme events (shocks). The answer to this question is unclear. Such climate resilient patterns of growth are not well defined and there is little understanding of what this might involve in practice.

Some initial findings are presented. It is clear that achieving climate resilient patterns of growth will involve much more than just 'climate proofing' investments. At the macro-economic level, there will be a need to encourage sectoral shifts away from climate sensitive areas (such as agriculture). Such policies are consistent with development, but are challenging to achieve. There is also a need to encourage long-term planning and policy in areas such as spatial planning to reduce vulnerability, which will require strong institutions, good governance and effective policy enforcement.

Alongside this, there is a continued need to increase the capacity of economies to cope with future climate variability (extreme events or shocks), noting that this will also have benefits for reducing current risks. In all these areas, the potential for climate resilient patterns of growth will be strongly determined by future socio-economic development. Given these challenges, it is likely that the availability of international finance for adaptation will not, on its own, deliver climate resilient patterns of growth. A clear immediate focus is to build the evidence base in this area.

Is it not yet clear how low carbon growth and climate resilient growth will fit together, i.e. whether they will naturally align with similar policies and objectives or whether they will involve conflicts or trade-offs.

At the project level, there can be potential synergies or conflicts between low carbon objectives and adaptation. These can be partly reconciled by co-ordination between mitigation and adaptation domains. For example, it is possible to screen low carbon development to ensure options do not inadvertently increase vulnerability to climate change – an example being the screening of future hydro power projects against future climate projections of rainfall.

Similarly, it is possible to check adaptation options to make sure they do not conflict with low carbon objectives, for example, implementing options that do not increase energy related emissions such as passive ventilation rather than energy powered air conditioning to cope with future warmer temperatures. While this sounds relatively easy, in practice there are likely to be potential conflicts or trade-offs involved, e.g. when the need to increase water resources to address future aridity leads to increased energy associated with water transfers or even desalinisation.

However, at the aggregate and macro-economic level, it is not yet clear whether the combination of low carbon and climate resilient patterns of growth will align. Some macro-economic shifts which enhance climate resilience may lead to economic structures with lower carbon intensity, though this will not always be the case. Such effects will also vary on a geographical basis. Similarly major planning changes towards low carbon development may sometimes reduce vulnerability, but in other cases will not (e.g. higher building / population density in major cities to reduce private transport demand will increase heat island effects and increase the health related vulnerability to higher temperature).

The stocktake has provided some useful insights on the economic impacts of low carbon, climate resilient patterns of growth. However, important further research is required to improve understanding.

For low carbon growth studies priorities include:

- Increasing use of macroeconomic models to better understand the dynamics feedbacks in the economy resulting from the radical changes associated with low carbon patterns of growth
- More sensitivity analysis on discount rates, particularly use of higher discount rates, to test cost-effectiveness from private sector perspective, and consumer requirements for faster payback on investment.
- Longer term analyses. Focusing on 2030 as an end date means that there is no consideration of additional measures after this date, which are potentially more expensive (and less certain e.g. may not be currently commercial)
- Uncertainty assessment would be useful in understanding the financial trade-offs between different levels of ambition, and what might be the optimal hedging strategy
- Increased quantification of co-benefits to aid policy makers is important, as is the assessment of socio-economic distributional impacts

- Synergies and conflicts between adaptation-mitigation strategies need to be better understood for ensuring near-optimal investment levels and timing

For climate resilient patterns of growth, priorities include:

- Future systematic review of emerging evidence. A large number of studies will emerge over the next 12 months that are assessing the economics of climate change and adaptation. This review should be repeated once this information is available.
- Building the evidence. There is a generally low level of evidence on the economics of climate change and adaptation and more studies are needed at different scales and different locations. This includes more studies that consider the effects of both slow onset change and shocks.
- Specifically addressing climate resilient patterns of growth. The recent focus of studies on the economics of climate change/adaptation has not addressed the core question of how to achieve climate resilient growth. This is a priority area for future analysis.

Further work is also needed to explore how to take forward low carbon and climate resilient patterns of growth together (synergistically). This is identified as an urgent priority following on from this study.

1. Introduction

The challenge of establishing patterns of low carbon growth

1.1. The emerging discussion on the science of climate change internationally suggests strong support for cutting GHG emissions by at least 50% below 1990 levels by 2050, and aiming to limit temperature changes to a 2ºC average temperature rise above pre-industrial levels. This was re-iterated in the recent Copenhagen Accord.[1]

1.2. Under most scenarios, stabilisation levels below 490 ppm CO_2e require a peak in global emissions by 2015, and a reduction to less than 50% of current emission levels. For less stringent targets, global emissions peak around 2010–2030, followed by a return to 2000 levels around 2040 (Fisher et al 2007 (in IPCC 4th AR)).[2]

1.3. The challenge is also often framed by some commentators using the concept of per capita emissions, as an international benchmark. Global stabilisation of GHG gas concentrations at 'safe' levels implies that all countries may be required to limit emissions to around 2 to 3 tonnes CO_2e by 2050 (stabilisation at 450 to 550ppm respectively by 2050, though even the lower level would still carry a very high level of risk). Many Low Income Countries (LICs) are below this level, and therefore may have room to increase emissions (as other countries reduce their emissions).

1.4. Figure 1 shows per capita emissions for country and regions of the world that accounted for over 60% of global emissions in 2000. With the exception of India, all are currently above the 2t CO_2e/capita level, with significant increases predicted for the G+5 countries.

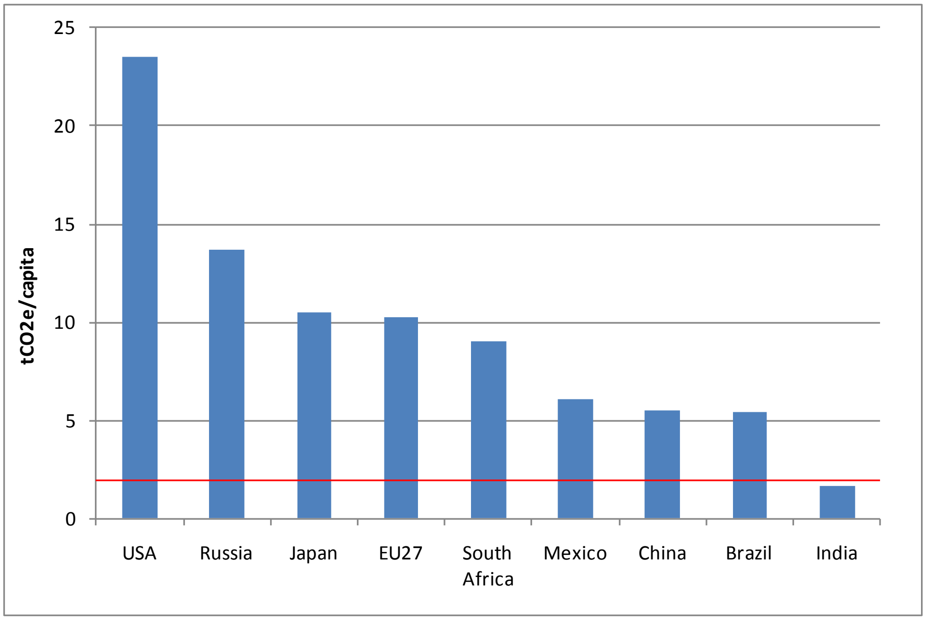


Figure 1. Per capita emissions of GHGs in 2005 by country / region (excluding LUCF)[3]

[1] Text of the Copenhagen Accord can be found at http://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf

[2] Given emissions and concentration increases which have already occurred, and given the uncertain relationship between emission levels and temperature increases, however, it is not now possible to ensure with high likelihood that a temperature rise of more than 2°C is avoided. A 50% reduction would help stabilise concentrations of greenhouse gases in the atmosphere at 450 ppm CO2e, resulting in a 50% chance of keeping temperature levels below 2°C

[3] Data sourced from Climate Analysis Indicators Tool (CAIT) version 6.0. (Washington, DC: World Resources Institute, 2009). Available at http://cait.wri.org

1.5. The global challenge is for countries to reduce GHG emissions to sustainable levels whilst maintaining economic growth. This is a particular challenge for developing countries, many of whom are in rapid growth phases, driven by high levels of fossil fuel use.

1.6. This reflects the historic pattern, shown in Figure 2, where GHG emissions have risen significantly as economies have grown. The extent of the decoupling of growth from emissions is challenging, and requires large-scale changes to the structure of the global economy.

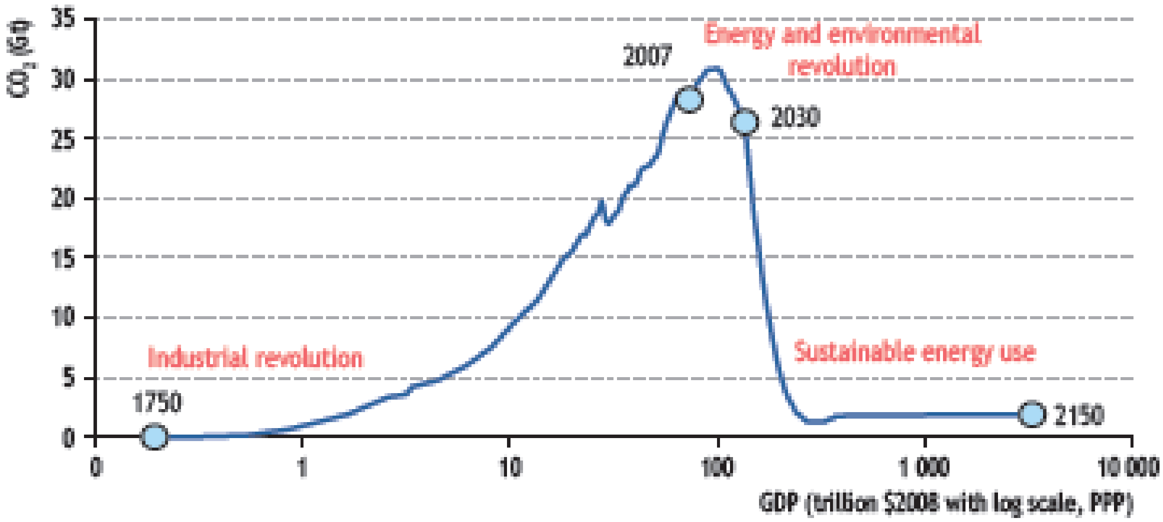


Figure 2. Approximated trend of emissions versus global GDP required to meet 450 ppm CO_2e stabilisation (Source: IEA WEO 2009)

1.7. Progressing a global deal on an ambitious stabilisation objective is challenging, as reflected in the recent Copenhagen Summit. Whatever agreement finally emerges, it is likely that it will put the focus of mitigation action on developed countries but will also expect some form of commitment from the developing world. This was reflected in the UK Government's aspirations prior to Copenhagen (DECC 2009), where a view was taken that developed countries should meet an 80% reduction relative to 1990 levels by 2050.

1.8. However, a process should also be put in place that will see developing countries starting to take action, or build on actions already being implemented. This includes agreeing that developing countries need to develop low carbon strategies, setting out the actions that will be implemented to reduce emissions or slow emissions growth. Many such strategies are already being formulated through a number of initiatives[4] that have been reviewed as part of this study.

1.9. Not all developing countries will be expected to make absolute cuts, at least not in the near term, providing some room to grow emissions. Therefore, the use of 'low carbon' refers both to countries that will have to make absolute cuts and others that will need to slow the growth in their emissions, i.e. improve their emissions intensity in relation to economic output.

1.10. Without action in developing countries, meeting a global stabilisation target of 450ppm will not be possible, and achieving 550ppm will be unlikely, as illustrated in the Box below.

[4] For example, RECCS, the CCAP Developing Country Project and World Bank Low Carbon Growth projects.

The importance of developing country action in meeting stabilisation targets

WEO 2009 (IEA 2009) has developed an analysis to assess the reductions needed in energy-related CO_2 emissions to meet a stabilisation level of 450ppm CO_2e.[5] The predicted growth in emissions between 2007 and 2030 is approximately 11.5 $GtCO_2$. This growth predominantly comes from the developing world (as shown in the right-hand side bar chart of Figure 3).

The reduction required to be on the trajectory for 450ppm is 13.8 $GtCO_2$. Total emissions from OECD countries is approximately 13 $GtCO_2$ (in 2030), meaning that even if these countries became carbon free they could still not reduce emissions sufficiently to put the world on course to meet the required stabilisation levels. Post 2030, the required contribution by developing countries becomes even more important.

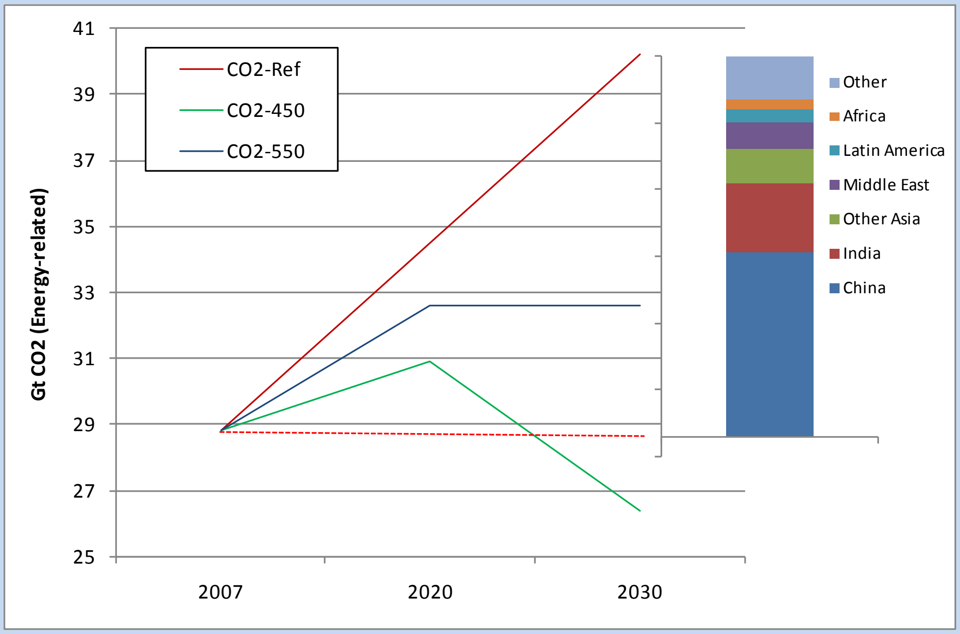


Figure 3. Energy-related CO_2 emissions under Reference Case and two Stabilisation Cases (Source: IEA WEO 2009). Bar chart shows contribution to emissions growth between 2007- 2030

1.11. The key question for developing countries will be the level of ambition of a low carbon strategy, balancing self-interests against future internationally agreed requirements to reduce emissions (somewhere between the assumed *business as usual* and that which might be *Required by Science* for temperature stabilisation).

1.12. This will depend on national circumstances, particularly the level of development and the contribution to global emissions. It may mean that low emitters will have to do less and that that lower income countries will need greater support. The United Nations Framework Convention on Climate Change (UNFCCC) takes these differences between countries into account through the principle of common but differentiated responsibilities and respective capabilities,[6] which means that although all parties have to act, they do not all have to act in the same way (i.e. not required to have the same emission reduction targets). Therefore, the extent that developing countries decouple economic growth from carbon emissions will be different.

[5] In meeting a specific stabilisation target, the reduction levels for CO_2 emissions takes account of what reductions may occur across other GHGs.
[6] Principle set out in Article 3.1 of the United Nations Framework Convention on Climate Change (1992)

1.13. Developing countries need to make the decision on their emissions pathways in the absence of an international climate agreement (implying future cuts for many MICs), the future structure of which is currently unknown. Therefore, countries need to be assured that the amount of mitigation associated with low carbon patterns of growth is in a country's self interest, and outweighs the benefits of delaying action.

1.14. The strategy is likely to be different between Middle and Low Income Countries. Middle income countries (including China, India, Brazil, Mexico and South Africa) may decide to adopt a more stringent low carbon path, due to the greater likelihood of being required to contribute to emission reductions in future years, due to the volume of their emissions and their capacity to take action. For lower income countries it may be less clear as to what the benefits are, due to the critical requirements of development, low level of domestic emissions, and the fewer options for investment and access to capital. For such countries, even where self-interest might be clear, affordability will remain a key barrier.

1.15. Whilst the focus of this review is on issues relating to *low carbon* patterns of growth, developing countries also need to plan for adaptation, particularly as they are predicted to see the greatest impacts of climate change due to current vulnerability and geographical issues e.g. location. Therefore, development and growth also need to factor in *climate resilience.* As Nicholas Stern argued,[7] development strategy has to fully integrate adaptation issues, to ensure that an economy can orientate itself in order to reduce vulnerability and increase future resilience. The growth benefits associated with adaptation are, however, less well quantified than those relating to mitigation, where the potential new markets for goods and services may be more clearly defined.

1.16. Therefore an important factor for developing countries will be to advance a climate resilient as well as a low carbon growth path. The challenge is how far developing countries can integrate both of these strategies whilst ensuring rapid future development. This review aims to examine the evidence to see how far countries can move towards low carbon, climate resilient futures.

The cost of GHG mitigation

1.17. A significant number of analyses have been undertaken to assess the costs of global reductions of GHGs for different stabilisation pathways. To put this developing country review in context, it is useful to assess what global, macro-scale analyses have estimated as impacts on growth, and the level of carbon price required to incentivise investment under different stabilisation targets.

1.18. These studies also provide insights into the carbon prices that might be available in a global market under different climate stabilisation targets, and the level of mitigation that developing countries could achieve through a global trading mechanism.

1.19. A review of different modelling analyses are summarised in Table 1 below. The following conclusions can be drawn from this information:

[7] Stern N (2009), A Blueprint for a Safer Planet, Published by The Bodley Head 2009, London

- GDP losses between 1-2% of GDP are envisaged to meet stabilisation targets between 550 and 450ppm – although there is a range of -/+ 2%.[8]
- Marginal costs of abatement estimated for longer term stabilisation pathways in 2030 and 2050 are in the range of \$50-100/tCO_2e. Wide variability is due to assumptions on the type of sectors and GHGs included, levels of technology learning, structural change, inclusion of developing world in trading, and discount rates assumed.
- Longer term oil prices, which can significantly affect cost-effectiveness of low carbon options, often use IEA assumptions. Current estimates, in the World Energy Outlook 2009 (IEA 2009), start from ~\$60 per barrel in 2009 to \$115 per barrel by 2030 (Real terms, 2008 prices). Analyses undertaken when current year prices were much higher may have resulted in higher estimates on cost-effective potential although this issue has not been reviewed in detail.
  The IEA suggest that future price increases are likely to be lower under a global CO_2 target due to reduced demand. Such market feedback often does not feature in mitigation analysis.
  It should be noted that there is significant uncertainty in such projections, based on issues such as investment in upstream capacity, new resource finds and development of unconventional resources.
- Average costs of abatement are of course significantly lower than marginal costs (at levels around <30/tCO_2e), and provide a useful metric of the level of investment needed as opposed to the price to incentivise investment.

1.20. For additional information, Weyant et al. (2006) provides an overview of marginal abatement costs across the main energy-environment models currently being used for global mitigation analysis. DECC (2009b) also provides a useful overview of different carbon prices in 2030 and 2050 from a range of analyses for different stabilisation targets.

[8] Given the additional costs associated with low carbon investment, most model analyses show some level of GDP reduction. Any gains in GDP are because baselines are assumed to be non-optimal, with significant room for efficiency improvement, or because it is assumed that technological change may be induced by mitigation policies.

Table 1. Review of global carbon prices under different stabilisation targets

Source	Description
Stern (2006)	• Estimated that stabilisation of greenhouse gases at levels of 500-550ppm CO_2e will cost around 1% of annual global GDP by 2050, based on both bottom-up and macro-economic modelling. • The range for bottom-up models is –1% (net gains) to +3.5% of GDP, while for top-down macroeconomic model it is -2% to +5% of GDP. More ambitious targets (towards 450ppm) could mean costs rising to around 2% of GDP. • Stern (2009) asserts that, based on McKinsey analysis, an average price of carbon of \$30/tCO_2 could achieve the required reductions per annum between 2030 and 2050 to get close to 500ppm stabilisation (30 Gt in 2030, 65 Gt in 2050 under a BAU case). Some countries would be required to undertake more mitigation, and for some countries, marginal costs of mitigation would be higher. • The global cost curve by McKinsey (2009d), cited in Stern's analysis, only considers marginal costs of €60/tCO2 (or \$90/tCO_2e) – and estimates average costs at €4/tCO_2e. They make the important note that transactions and programme cost (estimated at between €1-5/tCO_2e) are not included in the cost curve.
IPCC (2007) 4th Assessment Report	• Modelling studies, consistent with stabilization at 550ppm CO_2e by 2100, show carbon prices rising to 20-80 US\$/t CO_2e by 2030 and 30-155 US\$/tCO_2e by 2050. Induced technological change lowered these ranges to 5-65 US\$/tCO_2e in 2030 and 15-130 US\$/tCO_2e in 2050. • In 2050 global average macro-economic costs for multi-gas mitigation towards stabilization between 710 and 445ppm CO_2e, are between a 1% gain to a 5.5% decrease of global GDP. In 2030 macro-economic costs for multi-gas mitigation, consistent with emissions trajectories towards stabilization between 445 and 710ppm CO_2e, are estimated at between a 3% decrease of global GDP and a small increase, compared to the baseline.
van Vuuren et al. (2009)	• The IPCC reports that GHGs can be reduced by 30–50% in 2030 at costs below 100 US\$/tCO_2e based on an assessment of both bottom-up and top-down studies. This analysis supports this finding, concluding that in 2030 50% (range 30-60%) of emissions may be reduced at costs below 100\$/tCO_2e and at costs less than 20\$/tCO_2e, 10–35% of emissions. • Although uncertainties are considerable, the results of this study suggest that marginal abatement costs in 2030 associated with stabilization at 650, 550 and 450ppm CO_2e would, respectively, be around 0–20\$/t, 10–50\$/t and (or above) 100 US\$/t.
World Energy Outlook 2009 (IEA 2009)	• Under a 450ppm stabilisation trajectory, focusing on the energy sector, global GDP would be reduced in 2020 by 0.1% to 0.2%, and in 2030 by between 0.9% and 1.6% compared with the Reference Scenario. The growth in the world economy by 2030 (+100%) means that a 1.6% fall in GDP in 2030 is equivalent to losing a few months of growth over 23 years. In 2030, energy related emissions would have to be at a 26 Gt level, 14 Gt lower than in the reference case. • In the OECD, with industry and power sectors operating in cap-and-trade scheme, CO_2 prices are estimated at \$50/tCO_2 in 2020 and \$110/tCO_2 in 2030. The inclusion of other major economies post-2020 would lower the price to \$65/tCO_2 in 2030.
Energy Technology Perspectives (IEA 2008)	• The ACT scenario sees emission levels stabilised at current levels in 2050. Additional investment costs estimated at US\$ 17 trillion between now and 2050, an average of around US\$ 400 billion per year (or 0.4% of global GDP each year). • A 2degrees (C) stabilisation case (or 50% reduction relative to current levels) could see marginal costs reach \$200/tCO_2 – or up to \$500/tCO_2 in the event of technology failure. Average costs are estimated to be between \$38-117/tCO_2. At over \$1 trillion per year, this represents a reduction in GDP of 1.1%. Note that marginal / average costs are higher than in other estimates because they only include energy system costs; in the same way absolute investment values are lower.
Russ et al. (2009)	• Using POLES, a world energy sector model, and GEM-E3, a global CGE model (see Appendix 1 for model descriptions) the economic impacts of limiting global temperature increases to no more than 2 degrees (C) were assessed. • In POLES, emission reductions of developing countries are limited to 20% below their baseline emissions in 2020. The analysis suggests that most countries would face costs amounting between 0.4 -1.2% of their GDP. In the central case, the marginal price of abatement in 2020 is 43 €/tCO2, increasing to 72 €/tCO_2 without global trade and falling to 22 €/tCO_2 if there is perfect trade at a global level. • Using GEM-E3, the impact on world GDP in 2020 is estimated to be a decrease of 0.9%, compared to the baseline. While some developed countries, such as the EU27, have higher GDP reductions than the world, other economies such as China, India and Brazil have lower GDP losses.

Study objectives

1.21. Whilst large variations in costs estimates are apparent, it is clear that the potential for emission reductions is large, and that the associated mitigation costs are not prohibitive. However, Working Group III notes that an important knowledge gap exists in the understanding of mitigation potential and costs in developing countries (IPCC 2007).

1.22. The objective of this study is to review the evidence from the economics of climate change literature to assess to what extent developing countries, in contributing to global reductions in GHGs, can move to a low carbon development path, without compromising economic growth. In addition, developing countries will need to develop strategies for adapting to increasing climate change, and therefore it is important to understand whether the necessary investment can be made whilst maintaining growth.

1.23. The challenge is that if developing countries are to invest in low carbon technologies there will be an additional cost vis-a-vis the alternative business-as-usual path. However, there are also likely to be no regret measures[9] which if implemented could help reduce costs, and enhance productivity and competitiveness, and other potential ancillary benefits. This study has reviewed the evidence to try and assess the scale of the additional investment needs, the impacts this has on the economy (positive as well as negative e.g. green jobs), and policy co-benefits (which are rarely quantified in such analysis).

1.24. This report is structured as follows:

- A broad review of the economics of climate mitigation in developing countries is described in Section 2. This section provides insights into the main question of whether significant GHG reductions can be made whilst maintaining growth, and where the main opportunities lie.
- Section 3 outlines the evidence concerning the impact on economic growth of ensuring future climate resilience through investment in adaptation.
- Section 4 assesses issues concerning implementation of low carbon, climate resilience growth strategies.

1.25. Further information on low carbon growth studies is provided in Appendices 2-4. The appendices provide a case study using the Mexico low carbon growth reports (which are in agreement that Mexico has significant low carbon growth potential) and one for Kenya based on the recent East Africa RECCS (one of the few low income country studies). Appendix 1 and 5 describe different approaches to assessing the economics of mitigation and impacts / adaptation. Appendix 6 identifies research gaps, and describes how to improve future research in low carbon, climate resilient patterns of growth.

[9] Over the lifetime of the measure, the additional costs will be outweighed by savings, usually a result of reduction in fuel costs.

2. Feasibility of Low Carbon Growth in Developing Countries

2.1. The main focus of this stocktake has been to assess the economic impacts of developing countries moving to lower carbon patterns of growth. A literature review has been undertaken to assess the evidence, and determine whether developing countries can maintain growth levels whilst at the same time significantly reduce levels of GHGs.

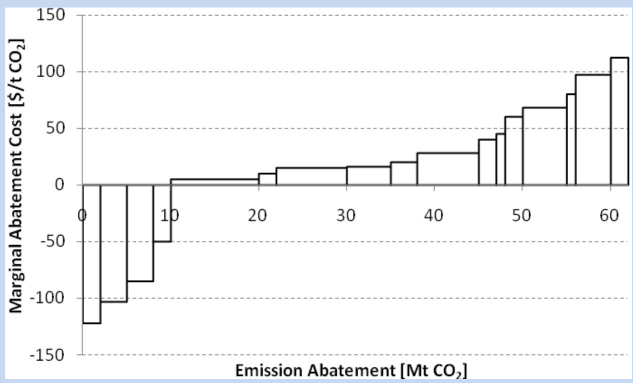
2.2. Most of the evidence focuses on cost-effectiveness analysis, assessing the extent to which a specific country can reduce emissions, and the costs of the different measures to achieve this. These static representations of cost-effectiveness of mitigation, often represented as marginal abatement cost curves (MACCs – see Box below), provide useful insights into the total investment needs but do not assess the dynamic effects of such investment on economic growth. The trade-offs analysed are therefore limited, producing few insights on the potential spurs to growth (or not) from the adoption and diffusion of new technologies.

2.3. In addition, the MACCs' representation of low carbon opportunities is dominated by technical measures for reducing GHGs. Two other potential building blocks of low carbon patterns of growth are often not represented: 1) Structural change e.g. new urban design or industrial re-structuring and 2) Behavioural issues e.g. rebound effect, changing societal view of environment, demand responses (for example, as reflected by price elasticities of demand).

A brief guide to Marginal Abatement Cost Curves (MACCs)

Many of the studies reviewed use a MACC-based approach. A MACC is a graph used for usefully presenting the marginal cost of emission abatement for varying amounts of emission reduction. This is shown in the graph below.

Each graph bar represents a specific measure, with the vertical axis indicating the cost of reducing a tonne of CO_2 (cost-effectiveness of abatement), and the horizontal axis indicating the potential reduction associated with each measure. The total cost of each measure if fully implemented is therefore the marginal cost (y-axis) multiplied by the abatement potential (x-axis).



Negative cost measures represent a situation where the implementation of a given measure will result in financial savings, not costs. This is typically observed for efficiency measures that reduce fuel consumption, and therefore costs.

MACCs always consider cost-effectiveness in a specific year, and against a baseline in that year. The baseline is critical for informing what the potential abatement is e.g. if there is significant coal generation assumed in the baseline, there will be greater potential than if generation was predominantly gas-based.

According to the underlying methodology, MAC curves can be divided into expert-based and model-derived curves. Simply put, expert-based MAC curves assess the cost and reduction potential of each single abatement measure, while model-derived curves are based on the calculation of partial- or general-equilibrium models. Most of the MACC approaches reviewed are expert-based.

Whilst recognising the importance of this approach, particularly for informing policymakers about abatement potential, some inherent weaknesses of this approach are described in Appendix 6.

Reviewing the evidence base

2.4. Over the past five years, a range of studies have emerged, focusing on the opportunities for developing countries to reduce their emissions. Most studies have focused on the large developing countries - China, India, Mexico, Brazil and South Africa, due to their contribution to global GHGs.

2.5. This stocktake focuses on (but is not limited to) reviewing four main groups of studies, as shown in the Box below.

Primary studies reviewed for LCG stocktake

- ***Regional Economics of Climate Change Studies (RECCS)***
  These regionally focused studies, supported by the UK Government, aim to mainstream mitigation and adaptation into local and regional institutions. They seek to explore alternative mitigation scenarios and the likely impacts of climate change and costs of adaptation. The mitigation studies differ in the extent of mitigation they are costing but typically go beyond the self-interest level.

- ***Project Catalyst***
  The studies, primarily by McKinsey and Company, aim to show what key developing countries can deliver as part of a new global deal, focusing on a stabilisation target to reduce risks of temperature increases above 2ºC. In the main, the analysis is based on assessing potential across different sectors using the global MACC curve, with some element of adjusting for country/region-specific factors.

- ***Centre for Clean Air Policy's (CCAP) Assisting Developing Country Climate Negotiators through Analysis and Dialogue project***
  The main focus of CCAP's *Developing Country* project is to strengthen the capacity of key developing countries to take action to reduce greenhouse gases and to prepare for negotiations on the future structure of climate policy under the UNFCCC. Mitigation strategies are based on known mitigation options. The project is also identifying specific "win-win" opportunities to ensure economic and other development-related benefits through cost-effective actions that will also reduce GHG emissions.

- ***World Bank Low Carbon Growth studies***
  The aim of these studies is to help mainstream mitigation into national economic strategies. They seek to understand the extent to which countries can cost-effectively mitigate, given current technology and financing. Few results have been published by these studies so it is not yet possible to draw systematic findings.

2.6. The main characteristics of the studies reviewed are presented in Table 2. In the main, these studies do not explicitly (nor state their objective as being to) assess the impact of different low carbon patterns of growth. For example, macroeconomic analyses of mitigation costs on economic growth are limited in number. Rather costs are estimated from bottom-up MACCs, from which inference can be made concerning potential impacts on growth.

2.7. With the exception of Project Catalyst and RECCS, few studies explore the feasibility and costs of specific mitigation objectives, linked to global stabilisation targets. In the main, these mitigation studies consider 'promising' measures that will move countries towards lower carbon patterns of growth.

Table 2. Comparison of study characteristics across different initiatives

	RECCS	**Project Catalyst**	**CCAP**	**World Bank LCG**
Broad objective	Integrated assessment of climate economics, building on Stern Review at regional level	Assessment of full technical potential, and associated costs	Assessment of promising mitigation options and issues of implementation	Mitigation options that complement current growth strategy
Political context	Independent but significant policy interest	Policy driven; close consultation with Government	Limited policy oversight and buy-in	Significant political involvement
G8+5 country (C, I, B, M, SA)*	M, B, C	C, I, B, M, SA	C, I, B, M**	C, I, M, SA, B***
Other country / region	East Africa, South East Asia, Caribbean, Latin America	Guyana, Indonesia	Indonesia	Indonesia
Mitigation only	No	Yes	Yes	Yes
Mitigation ambition	Medium-High	High (stabilisation focus)	Low-Medium	Low-Medium
Analytical approach	Range of assessment tools	MAC curve (based on global MACC)	MACC focused but other tools also e.g. MARKAL for India	Range of mitigation assessment tools
Type of mitigation options included	All	All	Highest potential (so limited no. of options); known options	Known options
Time horizon (end year)	Study dependent (2030+)	2030	2025-2030	Typically to 2030
Level of detail for option characteristics	Medium	Low	High	High
Sectoral coverage	Near complete	Complete	Near complete	Study dependent
Funding	Donor	Private	Donor	Donor

* **C**hina, **I**ndia, **B**razil, **M**exico, **S**outh **A**frica
** CCAP have reported on action being taken by Mexico but a full review of mitigation potential has not been undertaken
*** Although included in the list of WB LCG studies, the China analysis focused on energy efficiency rather than a broader and national assessment of cost-effective mitigation options

2.8. Therefore, the level of ambition differs significantly between studies. This reflects different priorities and purposes of the studies, and the political context in which they have been commissioned.[10]

2.9. Differences in ambition often lead to different approaches to the study analysis and focus. For example, the CCAP analyses are much more focused on promising measures, issues of implementation, and the barriers to uptake. Other analysis, in particular the McKinsey work, is more focused on assessing technical potential than on implementation issues (although certainly does not ignore such issues). This can make comparison difficult, as outlined in the Box at the end of Appendix 6, and highlights that caution is needed when drawing generic findings.

2.10. Further information on the different studies reviewed can be found in Appendices 2-4.

Economic impacts of low carbon patterns of growth

The cost of mitigation options in developing countries

2.11. The cost of mitigation opportunities can provide a useful indicator of what the economic impacts on growth might be from future low carbon patterns of growth. From the evidence base, large potential for low cost mitigation is observed. The review has found that for most large developing countries, low cost measures (of the options appraised), defined as less than \$25/tCO_2e, account for over 60%, in some cases 80% (Indonesia, Mexico), of total mitigation potential (see Figure 4).

2.12. The higher estimates for Indonesia[11] and Brazil appear to be primarily driven by low cost forestry measures.

2.13. It is important to note that the ambition level in the CCAP analyses for India and Brazil are significantly lower than seen in the other analyses presented, as illustrated in Figure 6. This is reflected in the limited number of mitigation opportunities assessed.

2.14. The proportion of low cost measures that are negative cost is also high. Such measures (often referred to as *win*-win or *no regrets*), which are often energy efficiency related, are options implemented that result in net savings (as opposed to a net cost) over the lifetime of the measure (ignoring transaction and policy costs). This is usually due to fuel savings or because they are simply more economic than the alternative they are being appraised against. With the exception of Mexico, such measures account for between 10-30% of mitigation potential. For Mexico, the level is between 40-60% (see Figure 4).

[10] A broader issue on comparability relates to hidden bias in the analysis, often driven by the political context in which the study is being undertaken. This is very difficult to determine but in certain cases self-interest in a political sense can have an impact on study design and outcomes. Issues around target setting for developing countries are of course extremely politically sensitive, and therefore this issue needs to at least be highlighted. It may well be in a country's interest, for example, to present a higher baseline or downplay available mitigation opportunities in order to avoid more stringent targets in future years

[11] Indonesia RECCs analysis only includes energy sector emissions. The overall mitigation reduction potential is significantly lower. Other RECCs analyses are not included here as either do not provide any additional mitigation assessment (Mexico) or are restricted to only 2-3 measures (Brazil).

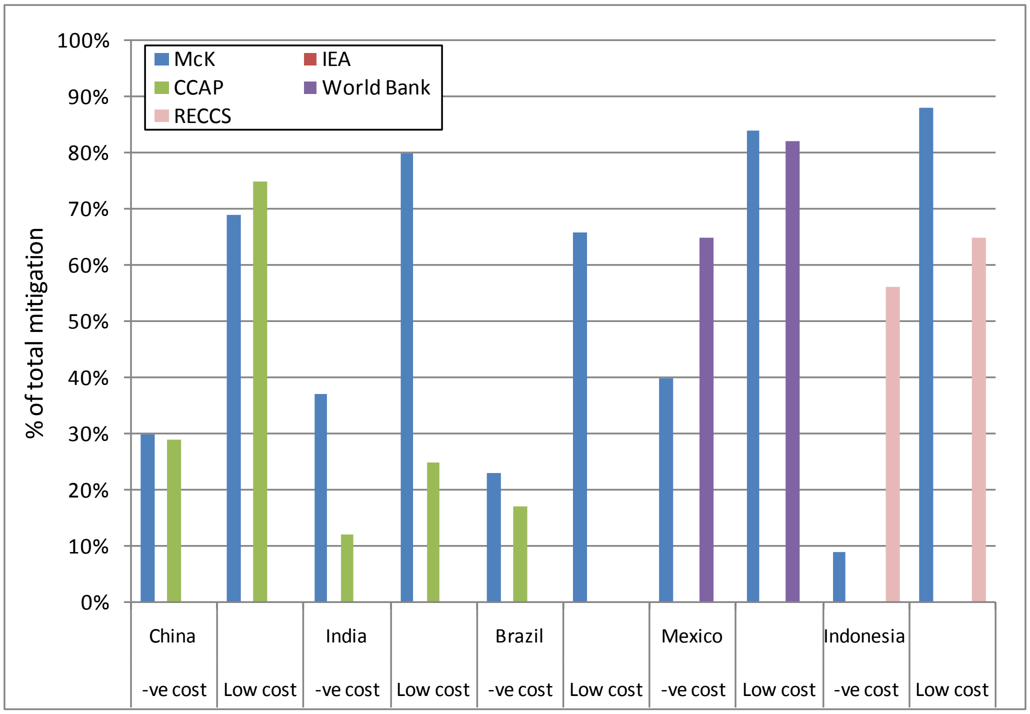


Figure 4. Negative and low cost mitigation potential by region / study group, as % of total mitigation (Analysis year is 2030 in most cases)

2.15. The large amount of mitigation potential at relatively low cost is encouraging, as it indicates that countries can at least move towards low carbon patterns of growth without adversely impacting economic growth and that some may be able to get a substantial way towards the extent of decarbonisation required by science without adverse impacts on growth. Indeed, these levels of negative or zero cost abatement potential are typically higher than observed in developed world analyses, due to greater potential for energy efficiency improvement, more potential in lower cost sectors (forestry, agriculture) and typically lower operating and maintenance costs associated with options.

2.16. Three important caveats concerning lower cost potential need to be made (These are further described in Appendix 6). Firstly, negative cost options are rarely easy to implement due to a range of barriers. Experience in the developed world suggests that achieving the potential offered by energy efficiency options in particular is not easy. Many barriers are apparent, from lack of information, to company or household inertia, to difficulties implementing policy measures. The capital intensity of options can also be a significant barrier to realising what might be low cost options on a *cost per tonne* basis.

2.17. Secondly, MACC analyses have tended to use low discount rates (particularly McKinsey), in the main making the range of options more financially attractive.

2.18. Thirdly, the costs of many measures in MACCs are underestimated due to full costs not being accounted for (transaction, policy, and opportunity costs). Ecofys (2009) suggests that hidden costs not usually captured in financial analysis can significantly increase the payback period for selected household energy efficiency measures. Enviros (2006) analysis suggests that the inclusion in the analysis of additional hidden and missing costs can reduce cost-effective opportunities by between 10-30% in the buildings sector.

2.19. There are also two issues relevant to the studies reviewed that need to be noted. Firstly, the McKinsey cost analysis is derived from the same global dataset (McKinsey 2009d). Whilst derived analyses have been made country-specific, it is likely that similar data assumptions and therefore results will emerge, which is what is observed. Additionally, these MACCs do not necessarily capture country-specific structural measures, such as changes to urban infrastructure to promote lower carbon transport systems. Secondly, the CCAP and World Bank studies focus on the lower cost, 'most promising' measures, biasing results towards a low cost outcome.

2.20. Conversely, there are three reasons that could make many of the options appear more cost-effective than shown in the analyses. Most technologies included in the analyses are near or fully commercialised. Therefore, the financial risks associated with technical feasibility of options, or cost overrun, are low. Secondly, the benefits of carbon financing and other non-quantified co-benefits, if reflected in the cost assessment, could further increase cost-effectiveness.

2.21. Finally, if oil and other fossil prices are higher than currently projected, many of the lower carbon options could appear more cost-effective. However, a situation could also arise where oil prices may in fact be lower due to global climate objectives resulting in reduced demand for such commodities. This is an area of significant uncertainty but very important when estimating cost-effectiveness.

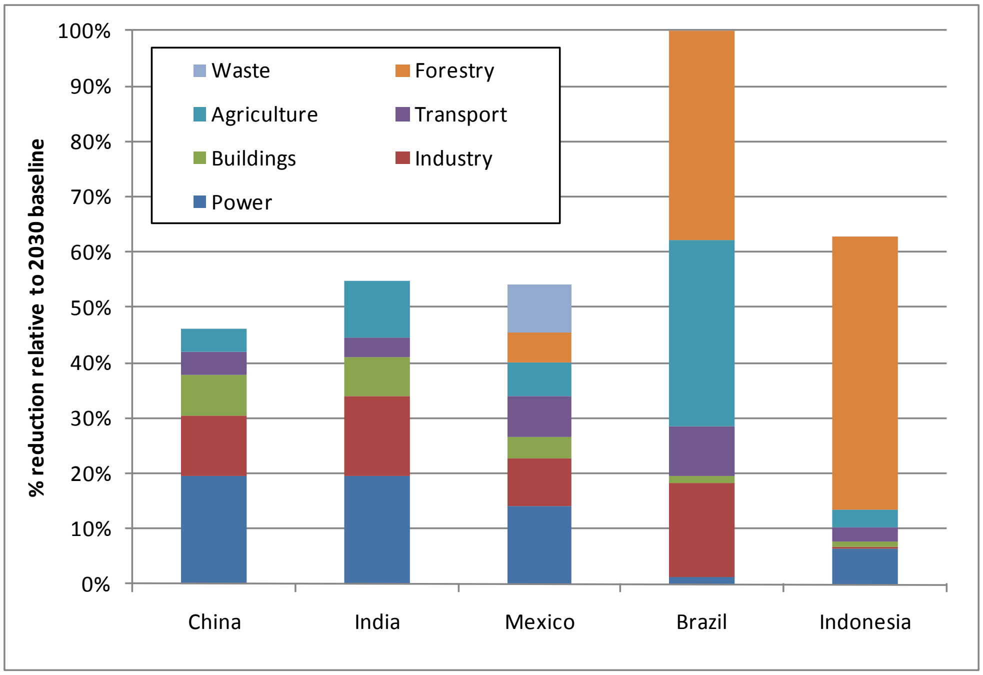
2.22. In conclusion, many low cost mitigation options do exist across most sectors of the economy. (Additional detail on these opportunities by sector can be found in Appendix 2). The analyses reviewed provide robust and important first assessments of the level of opportunities; follow on analysis is required to further develop cost estimates (and better assess co-benefits) and consider the issues around implementation, particularly barriers that exist, which tend not to get reflected in the cost analysis.

Different low carbon growth opportunities and pathways

2.23. Low carbon pathways differ significantly by country or region due to the size of sectors (in emission terms), and the potential for low cost or cost-effective abatement within those sectors. The analyses reviewed show these differences between countries, and differences across specific analyses for a single country or region.

2.24. The most comprehensive set of analyses are those funded through Project Catalyst (shown in Figure 5).[12] The first observation is that all analyses are based on a comprehensive assessment of reduction potential by 2030 relative to the baseline. The reduction potential is estimated to lead to lower emission levels by 2030 compared to the base year across all countries except China and India (see blue values below graph).

[12] Whilst funded by Project Catalyst, the majority of research has been done by McKinsey.



% Level in 2030 relative to BY	+15%	+96%	-25%	-56%	-41%

Figure 5. Emission reductions relative to baseline by sector across Project Catalyst analyses[13].
(Measures are limited to those with costs in 2030 below €60 per tCO_2e)

2.25. As shown in Figure 4, low cost abatement potential account for between 60-80% of the abatement potential, whilst negative cost measures account for between 30-40%.

2.26. Brazil and Indonesian potential is dominated by forestry (incl. peat land protection in the case of Indonesia). The importance of the forest sector in Brazil is illustrated by the fact that the assessment suggests that the sector on its own could reduce emissions to below or near base year levels, due to both reducing deforestation and afforestation. The importance of this sector is underlined by the relative low costs of these measures (see Box below).

Costs of reducing deforestation in Brazil
Deforestation in the Amazon region is responsible for approximately 70% of national emissions and therefore presents the largest potential for mitigation. McKinsey (2009b) put the costs of reducing deforestation at €3.5 /tCO_2, or €2.4 billion per annum (average) for the next 20 years, when deforestation could be virtually halted. In the RECCS (FCO/DFID 2009)[14], a REDD price in the Amazon of over $3/tonne of carbon (around $450/ha) was estimated to effectively price out all but the most profitable cattle ranching in the Amazon, and achieve up to 70% reductions. A higher carbon price of $50/tonne carbon would be needed to reduce deforestation by 95% (Note that this high price only relates to a small proportion of area covered by forests). The study, using these values, goes on to cost a compensation scheme under REDD, with costs over a 70 year programme totalling $21 billion (NPV). A maximum value of $2.6 billion per annum was also estimated.

[13] Brazil's potential for the forest sector increases total reductions relative to the baseline to 239%. India's potential in the agriculture sector also includes the forestry sector.

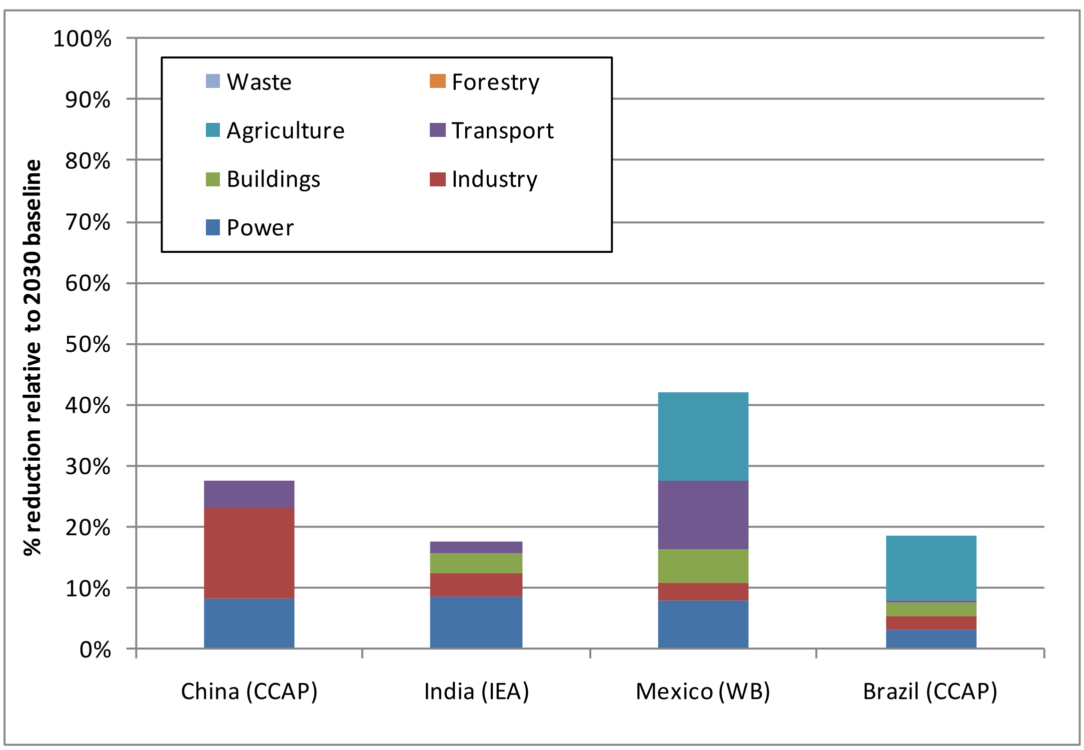
[14] Two studies were undertaken to assess deforestation mitigation costs - Strassburg (2009) and IPAM (2007). Strassburg uses a partial equilibrium model to assess economic return from land that has been converted from forest to other uses (both historically and in the future) and the maximum returns that may have been possible. IPAM uses a bottom-up model to assess opportunity cost for forest conservation versus activities to produce wood, soybeans and cattle. The approaches point to an <u>average</u> opportunity cost of $1,000/ha for the Amazon rainforest land used for agriculture.

2.27. In Brazil, low levels of potential exist in the transport and power generation sector because they are relatively low carbon already, due to ethanol use in road transport and hydropower generation.

2.28. Mexico and China can also achieve significant reductions but require mitigation efforts across all sectors. As shown in the previous section, much of this mitigation potential is relatively low cost. India can achieve about a 50% reduction (relative to the baseline), through reducing emissions across power, industry and transport in the main (as shown for China). Even with very large reductions under a *technically achievable* case, emissions are still projected to be almost double in 2030, relative to 2005. This illustrates the significant challenges of countries such as India and China with very high energy demand growth in fossil intensive power, industry and transport sectors.

2.29. Other analyses undertaken are much less ambitious, focusing on promising sectors and / or lower cost options (see Figure 6). This lower ambition is illustrated by the blue values below the graph showing emission levels relative to the base year. The Mexico World Bank study is also relatively low ambition (not climate target driven) but identifies significant amounts of lower cost abatement potential, allowing for reductions relative to the emission level observed in the base year.

2.30. The China CCAP study confirms that power and industry sectors offer significant potential. The Mexico World Bank study confirms the importance of the power and transport sectors, although suggests more potential in agriculture and less in industry. In addition, it also shows a consistent picture relative to mitigation potential levels. The Brazil CCAP study includes very few measures (~8) in its analysis and therefore is not comparable with the Brazil McKinsey analysis.



% Level in 2030 relative to BY	57%	156%	0%	46%

Figure 6. Emission reductions relative to baseline by sector across other selected analyses (Most of the reduction potential in this graph is either negative or low cost)

2.31. Most of the studies focus on larger middle income countries. A good example of a low income country study reviewed in this stocktake is the East Africa RECCS, which finds a significantly different picture. In this region, the electricity sector is already fairly decarbonised. The largest increase in the baseline (and therefore potential for future reductions) is in the agriculture and transport sectors. Many such countries will have agrarian-based economies, and therefore the agriculture sector is still likely to be important in 15-20 years time. It will therefore continue to form a significant proportion of emissions, and potentially be an important sector for focusing mitigation efforts.

2.32. A very different example of a low income country analysis is Vietnam, analysed as part of the South East Asia RECCS (ADB 2009). The analysis, using model-derived MACCs, shows significant abatement potential at negative costs (around 50% of energy-related CO_2), primarily from energy efficiency improvements in electricity generation and industry. Further reductions are available including decarbonisation of the power sector (fuel switching, CCS etc). Realising total mitigation potential in 2020 would require investment of up to $1.8 billion or around 1.3% of its GDP, but would result in Vietnam moving emission levels below those in the base year.

2.33. More detailed discussion of each country review can be found in Appendix 2.

Determining the impacts of a low carbon pathway on growth

2.34. With the exception of the South Africa LTMS analysis, and the Mexico World Bank and McKinsey reports, few studies have undertaken full macroeconomic analyses of the impacts of ambitious GHG reductions. These macroeconomic analyses do support the bottom-up MACC approaches, finding that significant levels of mitigation can be achieved whilst at same time supporting growth. As described in section 1, the IPCC review of such studies also draws a similar conclusion. The Mexico analyses are described in more detail in the Box below.

The impacts of ambitious GHG reductions on economic growth in Mexico

Two studies have undertaken useful economic analyses of the costs of moving to a low carbon pathway. The Centro Mario Molina (CMM 2008) study highlights significant abatement opportunities in 2030 based on bottom-up MACC approach, estimating potential to reduce emissions by over 50% relative to the baseline. Average costs of abatement in 2030 are approximately $2/t$CO_2$, reflecting that 216 Mt$CO_2$e, or 40% of total potential can be achieved at negative cost. Increasing investment needs are estimated to be US$7.3 billion / year (2011–2015) rising to US$18 billion (2026–2030), or 2.8-3.1% of total economy wide investment. Crucially, these reduce to $4.9 and $2.8 billion if netted against energy and operating cost savings.

A top-down macroeconomic analysis using E3MG found that large emission reductions do not harm growth prospects; in fact growth in GDP increases by up to 1% relative to the baseline, and could create half a million new green jobs. There are some distributive effects, with job losses in some sectors; however, the impact is net positive. A small reduction in consumption due to increased prices is largely offset by overall growth in consumption in future years. In 2030, household consumption is expected to be more than double current levels. In other words, the cost is very small, with growth in spending per household of 3.18% per annum in the low carbon scenario compared to 3.22% under the reference case.

Growth is not negatively affected for a variety of reasons. Firstly, energy costs are a small proportion of total economic costs. Additionally, low carbon technical measures are estimated to lead to small incremental cost. Finally, borrowing of capital occurs over time, therefore not affecting economic consumption significantly. The analysis is premised on early action, starting investing in low carbon technologies now. This is crucial to ensuring lower costs, due to avoided lock-in to higher carbon technologies and the need for additional and disruptive investments in future years. Early action and a move away from a fossil-based energy system will also lower reliance on potentially higher cost energy in the future, leading to some comparative advantage.

The second study by the World Bank (Johnson et al 2009) uses analysis under the MEDEC (México: Estudio sobre la Disminución de Emisiones de Carbono) study to determine economic costs of a low carbon strategy. Whilst only considering high potential, low cost measures, the analysis points to similar reduction potential as Centro Mario Molina (CMM 2008) in 2030, of 42%. 82% of the potential from interventions assessed is below the $10/t CO2e cost level. 65% of reductions (26 of the 40 options assessed) can be achieved at negative cost. The aggregate costs are put at $64 billion between 2009 and 2030, or about $3 billion a year, equivalent to about 0.4% of Mexico's GDP in 2008. The $3 billion value is similar to the CMM (2008) estimate, where financial savings are also accounted for.

Johnson et al use the CGE model developed by Boyd and Ibarrarán (2008) to assess the macroeconomic impacts of the low carbon scenario. Implementation of the options was estimated to increase the overall level of GDP by as much as 5% in 2030. While this appears high relative to the E3MG estimate discussed above, a key factor in the observed positive impact must be the level of energy savings achieved through negative cost measures. Agriculture and forest sectors are estimated to be the biggest winners (note in this analysis this includes biofuels / use of biomass products) whilst welfare gains were greatest for the lowest decile groups, suggesting a progressive rather than regressive strategy.

Another important contribution to the economics of climate change evidence base for Mexico is the RECCS analysis (Galindo 2009). Whilst the focus is on impacts / adaptation, a simple approach is taken to determining mitigation costs, estimated by assuming a specific carbon price multiplied by the amount of reduction (50% by the year 2050 and 2100 relative to 2002). At a 4% discount rate, costs for the 2100 target are between 0.7% GDP using $10/tCO_2e$ and 2.2% using $30/tCO_2e$. In 2050, they are 0.56% and 1.75% respectively. The analysis does mention that these cost estimates probably represent the upper limit, given that no cost minimization was applied in the analysis e.g. using cost curves or estimating cost reductions through innovation. No analysis is undertaken at a sectoral level, although the MACC analyses reviewed in this study are cited.

At the economy level, the studies appear to point towards relatively low incremental costs associated with necessary investments. In fact, benefits to growth are observed. Financial mechanisms that incentivise the move to a low carbon growth pathway through the use of a carbon price will make low carbon investments more attractive, and again reduce any foreseen impacts on growth. The issue here will be about the type of mechanisms available to provide incentives, and then access to such finances at the sectoral level.

2.35. The South Africa study suggests that growth in GDP could be achieved even with relatively ambitious cuts. A recent report by the Climate Group (2009), using Cambridge University's E3MG model, also supports such a view of potential growth but premised on collaborative action e.g. extensive and functioning carbon trading markets.

2.36. Positive growth effects illustrate an important potential co-benefit of a low carbon pattern of growth, as they consider feedbacks from investment into the wider economy. This includes increased output in high value, low carbon industries, employment effects and improved efficiencies in production, reducing costs. MACC analyses do not allow for such feedbacks, and therefore provide a very static view of impacts. (Of course they have other strengths such as explicit detail on technology options).

2.37. The South Africa LTMS analysis does discuss the issue of low carbon industries strategically, as a potential opportunity for the economy to re-focus on manufacturing and services that are closely aligned with increasing demand for low carbon industries, both domestically and regionally, and away from traditional heavier industries.

2.38. It is important to note that impacts on GDP are not uniform across all sectors of the economy, or in social terms, across society. For example, the CCAP (2006a) India report undertook economic analysis at the sector level and found that mitigation actions resulted in a net decrease in GDP in the industry and power sectors of R28bln and R1.9bln respectively, but an increase in the transport sector of R2156bln (reflecting differences in costs of action). The associated change in employment was -0.8m and -0.1m in the industry and power sectors, with an increase in employment in the transport sector by 58.4m. This shows the importance of a sectoral view of impacts when undertaking this type of analysis, that there are likely to be winners and losers.

2.39. Most of the McKinsey analyses and the LTMS study for South Africa provide an aggregate cost metric, where annual costs are compared against projected GDP. [15] This useful indicator of potential impacts on growth suggests that in most instances costs will not be higher than 1% of GDP; indeed the South Africa study states that significant cuts can be made at very low or even negative costs (albeit against a very high baseline).

2.40. The less ambitious McKinsey China and India analyses suggest a higher range of between 1.5-2.5%, translating into very large capital requirements. Whilst less ambitious than other analyses i.e. not driven by per capita targets, they still result in significant reductions (as seen in Figure 5).The McKinsey Brazil analysis estimates that to cut GHGs by 70%, €5.7 billion per annum would be required to curb deforestation, and €8 billion per annum by 2030 for other measures. This would amount to 1% of projected GDP in 2030. These types of value are consistent with what is estimated by the broader economics of mitigation literature (discussed in section 1).

2.41. From the different types of analysis (macro-economic / MACC-derived aggregate mitigation costs), there is an emerging view that for some countries the additional costs associated with the required investments are not prohibitive, a similar finding that emerged from the Stern Review and other developed country analyses.[16] This is often the case even where ambitious reductions are required, for example in Mexico, Brazil and South Africa.

2.42. For other countries, particularly China and India, it is less clear as to the costs required to reduce emissions to levels required for global stabilisation. It is likely that, based on the existing evidence, that costs would be higher than observed for other developing countries due to the magnitude of the reductions required, and the increasingly expensive investments that would be required.

2.43. For those countries for which there may not be significant impacts on growth or additional costs, there are likely to be significant challenges associated with raising capital, restructuring energy systems, and introducing effective policy; however, it is a positive indication that the challenge can be met by specific middle income countries, and that ambitious low carbon pathways may indeed be feasible without significantly damaging growth prospects.

[15] Some studies compare costs against GDP. While this is a useful indicator of potential impacts on growth, it is not the same as stating that this is how much growth will be affected by i.e. these % values are not impacts on GDP growth but rather a comparison of cost levels as % of projected GDP levels.

[16] Most of the LCG studies have been individual country studies. Lower cost options could emerge where regional trade in power is included (SEI 2009)

The co-benefits of climate mitigation action

2.44. It is evident from the review that the co-benefits of lower carbon options are significant due to strong synergies with other policy objectives. This includes the economic benefits associated with no regret measures and their macro-economic benefits (as already discussed), increased energy security (e.g. associated with increasing indigenous renewable supply and reduced oil imports), reduced air pollution from cleaner energy, raising capital through carbon financing, and introduction of more efficient, productive technologies. However, dis-benefits can also arise, particularly in relation to distributional effects, although in the context of the studies reviewed, these appear much less pronounced.

2.45. Whilst co-benefits are often described, these are rarely quantified or monetised into the analysis (as most assessments are restricted to a cost-effectiveness rather than a cost-benefit framework). This means that often the self-interests that would support the wider uptake of an option are not fully captured.

2.46. Where co-benefits are quantified in analysis, net benefits can often arise.[17] For example, an energy efficiency option can become significantly lower cost with the external costs of air pollution internalised, and the savings from reducing reliance on fossil fuel imports and saving on foreign currency payments. The Mexico World Bank study went some way in broadening the analysis to include time saving benefits, and estimated external costs saved across specific transport measures.

2.47. Highlighting these co-benefits to support self-interest arguments is particularly important for low emitting countries (that may not be subject to caps in the near future), as has been highlighted in the East African RECCS work. This is the primary means of incentivising a move towards a low carbon growth pathway, which can only be justified if it helps economic growth, supports development etc.

[17] The quantification of co-benefits is an important part of EC impact assessment in the climate change and air quality policy areas. The EC impact assessment on *Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020* (see http://ec.europa.eu/energy/climate_actions/doc/2008_res_ia_en.pdf) puts costs of achieving the climate reduction target of -20% in 2020 would cost €91 billion or reduce EU GDP by 0.58%. However, it would also reduce the air pollution control costs by €10 billion. Furthermore, analysis for the EC by Pye et al (2008) shows that the economic benefits associated with a reduction in air pollution health effects was between €5-16 billion (see http://www.cafe-cba.org/assets/necdcba3.pdf).

Table 3. Low carbon options for Kenya and their co-benefits

Option	Policy driver	Co-benefits (as a GHG mitigation measure)
Expanding use of renewables (centralised)	Expanding capacity to meet future needs based on strong resource base	Reduce reliance on / payments for foreign fossil imports More cost-effective across many types Leverage carbon finance to fund investment Potential to build regional expertise, and export No air quality pollution
Decentralised generation from renewable	Rural electrification	Lower cost than alternative fossil generation Limit requirements for expensive grid expansion Sustainable energy for local economic growth No air quality pollution
Introducing improved stoves	Reduce biomass demand	Reduce indoor air pollution, and therefore health impacts Reduce fuel costs Protecting fuel Saving economic / leisure time (wood collection)
Improving efficiency of road transport fleet	Reducing reliance on fossil fuel imports	Reduce reliance on / payments for foreign fossil imports Reduce costs of vehicle use Reduce air pollution Reduce road traffic accidents (due to newer cars)
Planned public transport scheme for Nairobi	Meeting urban transport demand	Reduce congestion Reduce air and noise pollution levels Save travel time / enhance productivity Reduce road traffic accidents
Tackling energy inefficiency in SMEs	Reducing industry fuel costs, increasing competitiveness	Reduce fuel costs, enhance competitiveness Enhance energy security Reduce air pollution
Improve livestock and cropland management	Improve agriculture productivity and reduce land degradation	Protect / enhance arable land quality Safeguard rural livelihoods Increase economic productivity of sector
REDD / Afforestation	Protect forestry-dependent economy and energy supply security	Protect biodiversity, and dependent sectors Ensure security of wood fuel supply

Limitations of LCG studies

2.48. From the above review, it is clear that an important body of analysis has emerged over the last five years concerning the mitigation opportunities and costs for developing countries. The focus of this analysis has primarily been on the assessment of sector-based technical opportunities rather than wider assessment of the impacts on growth although there are some notable exceptions. This section therefore highlights some of the limitations of the evidence base in addressing the key question posed by this stocktake.

To what extent can Developing Countries move towards a Low Carbon Pathway without compromising future economic growth rates?

2.49. The studies reviewed represent a significant and important step forward in making first assessments of *mitigation potential*, from which it is possible to infer the extent of *low carbon growth potential* without compromising growth. That is to say, the levels of low cost potential suggest many developing countries can move towards a Low Carbon Growth path without damaging growth. A limited number of studies that do measure the impact (positive and negative) of additional mitigation costs on future growth rates confirm this to be the case.

2.50. The limited insights on macroeconomic effects are in large part due to the prevalence of bottom-up engineering approaches. A general comment is that the studies would benefit from further linkage to macro-economic models and quantification of other co-benefits to better understand overall costs / benefits to the economy. Sensitivity analysis that assessed impacts at different ambition levels would also be useful, providing understanding of additional costs and / or impacts on growth at different reduction levels.

What is the impact of demographic and structural change on future uptake of low carbon options?

2.51. A significant challenge facing many developing countries is the projected level of urbanisation, and the need for spatial planning. The future urbanisation trends projected are extremely dramatic – the urban population of developing countries is predicted to rise from 2.4 billion in 2007 to 3.6 billion in 2025: a 50% increase over the next 15 years (1.2 billion extra urban dwellers).[18] The trends are particularly important for Africa and Asia: over the next four decades, the urban population of Africa is likely to treble and in Asia it is predicted to more than double – and there will be the emergence of 5 new Asian mega-cities and 2 new Africa ones.

2.52. No studies considered this issue when discussing mitigation. This does raise important issues about the baseline projections, and also the effective potential for mitigation options. It is worth flagging as an issue of importance, because the decision about urban planning will impact on the types of options and levels of mitigation that may be possible, and because spatial growth is largely irreversible (e.g. land-use changes are irreversible, and the trend towards low or high density urban areas has to be planned for early, otherwise there is a high risk of lock-in).

2.53. This is particularly true for transport, and options for public transport within metropolitan areas. If a city is widely dispersed, public transport options may become less feasible or cost-effective. Though the World Bank Mexico study considered mode shift, the other studies that considered transport did so only for vehicle efficiency options. The wider consideration of urban and spatial planning was missing. While this is extremely difficult, it is also clear that failure to address these options is a significant omission, and a priority for future studies.

2.54. In many of the analyses it also not clear the extent to which other factors concerning structural change in industry, building design and transport demand patterns are reflected in demand forecast, and what such differences will mean for mitigation potential. This is potentially more relevant in the longer term studies. There is also the social dimension, particularly how society will perceive climate change and what that might mean for political decision making and consumer behaviour. A range of issues, primarily those that do not fit easily into modelling studies or cost curve analysis, are still to be researched.

[18] Note world population is expected to grow from 6.8 billion currently to about 8.3 billion by 2030 (UN, 2008) thus virtually all of this increase takes place in the urban areas of developing countries

What are the distributional implications of patterns of low carbon growth?

2.55. The studies have undertaken a limited assessment or make little acknowledgement of potential negative impacts (beyond cost) of mitigation options. These could include increasing fuel poverty due to higher tariffs from low carbon generation (and subsidy removal) or distributional impacts e.g. it is unlikely that the poorest communities will benefit from new employment opportunities but might well be hit through increased fuel or food prices if a carbon tax is introduced.

2.56. The World Bank report for Mexico did undertake some analysis and found that the noted increase in GDP was not evenly distributed, with the largest gain for the agricultural and forestry sectors. The impact on the level of welfare was progressive, with income per capita growing for all income groups with the greatest increase accruing to the lowest deciles. So this study points to progressive rather than regressive effects.

2.57. The LTMS study for South Africa also considered the distributional impacts of mitigation action. Output and employment losses in the coal mining and electricity generation sectors were offset by gains in other sectors that benefit from lower production costs, resulting in unambiguously positive but small employment effects. Household welfare effects are also small but positive, with the distribution of gains depending on the type of energy efficiency modelled. The analysis concluded that distributional effects were too small to raise significant concern about the socio-economic implications, both for efficiency improvements and shift to lower carbon generation.

2.58. The RECCS work in East Africa also included an assessment of the distributional consequences of mitigation policy and finds that the degree of sector focus could have very different benefits for different groups, and consequently for inequalities. It broadly found that electricity projects would be likely to benefit already wealthier/urban groups, whilst forestry and agriculture projects had more potential to benefit poorer/rural populations. However, significant stove improvement programmes would benefit the rural poor, through saving on fuel costs and reducing indoor air pollution.

2.59. Whilst the above provide some useful insights, it is difficult to draw broad messages from across all regions. It is clear that distributional effects will arise but that these will be very different based on mitigation action implemented, and that policy makers need to be proactive in reducing any regressive effects.

Could ‘regionalising’ mitigation options enhance cost-effectiveness of action and protect growth?

2.60. Most studies have been undertaken primarily on a national basis, tending to exclude the potential for lower cost abatement by integration of regional power grids and greater regional trade in lower carbon goods and services. A greater focus on regional assessments, developed to some extent in the SEA RECCS, could provide some useful insights as to how regional action or initiatives make moving towards a lower carbon pathway more attractive or not.

2.61. The benefits of increased regional energy cooperation in East Africa are also highlighted in the RECCS analysis, with Kenya potentially accessing a significant proportion of future electricity from Ethiopia. Note that there are of course energy security risks in too much reliance on a single source. In addition, transnational grids for the East Africa region could mean that higher fossil generation countries could access lower carbon electricity. A large grid network could also have some benefits for ensuring supply, particularly if loaded with significant intermittent renewable resources, or where domestic capacity may be offline for a particular reason.

What are the key linkages with adaptation strategies?

2.62. Future mitigation studies rarely take account of the impacts of climate change on the future energy sector and on mitigation measures. Even in the SEA RECCS, adaptation and mitigation were considered in relative isolation although in the Brazil report (see Box below) this was better integrated. This is an important research gap that needs further work.

Mitigation-adaptation linkages for the energy sector in Brazil (FCO/DFID 2009)

The following impacts on the Brazil energy sector were identified from climate change: significant reductions in hydro-electric reliability, particularly in some basins, no adverse impacts of biofuel crop production, and an increase in AC demand of 6% (household) and 5% (services) in worst case.

The effect of the above impacts on the energy system out to 2035 were assessed, based on “with” and “without” CC impacts scenarios. Optimization modelling of energy supply was undertaken using MESSAGE to see what lowest cost solutions could be introduced to deal with possible energy losses, primarily through reduction in hydro output.

Due to reductions in hydro potential, it was estimated to be necessary to install an extra capacity of 162 TWh and 153 TWh a year in A2 and B2 scenarios respectively. The additional capacity would be composed, mainly, of natural gas, advanced technology for burning sugarcane bagasse and wind energy. If aggregated, these options would imply costs in the order of US$51 and 48 billion in A2 and B2 scenarios respectively. The main strategic implication would be the redistribution and / or increased pressure on the natural gas supply to ensure gas was supplied to the new generation capacity.

2.63. It is highlighted, however, that this integrated approach is also an issue for developed countries - recent UK analysis for the CCC (AEA 2008), and prior to that for the Energy White Paper, using the MARKAL model, did not take account of future temperature rises and changes in electricity demand, the potential implications of a major low carbon economy and renewables in a future climate, or the increased costs associated with protecting generation plants from increased coastal flooding etc.

Moving towards low carbon patterns of growth

2.64. Section 4 considers further the issues of implementation. From the review of the evidence base, the following factors appear to be important for realising low carbon growth objectives.

- Start now to avoid more costly action in the future; if investments are to be low carbon (and climate resilient) this has to be taken into account now to prevent lock-in to higher carbon technologies and the potential re-investment under any future agreements that cover developing countries.

- A robust strategy needs to in place, backed by strong political will. Evidence of low carbon growth potential is important but will never be achieved without strong political backing, and the right policies in place that provide the long term stable framework for investment.
- An economy wide view of mitigation opportunities is required, with all sectors contributing if significant reductions are to be realised. Opportunities, particularly those that are low cost, are not restricted to specific sectors but available across all.
- Timing of options in important to ensure technologies are implemented at the cost-optimal time.
- Accessing capital by providing the necessary political signals and having the necessary institutional capacity in place. Finance is key to delivering a strategy.

2.65. The extent to which developing countries can achieve low carbon patterns of growth without damaging growth is still not clear. What is clear is that the challenges will differ significantly between countries. The example of Mexico (see Box below) is going to be significantly different from China or India, or a Low Income Country.

The opportunity for low carbon patterns of growth in Mexico

The evidence reviewed for the Mexico case study (Appendix 3) suggests that costs of moving a significant way towards a low carbon economy are not prohibitive so long as the opportunities are pursued in a phased manner, reflecting their cost, technological maturity and ease of implementation. The key question is whether this overall finding is specific to Mexico, or is also applicable to other developing countries, considering a future lower carbon pathway. Therefore, it is important to note on what basis a low carbon growth pathway in Mexico is possible, and at limited additional cost:

- The analyses are premised on <u>action being taken early</u>, avoiding lock-in to high carbon technologies. Introducing lower carbon technologies after investment in high carbon technologies in later years, possibly in the face of mandatory targets, would be significantly more expensive. Examples of early action include investing in low carbon electricity generation to meet rapidly increasing demand, ensuring minimum efficiency standards for appliances and securing reductions in deforestation.

- It also requires that policy be implemented consistently over many years – investors need confidence that there will be stability in the policy framework

- Economic and population growth rates are not as high as forecast in other developing countries. As these are the primary drivers of growth in carbon emissions, the fact they are lower will make a shift to a lower carbon pathway relatively easier.

- Analyses highlight significant amounts of energy efficiency potential across all sectors, resulting in large cost savings to the economy. However, the analyses do not highlight the difficulties associated with implementing such measures. The lack of consideration of policy and transaction costs in implementation is a key area for further study in the cost assessment. Policies to realise the potential of such measures are likely to push the costs of these measures up significantly.

- In addition to negative cost options, there are a range of options in the low cost range ($0-20 / tCO_2e) that also ensure a move to a low carbon pathway is not prohibitively expensive. Importantly, Mexico can go a long way to establishing a low carbon pathway primarily on the basis of relatively cost-effective options. All sectors of the economy provide either negative and / or low cost options. Only by tapping this reduction potential across all or most sectors can significant reductions be achieved. Sectors contributing the most potential include power generation, transport and other energy end use sectors.

3. Climate resilient patterns of growth

3.1. This chapter reviews studies on the economics of climate change impacts and adaptation to see what these imply for patterns of growth that may help build resilience[19] to climate change.

Introduction

3.2. The potential impacts of climate change will have significant economic costs, with estimates of global net losses of 1-5% of GDP (equivalent) for 4ºC of warming (Yohe et al, 2007). However, these costs will be unevenly distributed and much higher costs are anticipated in developing countries. There are several reasons for this: many of the largest changes are projected to occur in these countries; their economies rely more on climate-sensitive activities; many operate close to environmental and climatic tolerance levels; and their ability to adapt may be limited because of technical, economic and institutional limitations (Tol et al, 2004).

3.3. Climate change therefore has the potential to erode away achievements in economic and social development though industry, settlements and society are often capable of considerable adaptation, depending heavily on the competence and capacity of individuals, communities, enterprises and local governments, together with access to financial and other resources.

3.4. To date, the focus of work in this area has been on the prediction of the economic costs of climate change, and on the potential costs (and benefits) of adaptation options that respond to these risks. However, a different question is starting to emerge that centres on how to achieve climate resilient growth[20], considering what patterns of growth are likely to help build an economy's resilience. The answer to this question is unclear and climate resilient patterns of growth are not well defined with limited understanding of what this might involve in practice.

3.5. Against this background, this part of the study has reviewed the recent work on the economics of climate change and adaptation, to provide a stocktake of knowledge and methods, to synthesise existing information, to identify gaps in knowledge and to interpret the implications for this work in the context of climate resilient patterns of growth.

The Existing Evidence Base

3.6. The study has reviewed a number of studies, drawing especially on the Regional Economics of Climate Change Studies (RECCS) and the global results from the World Bank study on the Economics of Adaptation. The material reviewed and the aggregation level/descriptions are presented in the box below. It is stressed that this is still an emerging area and there is far less evidence than for low carbon growth. Moreover, the existing studies are focused on

[19] The IPCC defines resilience as the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

[20] The DFID White Paper outlines that the UK will help countries plan and implement new climate resilient development strategies (targeting investments needed to build resilience). It also highlights the UK will help build the knowledge and capacity to develop climate resilient [and low carbon] economies. This includes the need to enhance resilient growth so that countries can absorb future shocks and still prosper.

the economic costs of climate change, and the costs and benefits of adaptation, rather than climate resilient patterns of growth[21].

3.7. These studies address a number of policy questions, which include:

- Estimating the economic costs of climate change, either at the global level or at the national level. The latter studies usually focus on the economic costs in a future year, e.g. in the period 2050 – 2100 and express results in total costs ($) or as an equivalent % of GDP.
- Estimating the costs, or costs and benefits, of adaptation, including:
    - At the global level, estimating the costs of adaptation (in $US) in a specific future year, most commonly 2030 (e.g. UNFCCC (2007); World Bank EACC, 2009). There are also economic studies, comparing the economic costs and benefits of adaptation over time (e.g. Hope, 2009) or the potential trade-off between mitigation and adaptation (e.g. Carraro et al 2009: de Bruin et al, 2009).
    - At the national level, studies such as the RECCS identify information on the costs (and sometimes benefits) of adaptation in a future period (e.g. 2050), which can raise awareness of the scale of the issue and have some relevance for national financing needs and for national planning and priorities.
    - There is also a new focus on national level investment and financial flow (I&FF) analyses, which consider the additional costs in the short-term (e.g. 2030) needed to make future investment more climate resilient. This is being advanced through the UNDP I&FF guidance and a large number of country case studies.
    - At the sub-national, sector or local level, information on the costs and benefits of adaptation can allow the design and prioritization of adaptation policies, programs and projects in decision making / appraisal (e.g. AICCA, 2006; ECA, 2009).

3.8. These studies involve a range of approaches, from top-down economic modelling through to bottom-up analysis informed by local case studies. While none of the studies reviewed are focused on climate resilient growth, they do provide relevant information, set out below.

[21] Note that other information on climate security (migration and conflict) and climate and labour productivity is also potentially relevant but has not been considered within this initial review.

Material reviewed		
Date	**Publication**	**Organisation**
***Global* scale - Adaptation Costs/Investment and Financial Flows-**		
2009	Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates.	World Bank. Global Report of the Economics of Adaptation to Climate Change (EACC) Study
2007	Investment and financial flows relevant to the development of an effective and appropriate international response to Climate Change	United Nations Framework Convention on Climate Change (UNFCCC).
2007	Fighting Climate Change: Human Solidarity in a Divided World. Human Development Report 2007/2008	United Nations Development Programme (UNDP).
2007	Adapting to Climate Change: What's Needed in Poor Countries, and Who Should Pay	Oxfam International.
2006	The Stern Review on the Economics of Climate Change.	Stern Review
2006	Clean Energy and Development: Towards an Investment Framework	World Bank.
Review studies		
2009	Potential costs and benefits of adaptation options: A review of existing literature	United Nations Framework Convention on Climate Change (UNFCCC).
2009	Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates.	International Institute for Environment and Development / Grantham Institute (Parry et al)
2008	Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments.	Organisation for Economic Co-Operation and Development (OECD)
Economic Integrated Assessment Models		
2009	Analysis of Adaptation as a Response to Climate Change.	Copenhagen Consensus on Climate Change. (Carraro et al, 2009)
2009	Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modelling of Adaptation Costs and Benefits	Organisation for Economic Co-Operation and Development (OECD) (de Bruin et al, 2009)
2009	The Costs and Benefits of Adaptation.	Hope, 2009. In IIED (Parry et al) above.
RECCS –regional to national level		
2009	The Economics of Climate Change in Southeast Asia: A Regional Review.	Asian Development Bank (ADB), Mandaluyong City, Philippines, 2009.
2009	The Economics of Climate Change in East Africa	SEI for DFID/DANIDA
2009	The Economics of Climate Change in Mexico	Federal Government/SHP/ Semarnat (Estados Unidos Mexicanos)
2009	The Economics of Climate Change in Brazil: Costs and Opportunities.	Brazilian public sector organizations.
Other national assessments		
2009	The Impact of Climate Variability and Change on Economic Growth and Poverty in Zambia	International Food Policy Research Institute
2009	Cultivating success: the need to climate-proof Tanzanian agriculture	International Institute for Environment and Development
2007	Economic impact of climate change in Namibia: How climate change will affect the contribution of natural resources to the economy.	International Institute for Environment and Development
Sub-national level		
2009	Shaping Climate-resilient Development a framework for decision-making.	Economics of Climate Adaptation Working Group (ECA).
2006	Estimating and Comparing Costs and Benefits of Adaptation Projects: Case Studies in South Africa and The Gambia	Assessments of Impacts and Adaptations to Climate Change (AIACC).
2005	Climate Proofing: A Risk-based Approach to Adaptation. Asian Development Bank (Pacific developing member countries)	Asian Development Bank

The economic costs of climate change

3.9. The economic costs of current extreme weather (climate variability, associated with droughts, floods, etc) are already large in many developing countries. Extreme events often lead to damages that are several percent of annual GDP and potentially much more in smaller areas. However, these costs are not attributable to climate change.

- As an example, the East Africa RECCS found economic costs of current periodic droughts and floods in the region range between 1 and 10% equivalent of GDP (per event) and that they occur with regular frequency reducing long-term growth.
- Several studies (including Parry et al, 2009) highlight that many developing countries currently have an 'adaptation deficit' which means they are not adapted to these events. This deficit needs to be addressed otherwise it will increase the vulnerability to future climate change.

3.10. There will also be large economic costs in the future from climate change. This will arise from changes in[22]

a) long-term trends e.g. associated with sea level rise, temperature changes, precipitation changes (sometimes referred to as slow onset change);

b) changes in the future patterns of climate variability and extreme events (sometimes referred to as shocks).

3.11. All the studies confirm that the future economic costs of climate change will be potentially large, and that economic damages will be higher in developing countries. As examples, the headline economic costs of climate change in the RECCS have been estimated as:

- Equivalent to 7% of GDP in 2100 in South-East Asia (market and non-market sectors, future GDP levels) under a business as usual (A2) scenario and equivalent to 3.5% under a 450 ppm stabilisation scenarios (ADB, 2008).
- Equivalent to over 6% of GDP (current) in Mexico (Galindo, 2009).
- Equivalent to 0.5% and 2.3% of GDP (future) for alternative future scenarios in 2050 for Brazil (market sectors).
- Equivalent to 3% of GDP by 2030 in Kenya (market and non-market sectors, future GDP levels) (SEI, 2009).

3.12. While these economic estimates are highly uncertain, they are extremely large. At the upper end (in a world without stabilization) they would be unsustainable for a functioning economy.

3.13. The RECCS (cited above) are primarily associated with the economic costs of long-term trends, rather than changes in climate variability (future shocks). They usually consider future time periods (e.g. for a future period such as 2040-2070) and undertake assessments of future impacts across a range of sectors. They do not look at how the sum of annual losses might add up and affect future growth.

3.14. Some studies (e.g. Brazil) have used computerized general equilibrium models (CGEs) to capture wider costs (economy wide), rather than only considering sectoral assessments.

[22] A third category of economic costs, associated with major global irreversible effects, so called tipping points / extremes, are also important, but not considered here in the context of medium-term effects in developing countries. Note also that long term trends and variability can act in combination.

There are also examples in the wider literature of the use of CGE models to look at the agriculture sector (e.g. Tanzania (IIED, 2009)). However, these examples use functional relationships associated with long-term trends and apply these to the models using static assumptions on cross sectoral linkages, assuming the structural composition of the economy and the multiplier effects between sectors are the same in 50 years time as now assessed.

3.15. There is a separate set of analysis that considers the future economic costs of extreme events and shocks. It is stressed that the prediction of the future changes to climate variability and extreme events is extremely uncertain. In many cases the climate models show a very wide range of projections, which are often different in sign. As an example the East Africa RECCS reports that the future pattern of droughts predicted by the models for Kenya vary; many show decreases in future severity, but some show increases.

3.16. Some of the studies have explored the potential effects of future climate variability.

- The World Bank EACC study does consider extreme events. It highlights that country-specific factors are powerful determinants of losses from extreme weather events. It used historical panel data to derive risk equations and combined these with future projections and then looked at social protection measures as an adaptation (female education).
- Some of the other studies have considered these events, though with varying degrees of sophistication. The Zambia study (IFPRI, 2009) applied a CGE model to look at agriculture and current climate variability as well as future climate model projections. The ECA (2009) study applied a very static and simple analysis with historical analogues but showed very high economic costs for extreme events.

3.17. Outside of the list of studies outlined above, there are some other studies that have considered existing climate factors and growth, for example the recent work of Dell, Jones and Olken (2009). Their work examines the impact of temperature and precipitation on national economies and finds higher temperatures (especially associated with shocks) substantially reduce economic growth in poor countries (a 1 degree C rise in temperature in a given year reduces economic growth by 1.1 % on average). It also finds that higher temperatures appear to reduce growth rates (not just the level of output) and have wide-ranging effects, reducing agricultural and industrial output, investment, innovation, and political stability.

3.18. They also report that decade or longer increases in temperature also show substantial negative effects on poor countries' growth and conclude that this suggests substantial negative impacts of future climate change on poor countries. There are some studies that apply similar approaches and apply to future projections of climate change, including recent studies in East Africa (GTZ, 2009).

3.19. There has also been a recent set of studies from the World Bank, including consideration of extreme events and climate change as part of the World Development report (2010: Development and Climate Change).

Vulnerability and development

3.20. All the studies conclude that the impacts of climate change will be unequally distributed and highlight socioeconomic distributional effects. Some studies assess the potential differences between regions, e.g. in the Brazil study, but this is usually reported in qualitative terms. The studies have also not considered the distributional effects between the public and private sectors.

3.21. The studies report that economic development can reduce vulnerability to climate change. It makes economies less dependent on climate-sensitive sectors, such as agriculture, reducing their vulnerability. Development can also reduce vulnerability by increasing levels of incomes, health, and education, and thus capacity of households to adapt as well as improving the institutional infrastructure and the ability of governments to assist. Economic growth and wealth is also key to adaptive capacity (see Stern, 2006).

3.22. However, in certain cases, development can increase vulnerability. The more developed the country the greater the value of infrastructure and personal property at risk from climate change and therefore greater the absolute cost of climate protection. Certain patterns of growth and development can also increase vulnerability, by increasing future exposure potential, such as through development in locations that are more susceptible to climate risks, or when building growth or development around activities that will be affected by future climate change (e.g. those that require high water inputs, etc).

3.23. Development alone is not enough to put sub-national regions or countries on a positive trajectory with regard to climate adaptation. Even with mitigation, there will still be high potential impacts from climate change, and a need for adaptation.

Adaptation

3.24. The studies show that adaptation has potentially large benefits, relative to costs, in reducing the potential impacts of climate change. However, adaptation will be costly. There are wide ranges on the estimated costs but it is clear they could be significant.

- The EACC study summarises global estimates for developing countries. Under the drier scenario, the global costs of adaptation for developing countries over the period 2010 – 2050 were estimated at US$78 billion per year. Under the wetter scenario, the costs were higher at US$90 billion. Costs increase over time. The sectoral assessment shows total costs are dominated by the coastal sector (on average, around $30 billion/year) followed by infrastructure (on average, $14 to $30 billion /year), compared to the average total of $78 to $90 billion. The study reports that the costs of adaptation are of the same order of magnitude as current Official Development Assistance.
- However, a review from Parry et al (2009) highlights that studies such as the UNFCCC (and by implication, the EACC study) only capture a limited set of climate change effects, within a small number of sectors and with limited consideration of impacts within sectors. They therefore consider the adaptation cost estimates (as above) are underestimated, perhaps by a factor of 2 or 3 for the sectors considered, and significantly more for all sectors / effects.

3.25. The Parry study also highlights the level of residual impacts, as adaptation reduces economic costs but it does not remove them completely. They report that in many sectors, residual costs could be 50% of climate damages. In practice the level of adaptation (and the costs and benefits) will vary with the decision rule applied[23].

3.26. Adaptation costs can be reduced by governments and the public sector ensuring that incentives for innovation, investment and private decisions reflect the scarcity of resources (once the impact of climate change is taken into account). Some examples demonstrate that the costs of adaptation may be dramatically reduced by a combination of technical change and private initiative. However, none of the studies have a detailed assessment of the distribution of impacts or adaptation between the public and private sectors.

3.27. Other studies (e.g. UNFCCC, 2007) have highlighted that private sources of funding can be expected to cover a large portion of the adaptation costs in some sectors, such as agriculture and infrastructure (but also that public resources will be needed to implement policies or regulations to encourage the investment of private resources in adaptation, especially in developing countries).

3.28. Some of the studies treat adaptation as set of (technical) options. As an example, in the coastal sector this would include consideration of hard physical flood protection, and most studies give less attention to non-technical ‘soft’ options (e.g. integrated coastal management). More progressive studies recognise that adaptation involves a social and institutional process, as well as involving outcome based options. There are also particularly issues over the flexibility of options (and reversibility), as well as the issue of timing, that are frequently mentioned, but not yet analytically assessed. This also recognizes the need for adaptation to work within a framework of uncertainty.

3.29. The studies also highlight that adaptation will also require doing development differently: climate-proofing infrastructure to make it resilient to climate risks; building sea walls or other coastal protection measures to adapt to likely sea level rise; and most importantly, accounting for the inherent uncertainty in future climate projections in development planning.

3.30. It is also likely that adaptation itself will have distributional consequences, e.g. in terms of the way benefits or spill-over effects accrue within a population or socio-economic groups, though this remains largely unexplored as yet.

3.31. There is also the potential for mal-adaptation, in relation to adaptation that is inefficient, ineffective, inequitable or shifts vulnerability from one actor to another. It is possible that some adaptation could actually slow growth. Such issues necessitate careful planning for the policy implementation of adaptation, recognising the need to focus on early adaptation decisions that can be robustly justified in economic terms, and ensuring flexibility to keep open the benefits of future information and future options.

3.32. Some of the RECCS e.g. Brazil, East Africa start to look at the linkages between mitigation and adaptation. This includes some synergies but also some conflicts. Key areas for this interaction involve the urban environment (cooling demand) and spatial planning more generally, agriculture, land-use change and forestry. Some studies have considered

[23] Adaptation can aim to avoid all damages or return levels of welfare back to pre-climate levels (note this is often impossible). It can aim to maintain current levels of risk or reduce them cost-effectively within budgets or to pre-defined acceptable levels. It can reduce levels to the economical rationale point, ensuring benefits are greater than costs. In practice, objectives will vary between studies and stakeholders and there will be trade-offs between doing everything possible versus living with the risks. Note that the EACC study assumed perfect adaptation, i.e. no residual damages.

synergistic options (e.g. agroforestry) while some also look at the potential interactions, e.g. with future rainfall under a changed climate and hydro electric demand.

Methodological issues and key caveats

3.33. There are also some important methodological issues and key caveats with these studies:

3.34. All of the studies are highly uncertain, and should really only be treated as indicative with respect to the values they report. Some studies only analyze and report central estimates from single models for a limited number of scenarios (e.g. Brazil), rather than reporting the full range of possible outcomes. Other studies have made a more explicit consideration of uncertainty, at least in relation to climate model outputs (e.g. EACC, East Africa RECCS).

3.35. The future economic costs of climate change are strongly determined by socio-economic development, from population growth, increased wealth, land-use change, etc. This is important for a number of reasons.

- Previous studies show that socio-economic change can be as important as climate change in determining future economic costs (e.g. see the UK Foresight study, Evans et al, 2004). The East African studies show a very large increase in the costs of extreme events in future years (a fivefold increase over the next few decades – in the absence of adaptation) because of socio-economic development (population, assets, etc). This is a key issue because it highlights that future assessments cannot be constrained to the analysis of climate parameters alone and that without good development policy, impacts could increase[24].
- Socio-economic change is particularly important for developing countries, as it will lead to growth and development over the next 50 years, thus changing conditions dramatically from the economies of today. Failure to take this into account can thus overstate future impacts. Some studies (e.g. EACC) address these future development paths and the potential effects on vulnerability more explicitly.

3.36. The studies and numbers reported have different assumptions of autonomous adaptation[25], in some cases significantly[26]. Some of the studies do not factor this in but others do so very explicitly. Some care must therefore be taken in interpreting values between studies.

3.37. There are difficult attribution issues when looking at adaptation to current climate variability (and development) versus adaptation to future climate change. This has been captured in the concept of an adaptation deficit (see earlier). There is a question of whether addressing this existing adaptation deficit should be considered as adaptation to climate change or development (the existing deficit is not attributable to future climate change) – and this issue is important in terms of the international negotiations and funding.

[24] Note also that many studies (incorrectly) report the sum of socio-economic and climate change together as 'climate change'. This is mis-leading, as the impacts from socio-economic change will occur even in the absence of climate change. The lack of a counter-factual baseline over-attributes future economic costs to climate change alone (noting that adaptation has to address the sum of the socio-economic and climate change together).

[25] Defined as adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation;

[26] Note some autonomous adaptations are also impacts, e.g. increasing air conditioning is an autonomous response to higher temperatures and greater cooling demand, but it is also often described as an impact.

Uncertainty and recommendations

3.38. All the studies highlight the very high uncertainty involved in predicting the future impacts of climate change. This is a key consideration for interpreting the results.

3.39. This uncertainty also has implications for costs, and for the approach to considering and implementing adaptation. It requires decision making under uncertainty. Most of the existing estimates do not reflect costs that a given country would have to incur to hedge against the uncertainty of future climate. Policymakers will therefore have to make investment decisions without knowing which climate future will occur.

3.40. In terms of priorities, all the studies identify the need to increase the level of knowledge about climate change and adaptation and to build capacity.

3.41. They highlight the need to integrate climate change in environmental and development policies, in a way that Governmental actions can help to tackle the problem, evaluating regional and national vulnerability and proposing adaptation measures.

3.42. They outline the need to invest in no-regrets actions, that is, development actions that simultaneously increase resilience to climate change.

3.43. They recommend mainstreaming of climate change adaptation in development planning, and for it to be an integral part of sustainable development, poverty reduction and disaster risk management strategies. The studies also recommend enhanced policy and planning coordination across ministries and different levels of government for climate change adaptation.

3.44. They advise on the need for a more holistic approach to building the adaptive capacity of vulnerable groups and localities and their resilience to shocks.

3.45. Finally, they recommend the development and adoption of more proactive, systematic, and integrated approaches to adaptation in key sectors (water resources, agriculture, energy, coastal and marine resources, and forestry) that involve technical and non-technical adaptation measures, that are cost-effective, and that offer durable and long-term solutions.

Climate Resilient Patterns of Growth

3.46. As highlighted above, the studies reviewed here have not been aimed at climate resilient growth – so they do not look at what patterns of growth would reduce vulnerability. Furthermore, the studies do not address many of the sectors that are important for economic growth, i.e. they don't consider industry, manufacturing and services.

3.47. They sometimes consider infrastructure, but often at a very aggregated level in relation to a narrow set of risks from extreme events (rather than looking at energy or transport infrastructure as enablers for growth[27]). There is some consideration of the risk of settlements and cities to climate change (see Wilbanks et al, 2007) and some consideration of key economic hubs such as port cities (see Nicholls et al, 2008) but this remains a relatively understudied area.

[27] There are general considerations of infrastructure but this is not often categorised at the sectoral level to specific industry. The exception is the EACC study did have some analysis to specific areas of transport and water services. Within the service sector, there are some studies of tourism potential and changes from climate change, but were not addressed in RECC or EACC studies.

3.48. The lack of focus on industry and manufacturing is because these sectors have not been generally considered to be very climate sensitive, at least in comparison to sectors such as agriculture (though it may also just reflect a lack of studies)[28]. A number of industries (e.g. brewing) are starting to look at the implications for them of climate change-induced water shortages. Many of the effects from climate change are secondary or indirect, related to the concentration of economic activity and their inter-dependencies. These could be through power outages if water is not available either for hydro power schemes or for cooling thermal electricity plants.

3.49. These issues include the potential effects that climate change may have on the physical assets used for economic production and/or services, on the costs of raw materials and inputs to economic production, on the subsequent costs to businesses, and thus on competitiveness and wider economic performance and employment patterns in the sub-region and beyond. This makes analysis of these potential effects extremely complex.

3.50. Nonetheless, some initial conclusions on climate resilient patterns of growth can be made.

3.51. The economic costs of climate change are likely to affect future growth, so the concept of climate resilient growth is likely to become increasingly important.

- Detrimental effects on growth will arise from long-term changes (slow onset), particularly from cumulative effects over time. However, the longer time periods involved should mean that many potential effects can be reduced or prevented through planned pro-active adaptation.
- Similar reductions in growth may also arise from any changes in extreme events and from climate variability (shocks). As one off events, these reduce the level of annual income though have less effect on long-term growth. However, there is a concern that large individual events or cumulative patterns of extreme events (and the time between recovery periods) will also have detrimental effects on long-term growth (see Hallegatte, 2007; Dell et al, 2009).
- To date there is limited analysis of the consequences of long-term trends and changes in extremes acting together[29]. It is also not clear whether long-term trends and extremes will affect the same sectors or groups of society, in relation to distributional consequences.

3.52. At the macro-economic level, a key focus for longer-term climate changes is for sectoral shifts away from climate sensitive activities. These aims are similar to the existing challenge of development economists, e.g. the move away from agricultural dominated economies, but are difficult to achieve.

3.53. There is also a need to reduce an economy's sensitivity to climatic shocks, noting that this will also have benefits in reducing the risks from current climate variability. This can involve reducing exposure and sensitivity as well as improving capacity to respond, transferring risks, etc.

3.54. The potential for climate resilient growth will be strongly determined by the pattern of socio-economic development. Reducing risks will be as much about addressing fundamental socio-

[28] It is also conditional on the type of manufacturing and industrial activity, so for example, agricultural processing within a country will be very dependant on climate through the supply chain.
[29] There is work in the coastal sector (sea level rise / storm surge), but in other sectors, relatively little has been done.

economic development, as it will be about ‘climate-proofing’ investment. This suggests a strong need to consider both together, within a dynamic rather than a static framework over future years (rather than basing on the current situation), as well as considering the potential feed-backs between the two over time.

3.55. The studies indicate substantial adaptation financing is needed for climate resilience. In the absence of this, or if insufficient levels are provided, climate change will reduce economic growth. However, high levels of adaptation financing will also have macro-economic effects within recipient countries that could also be important (and that may make climate resilient growth harder to achieve).

3.56. It is difficult to see how countries could absorb the upper levels of adaptation financing being discussed. There are also issues whether the financing can be effectively spent in a short space of time and successfully used, and whether the large increases in donor money will have unintended consequences in particular sectors or to the economy (e.g. price changes, labour availability, etc).

3.57. Future investment will have to be made in the context of uncertainty. The current level of confidence from the climate models does not allow firm predictions of future climate over the life-time of long-lived assets, e.g. infrastructure. There is a need to screen investment for the potential range of possible effects. In some cases, it will be possible to enhance resilience with low cost options, but in other cases there will be costs associated with hedging strategies. This is a particular issue for private sector investment, or for areas identified at high levels of potential vulnerability. There will be much higher risks for investing in more climate sensitive (developing) countries in the future, affecting the expected rate of return.

3.58. Climate resilient patterns of growth are also likely to require significant domestic policy change, in relation to macro-economic shifts as well as long-term planning and policy (e.g. in areas such as spatial planning to prevent development in high risk areas). It is likely to require strong institutions, good governance, effective policy enforcement, as well as flexible and market driven responses to enhance private sector responses. The availability of international finance for adaptation will not, on its own, deliver climate resilient growth.

Review of Methods

3.59. The studies use a broad range of methodological approaches and models, descriptions of which are included in Appendix 5. These include:

- Economic Integrated Assessment Models (IAM)
- Investment and Financial Flows (I&FF)
- Computable General Equilibrium models (GCE)
- Impact assessment (scenario based assessment or econometric based)
- Vulnerability assessment
- Risk management
- Adaptation assessments

3.60. All of these approaches have strengths and weaknesses (see table in Appendix which also maps a selection of the reviewed studies against the approaches). They often provide different types of information, much of which is complementary. No individual approach can, on its own, adequately address all of the methodological aspects associated with climate resilient growth. There are therefore potential benefits in adopting multiple methods and models, then linking these together to provide a greater evidence base.

4. Realising low carbon, climate resilient patterns of growth

4.1. The evidence base indicates that countries must develop economic growth strategies that are simultaneously low carbon and climate resilient.

4.2. Low carbon strategies may be achieved at small incremental cost (relative to business as usual investments) given early and committed action. They must take advantage of emerging opportunities (new technology and service markets, sources of finance), but also mitigate against potential risks to growth (trade barriers or changing demand patterns).

4.3. At the same time, the existing studies show that climate change will have major economic costs in developing countries, potentially reducing growth. They also report potentially large adaptation financing needs. A key challenge is for developing economies to move towards climate resilient patterns of growth, i.e. patterns of development that will build an economy's resilience to a future changing climate, both against future long-term trends and future changes in extreme events (shocks). However, there is as yet, little evidence on what this might involve in practice.

4.4. Even less clear is how these two objectives inter-relate, i.e. the degree to which low carbon and climate resilient patterns of growth are synergistic, and even whether there are potential conflicts or trade-offs between the two.

4.5. Each country will have differing motivations with regards to the pace and extent of low carbon and climate resilient growth that they pursue. Potential climate impacts, prevailing economic structures, and resource opportunities will determine the level of ambition at a national government level. Strategies will differ in terms of policies and measures adopted, and in the respective roles played by national government, the private sector and international donors in their financing and delivery.

4.6. However, key questions still remain. First, are the economic costs of low carbon options identified in the studies a fair reflection of the real costs associated with implementation at a national level? Do national governments have sufficient capacity to enable such a transition? Do the studies provide sufficient analysis of potential routes to funding? Second, how can the international community respond adequately on the scale and within the timelines envisaged, and what lessons can be learned from previous efforts towards economic development and technology scale up?

4.7. This chapter reviews the key considerations that frame the political response to the climate-related growth agenda, and reviews some of the potential policies and measures identified in the studies. It then assesses whether the costs of transition presented are a true reflection of real costs, and then sets out some of the issues pertaining to delivery and technology deployment at scale.

Understanding the political context

4.8. Whether a country decides to adopt a low carbon strategy is a political decision that will be based on a variety of factors, informed by national self-interest, an international agreement and future risks of a 'no action' strategy. This political strategic dimension is beyond the scope of this study; however, it is important to consider the key influencing factors on the level of ambition, highlighting that low carbon growth opportunities and costs in one country or region may differ significantly for a variety of reasons. As well as perceived differences in the anticipated climate change impacts, these might include:

- Economic and demographic drivers
- Regional geography, resources and cooperation
- Policy co-benefits
- Institutional capacity for implementation
- Access to international finance

4.9. The shift towards climate resilient patterns of growth will also be a political decision, very strongly influenced by the potential vulnerability of the country to future climate change (provided these future risks are known and/or are recognised). It will also depend on whether future patterns of climate resilient growth align with existing policy or visions, and the degree of political will to change these. It will also be influenced by the same factors above (e.g. access to finance), the institutional capacity for change, and by the level of governance, effective policy and longer-term planning.

Economic and demographic drivers

4.10. Economic and demographic drivers are likely to be important factors in determining future emissions and therefore ambition levels. Higher baseline emissions in future years are likely to increase the challenge of reducing emissions below base year levels. However, a higher emission baseline may also offer greater opportunities for access to carbon finance.

4.11. High levels of projected economic or demographic growth, creating upward pressure on emissions, are likely to create cautious political conditions towards the setting of absolute GHG targets or binding timetables for low carbon development. For example, near to medium term growth projections of 6-8% GDP for China and India will make absolute emission reductions more challenging. This is compared to Mexico, with predicted GDP growth of 3-4% per annum and population growth of around 1%, stabilising in the 2040s. The result is a much lower emission baseline, making political action more palatable due to the perceived lower economic (and political) costs. The setting of relative intensity targets rather than absolute emission reduction targets may provide less stimulus for low carbon investment.

4.12. While demographic drivers such as population growth are important, of particular interest is the rate of urbanisation. A rapidly urbanising population is going to provide significant challenges to ensuring low carbon growth due to the increasing pressures on housing, transport systems, and other urban infrastructure. This is particularly the case in Kenya (SEI 2009b), which will see extremely high urbanisation in future years.

4.13. These demographic drivers are also extremely influential in the degree of exposure to climate change. While development can increase the adaptive capacity of developing countries, greater exposure may arise from socio-economic change in relation to higher populations, greater underlying demand on climate sensitive resources (e.g. water resources, ecosystem services), higher asset values, etc. Many studies project that future socio-economic development has as large an effect as climate in determining the future potential impacts of climate change.

4.14. The structure of the economy also impacts on the extent to which mitigation can occur, and the potential costs that fall on the economy. Fossil fuel exporters and producers of high carbon industrial commodities may feel limited in terms of the actions they can take without facing a major loss of revenue, large restructuring costs or potential issues of carbon leakage. Countries dependent on carbon intensive trade and transport structures, such as developing countries with large tourism or agricultural export sectors may suffer a loss in economic growth from internationally enforced carbon pricing. Border taxes may reduce trade flows of carbon intensive commodities or products.

4.15. Similarly, the sensitivity of the current and future economy to climate (long-term trends and shocks) is a key driver for vulnerability. At the macro-economic level, climate resilient patterns of growth may need to encourage sectoral shifts away from climate sensitive areas (such as agriculture). Such policies are consistent with development, but are challenging to achieve.

4.16. The issue of phasing of costs and benefits must also be taken into consideration, especially given that political structures tend to operate on a shorter time horizon than economic development, mitigation or adaptation planning processes. It is likely that the costs of transition related to both mitigation and adaptation will fall in the short run where as the growth benefits from economic restructuring will tend to be enjoyed in the medium-long run. Given the political cycle, it may be important to consider depoliticising the development of strategy for low carbon, climate resilient patterns of growth, as has been done to certain extent in the UK with the setting up of the Committee on Climate Change.

4.17. Likewise, it is not clear that the economic benefits derived from emerging technology markets will be equitable in their distribution between countries. Countries that have large domestic markets for low carbon goods and services are likely to enjoy economies of scale, and enjoy a resultant competitive advantage in export markets over those that must produce primarily for export only, either due to low income status or size. Countries that have established R&D and manufacturing bases in existing technologies are likely to dominate the markets for emerging low carbon technologies. Service markets are, however, more likely to be more localised.

4.18. An interesting example of transition to a lower carbon economy is that of South Africa (see Box below), which has a high future baseline and a relatively energy intensive industry and power sector, potentially restricting the ambition level or if not, pushing costs significantly higher through the use of more innovative technologies.

South Africa: Realising the Required by Science Objectives

Winkler et al (2007) undertook a wide ranging analysis to explore potential low carbon pathways, assessing the options and their costs, and the macroeconomic impacts on the economy. Some similar conclusions to those seen for Mexico emerge, based on a range of scenarios shown in Figure 1. In 2050, none of the sets of mitigation measures (packages) explored fully closed the gap between baseline (*Growth Without Constraints*) and the level required by science. Interestingly, South Africa can close the gap by 43% (*Start Now case*), using options that on average have negative abatement costs, therefore saving overall costs relative to the baseline.[30] The most ambitious *Use the Market* case closes the gap by 76%, with additional costs of only 0.1% of GDP

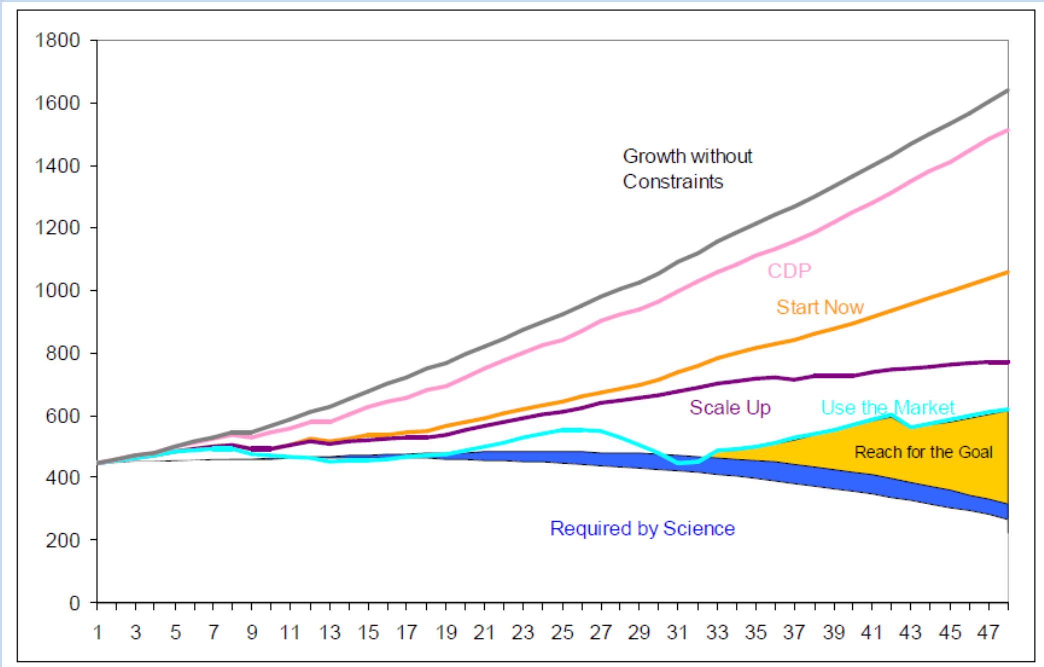


Figure 7. Mitigation pathways in LTMS analysis for different 'wedges'

The interesting aspect of this analysis is that the modelling cannot achieve the *Required by Science* ambition level. The report notes that this gap could be closed if more novel technologies were considered, or there was greater emphasis on behavioural change. This reflects the large contribution of fossil-intensive industries to economic growth.

The study confirms that South Africa could also achieve this through economic restructuring, moving away from the very energy intensive industrial base, with a large mineral extraction sector, and high use of coal, including in the power generation sector, to an economy with a low carbon industry focus. This highlights that there are developing countries that are much more energy intensive which could limit the extent of low carbon growth, or at least make it more challenging, particularly if some economic restructuring is needed.

Finally it also confirms the Mexico case study conclusions that relatively ambitious low carbon growth is achievable at additional costs that should not significantly impact on future economic growth. This is important also because such findings are based on analysis using country-specific modelling, not global approaches scaled to national circumstances.

[30] It is noted in the report that this is compared to a very high baseline with limited autonomous energy efficiency improvements.

Regional geography, resources and cooperation

4.19. The ambition of any emerging low carbon strategy will be dependent on natural resource base of a country, and how that translates into mitigation opportunities and costs. A country richly endowed with significant renewable resources or geological areas for carbon storage has greater opportunity for changing the generation mix, for example. Mexico and Brazil have relatively good access to reliable renewable resources, particularly hydro. Indonesia and Brazil both have large rainforest areas, which is an important sector for reducing emissions at relatively low cost.

4.20. Regionalising low carbon strategies could encourage stronger ambition, particularly if mitigation action can be undertaken where it is most cost-effective. This could be represented in reality through regional energy networks (as discussed in the East Africa case study (Appendix 4), through electricity networks) or by setting targets as a block (as per the EU example).

4.21. Stronger ambition in a region could also arise through growth in low carbon industries; for example, the market for solar heating systems in Kenya could spill-over into neighbouring countries, due to increasing affordability as a consequence of market uptake. In addition to low carbon technologies, export of low carbon fuels (e.g. biofuels) could also increase regional ambition and action.

4.22. Vietnam is investing in dam building in Laos and exploring opportunities in Cambodia to provide electricity for domestic consumption (Baumüller 2009). Another interesting project called Desertec has been conceived that could see North Africa exporting large amounts of renewable energy (mainly from concentrating Solar thermal power (CSP) to Europe.[31] However, geopolitical considerations, the allocation of costs and revenues and resource ownership issues continue to provide significant barriers to cross-border approaches. Revenues must flow back to developing countries from such activities to make them attractive.

Policy Co-benefits

4.23. As highlighted throughout this report, co-benefits are critical for justifying a low carbon pathway, particularly for low emitting countries (as discussed in the East Africa RECCS, SEI 2009b). In his paper assessing how to promote renewable energy and energy efficiency in Ghana, Gboney (2008) outlines the different co-benefits associated with mitigation options.

Table 4. Co-benefits of mitigation actions in Ghana

Type of co-benefit	Co-benefit	Description
Energy	Diversification of energy supply	Diversifying away from fossil fuels and main renewable source of hydro, improving energy security and generation reliability e.g. during low rainfall months
	Fuel switching	Move to greater use of natural gas will reduce GHGs relative to oil and improve thermal generation efficiency
	Reducing transmission investment	Through increased uptake of decentralised generation

[31] For more information on Desertec, see website www.desertec.org

	costs and distribution losses	
Environment (Social)	Human health	Reduced use of firewood through move to modern energy services (LPG) greatly reducing indoor air pollution effects and increasing energy efficiency / resource protection
	Ecological systems	Reduced air and agricultural pollution from less GHG emissions can yield co-benefits to strengthen and sustain natural ecological systems
Economic	Employment / growth opportunities	Low carbon options can induce growth / employment effects
	Improving competitiveness through efficiency savings	Two case studies show how energy efficiency savings can reduce operating costs in industry / commercial sectors

4.24. The main issue with co-benefits is how to better incorporate them into cost-driven analyses, so that the many non-carbon benefits (beyond negative cost measures) are recognised. This is vital if countries are to comprehensively understand what is in their self-interest.

Co-benefits of low carbon mitigation in Mexico

The Mexico analyses reviewed in this study (CMM 2008, Johnson et al 2009) note the following policy co-benefits of low carbon options:

- *Energy security*. The analysis by CMM (2008) estimates 27% reduction in oil consumption by 2030. This means less reliance on foreign imports, and reduction in future payments for an increasingly expensive commodity.
- *Health / welfare*. Greater agricultural productivity results in higher incomes, reduced traffic congestion improves economic productivity, reduces fuel consumption and improves urban environments, whilst a shift away from fossil fuels leads to cleaner local environments, and reduction in health impacts. Protecting forests safeguards economic sectors reliant on wood-based products, biodiversity and the welfare of forest-based communities.
- *Political leadership*. Mexico can leverage its position as a low carbon leader in future climate negotiations and in attracting foreign investment.

Concerning the above point on health and welfare, the World Bank analysis estimates the time benefits (due to less congestion) and reduction in external costs (due to less air pollution damaging health) associated with transport measures. For specific measures they are considerable.

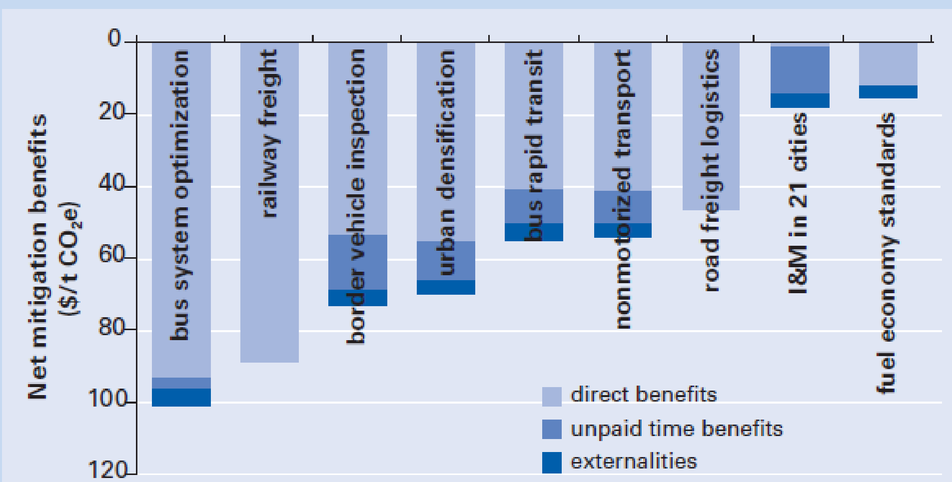


Figure 8. Externality and Time Costs for MEDEC Transport Interventions (Source: Johnson et al. (2009))

Institutional Capacity

4.25. While the above issues focus on how well placed a country / region may be to embark on a low carbon strategy, issues concerning ability to effectively implement a strategy are just as critical. Adequate institutional capacity is needed in a number of areas:

- Policy development and implementation
- Technical skills to operate and maintain technologies; this could also extend to whether there is capacity to develop technologies domestically
- Accessing capital, either through carbon financing or ability to attract private sector investment

4.26. These institutional aspects are even more important in relation to climate resilient growth. Adaptation is now recognised as a social process as well as an objective (an outcome to implement options, with a key driver in early stages associated with building adaptive capacity. Even if international finance is available, it is not yet clear whether this can be effectively used and it will certainly require a step change in effective capacity and institutions.

Access to International Finance

4.27. International carbon and development finance will continue to be required to underpin the economic transition to low carbon economies, both in middle and low income countries. The adverse effect of net positive cost mitigation options on growth could potentially be offset if countries are able to attract international finance. International finance is also likely to be particularly important in helping fund the often higher up-front costs of many energy efficiency and other net negative cost mitigation options.

4.28. However, in line with their mitigation potential, current international carbon finance mechanisms are primarily designed to deliver mitigation funds to middle-income countries, and not surprisingly have become dominated by India and China. These mechanisms are supporting the development of successful manufacturing and export industries, which are expanding to dominate the production of low carbon technologies.

4.29. Low income countries are at present most likely to access international support for low carbon growth through GHG mitigation industries relating to biofuel production, agriculture or reforestation/avoided deforestation. Forestry payments present a significant potential financing opportunity for some countries, if international mechanisms such as REDD+ can be successfully developed. Transparency and governance will be central to securing international support for these sectors.

4.30. Where LICs do not have significant mitigation potential either industrial or deforestation, other mechanisms must be identified that can support the development of low carbon industries and services without recourse to mitigation finance, potentially as a component of adaptation financing.

4.31. There are a number of sectors where growth will derive from the response to climate change impacts, rather than mitigation. These include investments in health, water and sanitation, and investment in infrastructure adaptation to shifting climatic baselines, flood response etc.

4.32. Most LICs, however, continue to lack the institutional capacity to develop the requisite policy and investment frameworks for foreign investment, whether from donors or the private sector. There is a danger that international financial flows will be used to offset economic costs of climate change rather than used to deliver directly, or leverage further finance, to achieve sustainable economic benefits.

4.33. For LICs, the flow of international donor funds will be dependent on clear roadmaps for investment and must demonstrate sustainable commercial models. Adaptation funding may become conditional on low carbon strategy being implemented. Low carbon growth can be initiated by donor funds and supported by carbon finance and development funds, but must ultimately become commercially self sustaining. This will require considerable capacity support, both in sectoral analysis and investment planning.

4.34. Perhaps even more so, international support will be needed to help developing countries in adaptation and transition towards climate resilient patterns of growth. Without this, the economic costs of climate change will erode away achievements in economic and social development. However, international finance for adaptation will not, on its own, deliver climate resilient patterns of growth. Instead a more strategic objective will be needed, with longer-term planning, good governance and effective institutions.

Inter-linkages – synergies and conflicts between low carbon and climate resilience

4.35. At the project level, there can be potential synergies or conflicts between low carbon objectives and adaptation. These can be partly reconciled by co-ordination between mitigation and adaptation domains. For example, it is possible to screen low carbon development to ensure options do not inadvertently increase vulnerability to climate change – an example being the screening of future hydro power projects against future climate projections of rainfall.

4.36. Similarly, it is possible to check adaptation options to make sure they do not conflict with low carbon objectives, for example, implementing options that do not increase energy related emissions such as passive ventilation rather than energy powered air conditioning to cope with future warmer temperatures. While this sounds relatively easy, in practice there are likely to be potential conflicts or trade-offs involved, e.g. when the need to increase water resources to address future aridity leads to increased energy associated with water transfers or even desalinisation.

4.37. However, at the aggregate and macro-economic level, it is not yet clear whether the combination of low carbon and climate resilient patterns of growth will align. Some macro-economic shifts which enhance climate resilience may lead to economic structures with lower carbon intensity (e.g. moves towards a greater service sector), though this will not always be the case. Such effects will also vary on a geographical basis. Similarly major planning changes towards low carbon development may sometimes reduce vulnerability, but in other cases will not (e.g. higher building/population density in major cities to reduce private transport demand will increase heat island effects and increase the health related vulnerability to higher temperature).

4.38. Further work is needed to explore how to take forward low carbon and climate resilient patterns of growth together (synergistically). This is identified as an urgent priority following on from this study.

Policy and financing measures for low carbon transition

4.39. ESMAP (2009), recognises the policy and financing challenges related to low carbon growth. These relate to institutional policies, financing and partnerships with delivery agencies.

4.40. There are a large number of policy mechanisms identified in the literature. The focus of policy engagement for a specific country will depend on the sectoral focus, and the type of measure being implemented (low carbon technology deployment, structural measures such as urban mass transport systems, incentivizing low carbon industries, or demand side measures).

4.41. Concerning technologies, transparent tariff support policies e.g. feed-in tariffs and simplified planning consent arrangements may be most useful in encouraging the take up of smaller scale renewable technologies where there are potentially multiple providers and a competitive market place. For larger scale renewable and cleaner fossil fuel technologies, national targets and minimum efficiency and emissions standards can play a key role. Tax incentives and grant facilities may also be useful for encouraging R&D to support the adaptation of existing technologies to local market conditions.

4.42. The Box below provides examples of policies identified by sector (also refer to Appendix 3 for overview of Mexico policies and barriers).

Policies and barriers for low carbon growth options

Power sector

- Subsidy removal to ensure more efficient use of electricity, and generation companies can charge competitive rates. Move towards market liberalisation (Barrier: Social concerns that raising tariffs will impact on access to affordable energy)
- Carbon tax to disincentivise fossil sources, increase renewable competitiveness (Barrier: political opposition, requirement to get tax level correct to induce change)
- Incentivising renewables through different financial mechanisms e.g. feed-in tariffs (Barrier: knowledge of what to set tariff rate at, increasing consumer bills to pay for higher guaranteed tariffs)
- Reforming planning system so that it does not disadvantage clean energy (Barrier: high concern over reliability of renewable sources, historic reliance on fossil sources)
- Providing capacity for planning assessment to avoid over-reliance on existing plant retrofits and high carbon rental plants (Barriers: Capital constraints mean short term outlooks dominate)
- Reduce losses in T&D system, including reduction in unauthorised use (Barriers: Capital constraints to upgrade, and lack of administrative capacity to deal with non-payment / theft)
- Promotion of decentralised renewable technologies e.g. through subsidies (Barrier: capital requirement for Government and householder, also issues around technology maintenance capacity)
- Enhance regionalisation grid connections to ensure reliability of supply and possible flows of low carbon technology (Barrier: multi-national agreement needs to be in place, large capital requirements)
- Reduce investment risks of energy prospecting e.g. provide geothermal drilling assessments or ensure good wind monitoring data available (Barrier: cost outlay without guarantee of investment)

Industry

- Energy efficiency programme for industry (Barrier: industry inertia)
- Promotion of cogeneration with added incentive of selling electricity to the grid (Barrier: capital investment)
- Promoting fuel switching through carbon tax or similar mechanism (Barrier: fuel switching may

also require the additional cost of technology investment or retrofit)
- Promotion of benchmarking against international standards (through international trade associations) (Barrier: costs of upgrade)

Transport
- Invest in public transport schemes which meet needs of urban population (and are affordable) (Barriers: large upfront investment costs, complex planning in face of high urbanisation, consumer preference for private vehicles)
- Vehicle standards to ensure minimum levels of efficiency (for new and second hand car markets) (Barrier: enforcing ban on non-efficient vehicles)
- Mandatory annual Inspection and maintenance regime (Barrier: administrative capacity to implement very large scheme)
- Taxes on vehicles / fuels to support public transport financing (Barrier: politically unpopular, administrative capacity to implement very large scheme)
- Increase the availability of biofuels in the traditional transport fuels (Barrier: conflicts with land requirements for food, and demand for water)
- Behavioural measures such as driver training, information awareness (Barrier: difficult to influence driving behaviour)

Buildings
- Minimum appliance standards (Barrier: enforcement, in addition, if appliances used for longer than lifetime, difficult to see quick impact)
- Building retrofit programme (Barrier: large number of stakeholders to administrate, household inertia, principal agent issues between tenants and landlords)
- Improve awareness of energy efficiency benefits (Barrier: difficult to engage consumers even where benefits are clear – often due to required upfront investment to realise benefits)
- Removal of subsidies on fuels (Barrier: Social concerns that raising tariffs will impact on access to affordable energy)
- Subsidies for new efficient technologies (Barrier: still require household or commerce investment)

Agriculture
- Promotion of agro-forestry
- Programme to improve land management practices including incentives (Barrier: sector inertia, large number of stakeholders, monitoring impact of programme)
- Improvement programme for livestock management (Barrier: sector inertia, large number of stakeholders, monitoring impact of programme)
- Incentivising use of animal and crop wastes for energy e.g. biogas (Barrier: cheaper alternatives e.g. wood fuel, investment required)
- Access carbon financing (Barrier: demonstrating permanence, and issues of monitoring)

Forestry
- Accessing international financing (Barriers: institutional capacity, uncertainty in international mechanisms)
- Expansion and strengthening of domestic management and enforcement of existing programmes

4.43. While policy and regulatory frameworks are important, it should be noted they cannot alone overcome market barriers, such as familiarity with technologies or the provision of an O&M or service infrastructure. Nor does policy reform lessen the need for technology demonstration. This is especially true for larger scale technologies, such as IGCC, CSP or CCS,[32] although such technologies can retrospectively play a role in the setting of new emissions or efficiency standards. The policy implications of individual technologies for wider energy infrastructure

[32] Abbreviations refer to power plants including Integrated Gasification Combined Cycle (IGCC), Concentrating Solar thermal Power (CSP) and Carbon Capture and Storage (CCS)

should be also be taken into account as smaller scale sustainable energy technologies often require significant investment in network redesign, transmission and distribution capacity.

4.44. Low carbon growth policy, especially in relation to large scale energy sector or infrastructure change is a long term process and the timescales should not be underestimated. There is often significant institutional inertia among local regulators and policy makers, due to the perceived institutional risk of adopting new technologies, existing vested interests and a lack of capacity to assess the economic benefits and costs. Demonstration of the technologies elsewhere in a similar setting is often required before policy makers are willing to move, despite the perceived economic and environmental benefits.

4.45. In terms of financing, even where positive net present values are estimated for mitigation measures, upfront investments may still be significant (in CMM (2008), this was termed the capital intensity). Low carbon interventions also tend to require higher levels of investment than non-low carbon alternatives, increasing the need from private sector sources, international financing mechanism and public sector bodies.

4.46. In this regard, the studies reviewed often fail to provide clear pathways to funding. Allocating the distribution of costs across the economy is a clear responsibility of government. There is a clear need for governments to link the MACC outputs directly to budgetary planning processes, and then to create the mechanisms to ensure private/public sector investment accordingly.

4.47. From a planning perspective, the wide-scale deployment of low carbon and climate resilient technologies may require the involvement of a broader range of policy makers than traditional energy planning, and dialogues with representatives from the environment, water, agriculture and planning sectors may be necessary depending on technology. In this regard, the cross-sectoral benefits need to be well quantified, such as environmental improvements, strengthening of energy security, fuel risk mitigation through diversification, and industrial economic development.

4.48. It is vital that private sector developers be included in the policy consultation and formulation process, as regulators and policy makers are unlikely to have adequate understanding of technology prospects and cost curves and over the medium term. This is especially true for less mature technologies with a higher degree of market and technology risk. The private sector is also more likely to provide the bulk of capacity building and upgrading of skills required to manage a low carbon transition.

Does the economic analysis reflect the reality of low carbon growth policy implementation?

4.49. The focus of this stocktake has been on the economics of patterns of low carbon growth. The review has concluded that, with some important caveats, the technical costs of relatively large GHG reductions are low, and need only modest marginal carbon prices. All countries could make significant progress towards low carbon transition without the costs threatening economic growth; though the countries differ in terms of how far each could proceed. The studies set out a large number of mitigation opportunities, many of which can be implemented at negative or low cost.

4.50. Nonetheless, most of the studies do identify an overall net economic cost for achieving emissions reductions on the various stabilisation timelines envisaged. They also recognise that in the short run, mitigation policy is likely to present a net cost due to rising energy costs impacting upon disposable income and consumption.

4.51. There are a number of reasons however, to suppose that the actual costs might be considerable higher than those presented in the studies.

- Firstly, implementation can have significant costs (policy and transaction costs) that most analyses omit, as they are generally concerned with technical costs divorced from the type of policy used for implementation. McKinsey (2009d) estimate a range of €1-5/tCO_2e for such costs, which can be significant, particularly when average abatement costs are very low (<$5 in many of the analyses reviewed).

- Secondly, another implementation cost potentially underestimated relates to return of investment, modelled through discount rates. The MACC analyses reviewed tend to use very low rates, representing societal (Government) perspective, not a commercial outlook. This is problematic, particularly if it is the case that much of the necessary investment will come from private sector. This issue is discussed in additional detail in Appendix 6 of this report.

- Thirdly, it is clear that both the marginal and average costs per tonne CO_2e abated begin to rise rapidly with more stringent emission caps and constraints, indicating that the net cost of mitigation is highly sensitive to the level and pace of reduction required, as well as to a shifting scientific consensus. If implementation of emission constraints continues to lag scientific requirements, or if implementation of one set of measures identified fails and national abatement goals not met, alternative mitigation options (moving to the right of the MAC curve) are likely to be of significantly higher cost.

- Fourthly, the actual costs of mitigation depend not only on modelling assumptions, but also on the efficiency and nature of the policies adopted, and the extent of technological innovation achieved. The rate of low carbon growth is as much dependent on the pace of technological innovation (operating efficiencies) as it is on macro-economic policy. In the long run, technology price and efficiency changes remain an unknown, with potential for both upside and downside against projections.

4.52. In practice, costs associated with the individual mitigation options are likely to be higher than those in the studies reviewed due to significant implementation challenges relating to the scale and timing of envisaged measures. All of the studies base their economic assessment on the timely implementation (at zero implementation cost) of all measures identified. Experience would suggest that this is unlikely, with many market participants failing to pursue activities that are otherwise economically rational. A failure to appreciate implementation costs up front may result in governments underestimating the costs of delivery, particular for sectors where such delivery costs may be large in relation to the technology costs.

4.53. In particular, the dynamics of consumer response in relation to market based incentives is an area that is poorly understood, and an environmental technology cost analysis may not provide a fair reflection of likely policy outcomes. This is especially true of energy efficiency improvements, which provide a large proportion of negative and low cost measures in the MAC curves, but which many governments have struggled to implement in an effective way.

4.54. When making the economic case for a low carbon transition, many of the studies conclude that net economic benefits associated can only be fully achieved by active participation in the emerging industrial and service markets associated with the low carbon economy. Current well documented examples include photovoltaics in China (driven by cost of manufacture), and bioethanol in Brazil (driven by resource abundance).

4.55. However, there are significant difficulties associated with developing these at scale, and it is likely that many of these new industries will be dominated by a small number of countries, as is the case with existing manufacturing and service industries. This raises into question the equity and distribution of low carbon growth benefits at a global scale, and whether the benefits of new markets can be claimed by all countries to the same extent from a policy planning perspective.

4.56. The net positive economic growth case is also derived from more intangible developments such as improved resource efficiency, energy security, a more sustainable trade balance, improved international competitiveness and more rapid technology innovation. These benefits are less well quantified in the literature from an economic perspective and further research is required to understand these both at a regional and national level. These benefits are potentially large in scale, and a failure to fully quantify them may result in governments underestimating the net benefits of low carbon transition.

4.57. Taken as a whole, it should be noted that the LCG studies reviewed are not really growth studies in that they do not look at the dynamic impacts of higher costs and of technology innovation/adoption on growth, but rather tend to focus only on the static trade-off between higher abatement cost and growth. Therefore, the full picture is not provided concerning potential positive and / or negative dynamic effects.

4.58. In addition, it should be noted that the outputs of the MACC approach tend to derive from an environment / technology cost perspective, rather than from an economic development viewpoint. Certain growth trajectories are assumed, and the reports assess whether low carbon transition will increase overall costs to the economy (i.e. will the additional technology costs be economically disruptive). Analysis of traditional growth drivers – innovation, employment, new markets - tends to get much more cursory coverage in the reports.

4.59. The ambitious reductions that are required to meet the stabilisation level (where the risks of exceeding 2°C of warming is significantly reduced), are likely to result in wholesale economic and social change. The potential public costs of technology innovation and infrastructure reconfiguration are not well documented. Likewise, there is little analysis of the economic implications of running down carbon intensive industries in terms of employment, state aid, and regional regeneration support.

4.60. In respect to the least developed countries, it should be remembered that the challenges of low carbon transition are similar to those of development in general, with the additional costs associated with GHG externalities being embedded in the price of goods and services. In this respect, low carbon growth must be addressed in a wider context of economic development and reform.

4.61. Potential development issues identified include poor human capital; negative investment climate; market failures; lack of institutional capabilities; organisational challenges; and lack of access to finance. Low carbon, climate resilient patterns of growth should be developed as complementary to existing development priorities and not ones that compete or conflict.

4.62. The recent SEI (2009c) report on the economics of mitigation in China provides a useful overview of the clear economic benefits but also the significant challenge of meeting ambitious GHG reductions (see Box below). To meet such challenges both domestic and international policy will need to be developed to realise the ambition and / or potential for patterns of low carbon growth as reviewed in this report.

Moving towards a pattern of low carbon growth: A Chinese perspective

This recent report by the Stockholm Environment Institute (SEI 2009c) sets out a pathway for low carbon transformation in China. It recognises both the opportunities and challenges of delivering a pattern of low carbon growth and identifies several economic achievements by China in recent years related to decarbonisation. These include the mass production of electric cars and motorbikes, an expected doubling per annum of renewable electricity output from a baseline of 12m kWh in 2008 and more than 900bn kWh of electricity savings from energy efficiency investment between 2005-08.

A number of benefits of pursuing a low carbon growth path are identified in the report:

- Low carbon manufacturing and service sectors have more flexible labour models and are more efficient at absorbing the rural workforce than traditional high carbon industries in the mining and electricity generation sector
- International competitiveness is highly correlated with the development of a low carbon economy, resulting from more efficient use of energy and other resources in relation to economic output.
- The expansion of low carbon technology manufacturing represents an opportunity for a shift up the value chain allowing for the transfer of economic benefits to the domestic economy and the improvement of living standards
- Improvements in emissions intensity tend to promote increased private consumption as resources are transferred from energy costs to more productive activities (even if these activities also result in increased emissions). Energy costs tend to absorb a larger percentage of overall national income in poorer countries. This is especially true for net energy importing countries, where there is less scope to absorb these costs and manage the distributional effects.
- Low carbon innovation is also identified as the most effective way of increasing the flexibility of potential emission reduction pathways and thereby lowering the global carbon price, which in turn will reduce friction in negotiations of the distribution of emission rights.

However, there are a number of issues identified that concern the necessary scale and pace of structural change required in order to conform to a 230 $GtCO_2e$ emissions limit between 2005 and 2050 (China's share of global emissions identified as commensurate with a 2°C target). Such a target would require almost a complete restructuring of the economy, including electrification of vehicles, massive deployment of renewables, a complete switch to CCS based coal-fired generation, huge improvements in energy efficiency and significant changes to passenger transportation modes.

- Firstly, the report concludes that it is unlikely that China will have the necessary resources to fund a transformation on such a scale and in the timescales envisaged. Carbon finance mechanisms can provide some net investment flow to fund technology transfer and restructuring. However, the study estimates that current resource sharing approaches to mitigation would result in China having to become a net buyer of credits to meet a 2 degree emission pathway, and hence new mechanisms are required. One option is to review the system of carbon reporting to account for embedded emissions in traded goods, thereby transferring the emissions burden from producers to consumers.
- Secondly, the choice of carbon pricing and low carbon innovation mechanisms will determine to a great extent the distribution of potential negative effects in any domestic low carbon growth

scenario. The SEI report settles on a hybrid carbon tax and cap-and-trade scheme, but stresses both the domestic and international equity implications of both. In particular, any shift to global carbon pricing is likely to have inequitable impacts on the poorer communities in middle income and developing countries. The promotion of broad based low carbon industrial policy is identified as one way of avoiding the inequitable regional distribution of costs and benefits through the allocation of emissions permits alone.

- Thirdly, the report identifies the danger of low carbon policy misdirecting investment away from potentially economically beneficial activities towards only those that provide carbon finance opportunities and generate credits. The report identifies the use of permit auctioning and regulation to ensure this is minimised.

- The final and perhaps greatest challenge identified is the potentially disruptive effect of rapid "destruction" of existing capital (technological and economic) associated with a low carbon growth path. The transformation associated with a 2 degree target in China (forced retirement of much of the existing power sector), would entail job losses on a massive scale. European social policies aimed at retraining and sectoral support are identified as a potential model to manage such a process, along with active policies to improve the functioning of labour markets and move labour to expanding light industries and services. Increased labour mobility across regions within China, supported by integration of the welfare system would be required. The expansion of secondary and university education would also be necessary to provide a sustained supply of skilled labour.

The report concludes that innovation policy and international agreements on technology transfer are central, including funds to cover the IPR costs of diffusing low emission technologies in developing countries. However, commercialisation of existing technologies and promotion through domestic innovation is identified as the preferred route for China, accompanied by government support for demonstration projects, tax incentives for R&D partnerships, and the phasing out of subsidies for established high carbon technologies. In particular, opportunities to rapidly advance through or bypass stages of technological development need to be identified to grow industries and create jobs. The potential is large. For instance, a recently completed study by the China Green-tech Initiative estimates that China could build a green tech market worth USD one trillion per year.

In conclusion, the report concludes that while low carbon growth is the only way to meet the emissions pathways dictated by science, such pathways imply a complex economic transformation that will likely result in negative social effects and in the inequitable distribution of impacts. Further research is needed to understand how these changes should be implemented and phased in such a way that the potential downsides to not engender a sense of political paralysis in response.

Addressing technology deployment

4.63. Low carbon growth and climate resilience are likely to be achieved through the widespread dissemination of commercial and near commercial technologies to middle and low income markets. Experience indicates that this provides perhaps the largest barrier to both development and growth aspirations. Key questions are whether to encourage indigenous innovation of low carbon technologies or rely on international supply chains, to what extent national governments can support this process, and how best to buy down risk to encourage private sector investors into lower income markets.

4.64. A recent review for ESMAP (Savage 2008) of experience with energy technology deployment at the World Bank found that it is likely that efforts to support low carbon innovation in lower income countries are best focused on applied smaller scale technologies, as larger advanced technologies will continue to emerge from developed economies. It is unrealistic to expect that every country will develop a strong R&D base for low carbon technologies that can act as the basis for a domestic and export sector.

4.65. The review concluded that larger-scale technologies are more likely to be first deployed commercially in developed markets, and then replicated in MICs and LICs without significant additional R&D requirements once they can be shown to meet certain environmental and economic standards. The main barriers with the transfer of these larger scale technologies such as Concentrated Solar Power (CSP) are those of cost and regulation, rather than technology development (World Bank 2008c). This is characteristic of a failure to transfer existing technologies between countries and across economic sectors, and to make existing technologies more robust and affordable for developing country conditions.

4.66. While an R&D base may realistically be developed in middle income countries, low income countries are likely to benefit more from access to existing technologies and their adaptation to local conditions. Areas of support might include technology simplification, and reduction of operation and maintenance costs. The focus should be firmly on applied technology rather than early stage research (Crawford et al. (2006)). R&D support may be more usefully directed towards the 'localization' of smaller scale renewable technologies, perhaps for off grid applications where access to energy is the key issue.

4.67. There are significant market barriers to dissemination of low carbon technologies, particularly in relation to smaller scale – for example, distributed small hydro, solar PV, or energy efficiency technologies. These technologies tend to receive less government support and access to finance in developing markets than larger scale technologies. In addition, larger scale energy technologies tend to be developed and distributed by a small number of international companies that have good access to investment capital, established market channels and strong technical consulting support. The level of support may vary by market depending on level of international access and exposure (World Bank 2008b).

4.68. The need for capacity building and access to finance is much greater in LICs where world-class project preparation support is more difficult to access. In MICs, such as India and China for example, the level of sophistication among renewable energy developers is already quite advanced. Developers in these markets tend to have better access to financial markets and information about technologies. (World Bank 2008b)

4.69. The provision of concessional finance is important to encourage market entry for established low carbon technologies, even if they operate on a commercial basis in other countries. There will always be some incremental cost to introduce commercially proven technology to a new market due to the need to establish distribution, servicing and potentially manufacturing infrastructure in country (Taylor et al. 2008). Successful examples of low carbon technology transfer or investment have mostly included some form of concessional financing that has created a level of market momentum and replication effect in their given sectors.

4.70. Where concessional finance has taken longer to bring technologies to market, such as in the deployment of large scale renewables technologies, perceptions of higher technology risk may have discouraged both regulators and developers from engaging. Donors should focus on addressing financing and deployment risk, rather than address technology risk.

4.71. Understanding the level of concessional finance required to encourage market entry for new technologies is a complex process and innovative mechanisms need to be considered (Goel et al. 2004). International support for low carbon technology transfer and development has suffered from difficulties in setting a suitable level of financial support to encourage market entry. Donors do not wish to provide excessive returns but must ensure that risk diminishes sufficiently to encourage other market entrants.

4.72. The costs of market entry are dynamic, and technology and project development costs can rapidly fall during implementation. In addition, changing market conditions, such as restructuring and deregulation of power sectors or introduction of carbon pricing can change the attractiveness of a given technology. Strategy to encourage uptake of low carbon technologies may fail due to inadequate incentives from a project developer perspective. These projects are then faced with a choice between reducing technical or environmental standards and increasing costs (Savage 2008).

Issues for further investigation

4.73. Whilst the potential for low carbon and climate resilient patterns of growth are apparent, further research is needed to better understand the economic impacts arising from inherent uncertainties in the evidence base, and challenges of implementation. In addition, how to integrate these two objectives in a coherent strategy and subsequent policy initiatives is less well understood. Therefore, a range of recommendations for further research are presented in Appendix 6.

4.74. For low carbon growth issues, these include:

- Increasing use of macroeconomic models to better understand the wider economic impacts
- More sensitivity and uncertainty analysis around core assumption to better inform policy makers e.g. discount rates, growth rates
- Longer term timeframe for analysis
- Increased quantification of co-benefits and assessment of distributional impacts

4.75. For climate resilient patterns of growth, priorities include:

- Specifically addressing climate resilient patterns of growth. The recent focus of studies on the economics of climate change/adaptation has not addressed the core question of how to achieve climate resilient growth.
- Future systematic review of emerging evidence, with many news studies expected in the near future.
- Building the evidence. There is a generally low level of evidence on the economics of climate change and adaptation and more studies are needed at different scales and different locations.

4.76. Finally, further work is also needed to explore how to take forward low carbon and climate resilient patterns of growth together (synergistically). This is identified as an urgent priority following on from this study.

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Appendices

Appendix 1. Description of approaches used in economics of mitigation studies

There are a range of different approaches to the economic assessment of mitigation. The choice of which to use will be premised on a range of factors:

- Macroeconomic impacts vs. investment needs for specific sectors (and technology detail)
- Sectoral coverage i.e. within energy system or economy wide
- Spatial scale
- Coverage of GHGs or energy sector CO_2 only – Integrated Assessment vs. energy systems
- Uncertainty characterisation - Deterministic versus Stochastic
- Time horizon

<u>MAC curve approach</u>

Much of the analysis undertaken currently in developing countries uses expert-based MACCs, similar to those developed by McKinsey (2009b). Much has been discussed concerning this approach both in section 1 and Appendix 6, and therefore is not repeated here. Such an approach to mitigation analysis is important, particularly where other more sophisticated tools are not available. Importantly for developing countries, in-country capacity is easy to develop.

Whilst one of the great strengths of this approach is a simple representation of options to policy makers, there is also a significant trade-off to this simplicity in being able to provide full insights.

Model-derived MACCs provide additional insights; whilst providing a static snapshot of mitigation cost-effectiveness in a single year, these data will have more fully accounted for sectoral interactions due to being outputs of an integrated analysis. A weakness can be that some of the technology level detail can be lost in presenting results outside of the model framework, as a MACC.

MACCs can be classified as *bottom-up*, in the sense that they start from the level of a single mitigation option (highly disaggregated) and build up an aggregate picture of costs and potential. Inevitably capturing this level of detail is traded off against estimation of broader (non-GHG related) impacts e.g. on wider economy

<u>Economic models</u>

A typology of economic models includes:

- IAM models: Integrated Assessment models e.g. MERGE
- Macroeconomic models: CGE models (e.g. E3MG, GEM-E3), Macroeconometric models
- Partial Equilibrium Models: energy system optimisation models e.g. MARKAL-TIMES, MESSAGE, PRIMES

Note that there are hybrid versions of the above, which might be both bottom-up technology models (typically partial equilibrium) AND a module for allowing simple CGE representation e.g. MARKAL-MACRO. Many attempts have been made to couple different types of model with differing degrees of success.

For all of the above model types, there is always a trade-off between time horizon, geographical coverage and sectoral detail. A very simplistic typology shown below illustrates strengths and weaknesses of different approaches.

Model type	**Focus**	**Strengths**	**Weakness**
IAM	Long term costs and benefits of climate change at global level	Impact on the environment, e.g. temperature increase for climate change. Feedback on the economy through damage function (when macroeconomic)	Simplified sector / technology detail, and economic mechanisms (e.g. production function)
Macroeconomic			
Econometric	ST dynamics / costs of adjustment	Economy wide impacts, often at national level (‘top-down’)	Less detail at mitigation technology level with focus on coverage of economic sectors, and associated impacts
Gen. Equilibrium	LT analysis with the focus on equilibrium after all adjustments	Economy wide impacts, often at national or global level (‘top-down’)	
Partial equilibrium*	Energy system analyses, focus on short or long term	Bottom-up, technology rich, providing insights on technology pathways / costs. Integrated approach across sectors and demand / supply.	Limited consideration of wider economic effects, or distributional impacts

Energy system models (broadly categorised under the *partial equilibrium* category) can be further broken down into optimisation models (such as MARKAL-TIMES) and simulation models (LEAP). Simulation models are primarily accounting frameworks which usefully show the costs of different pathways. They do not cost-optimise and derive minimum cost solutions. Such models are often easier to set up, and therefore have been very important in developing country analysis, particularly models such as LEAP (as used by the MEDEC Mexico study).

Optimisation models solve for the least cost solution so are extremely useful for exploring the cost-optimal means of meeting a climate target (or provision of energy services). They are usually integrated across the energy system, capturing trade-offs between upstream and demand sectors. They are however more difficult to operate and maintain than other approaches, and do not necessarily handle non-CO_2 GHGs very well, as primarily energy models.

Appendix 2. Country / regional review syntheses

The evidence has been reviewed by country / region; here we highlight the key findings emerging from the review.

China

Studies reviewed include those from McKinsey (2009a), CCAP (2009a, 2006c) and IEA (2007).

The summary findings from the synthesis are as follows:

Mitigation potential	Very difficult to pull clear message from above studies due to non-comparability of baseline as illustrated in Figure . McKinsey suggest potential can get close to base year emission levels (15% higher) whilst this is not the case for other analysis (see red bar in Figure). Power sector, industry and buildings appear to offer greatest potential.
Cost-effective (C-E) potential	For options appraised, CCAP and McKinsey report similar levels of C-E / low cost potential (<$ or €20/tCO_2, strongly focused on energy efficiency measures.
Costs and wider economic impacts	All three studies assess economic impacts to some extent. McKinsey analysis suggests costs of 1.5-2.5% to realise full potential – but exclude cost savings. WEO alternative analysis suggests net benefits due to energy efficiency and taking account of savings from less investment. CCAP suggest small reductions in growth due to increasing electricity prices.
Implementation issues	The CCAP report indicates that once implementation issues are considered in greater detail, the potential of different measures decreases.

The studies reviewed are very different in scope and approach, making comparison difficult (see Figure A2.1 below). It appears that there is much discussion to be had over baseline emission estimates, and full potential. What the studies do indicate is that there is significant energy efficiency potential remaining, accounting for upwards of 30% of mitigation potential (and higher in the case of the WEO report). Further low cost measures are estimated to not result in significant wider economic impacts; however, see above discussion on issues with approaches.

A report by SEI (2009d) assessing deep cut reductions in carbon emissions was also reviewed as part of this study. It suggests that China could achieve an 80% reduction relative to 2005 by 2050 (4.8 GtCO_2 in 2005 and 1.9 GtCO_2 in 2050, or 3.6 tonnes reducing to 1.3 tonnes per capita by 2050) but would require a massive transition in respect of energy sources and technologies. However, this does not consider the central question of this report concerning the costs of achieving such an ambitious target, and what this might do to economic growth. In addition, mitigation potential estimates are sourced from the IEA and McKinsey studies reviewed here.

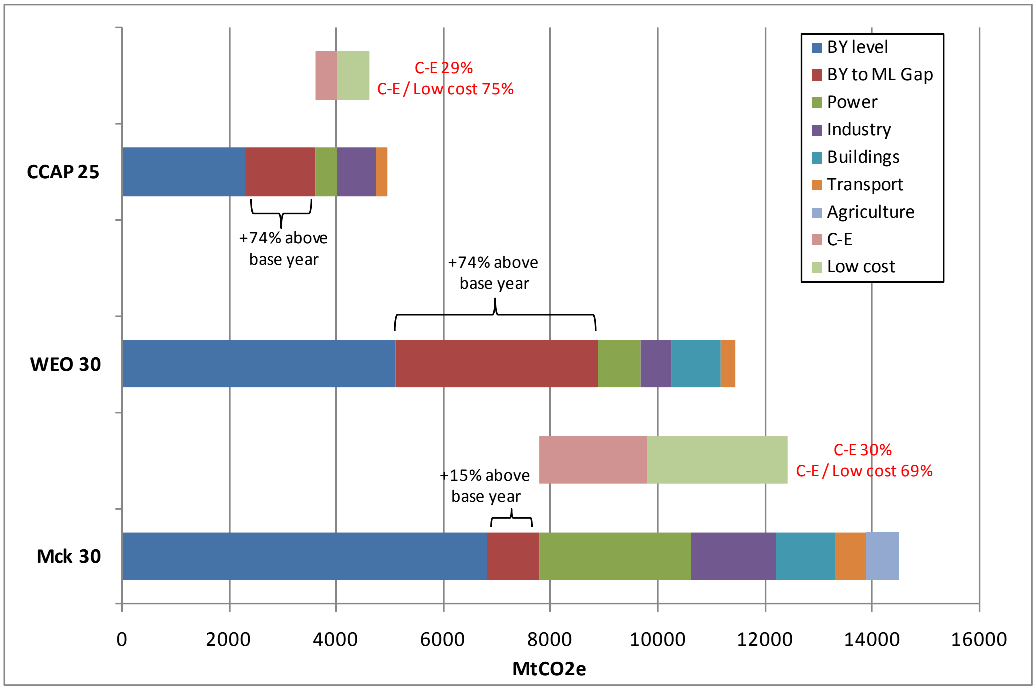


Figure A2.1. Comparison of mitigation totals for sectors in China

<u>Graph interpretation</u>

Using the above graph as an example,

- Blue colour bar is the analysis base year while red is the difference between base year and level after full mitigation potential realised
- Other colours represent mitigation potential by different sectors. The full length of the bar represents baseline emissions e.g. McKinsey projected emissions in 2030 t0 be over 14,000 $MtCO_2e$.
- The pink / green bar above represent amount of potential that is cost-effective (C-E) while the combination of C-E and low cost is represented by the full length of this bar.

Table A2.1. Comparison of key assumptions and results from China LCG studies

	CCAP / Tsinghua	**McKinsey**	**IEA**
Sectoral coverage	Power sector, selected heavy industry (iron & steel, cement, paper & pulp) and transport sector	Complete	Energy sector (consumption and production)
Analysis target	Technical potential	Technical potential	Implementation of alternative policies
Base Year	2000	2005	2005
Analysis Year (for mitigation / potential costs)	2020	2030	2030
Discount rate	10% for iron & steel and transport sectors. Not specified for others.	4%	Not specified
Mitigation potential			
Total Mt CO_2	1345	6700	2571
% change from baseline	-25%	-46%	-22%
% level relative to base year after reductions	+74%	+15%	+74%
-ve cost (*% of total*)	30%	29%	Not specified
<$20 cost (*% of total*)	75%	69%	Not specified
Costs			
Total (*units*)	Not specified	Total economic costs not specified. Additional investment requirements of €150-200bn per year over the period 2010-2030.	Net benefit (negative economic cost), unspecified magnitude.
% of GDP			

	CCAP / Tsinghua			**McKinsey**			**IEA**		
% of total mitigation	<0/tCO_2	<20/tCO_2	All	<0/tCO_2	<20/tCO_2	All	<0/tCO_2	<20/tCO_2	All
Power	3%	17%	30%	2%	30%	42%			31%
Industry	11%	42%	55%	11%	18%	24%			23%
Buildings				11%	13%	16%			35%
Transport	15%	15%	16%	3%	4%	9%			11%
Agriculture				2%	4%	9%			
Energy efficiency	26%	57%	69%	25%	35%	49%			69%
Lower carbon energy*	3%	17%	31%	2%	30%	42%			31%
Promoting C sinks / reducing AGR emissions				2%	4%	9%			

India

Studies reviewed include those from McKinsey (2009e), CCAP (2009b, 2009c, 2006a) and IEA (2007). Ecofys (2008) was also reviewed for comparison. At the time of writing, the Indian Government released a 5 study assessment, focusing on emission baselines (GoI 2009). The studies that comprise this review are more relevant to this study, although only the McKinsey analysis (2009e) has been obtained.

The summary findings from the synthesis are as follows:

Mitigation potential	It is very difficult to compare the India studies due to clear differences in baseline assumptions, and mitigation potential. In addition, there are significant differences between numbers of measures included in the analysis. All the reports indicate that emissions will remain above baseline over the course of the analysis, although the range of increase is large (between 19-150%). This represents a reduction of between 20-40% against expected baseline emissions. For the McKinsey analysis, it is higher at 55%.
Cost-effective (C-E) potential	The highest C-E potential is found in the McKinsey analysis, which is also the most comprehensive of the analyses reviewed. Low cost potential (including negative cost measures) is at ~85%. The most sizeable contribution to negative cost options are from industry / building energy efficiency improvements. Cost-effective / low cost potential in the Ecofys review is put significantly higher than in the CCAP analysis, although the differences in unit analysis makes direct comparison difficult, given that CCAP sectors have been pre-selected on the basis of mitigation potential.
Costs and wider economic impacts	The CCAP assessment identifies net investment by sector. There is also some macro-economic analysis of the mitigation measures in the industry, power and transport sectors in relation to GDP growth and employment. Ecofys does not explicitly address net costs (beyond identifying no regret options) or the economic implications of the mitigation scenario. WEO provides some qualitative analysis of potential net benefits due to increased efficiency. The McKinsey report cites some strong co-benefits of realising abatement – reduction in energy costs (based on 22% demand reduction), improved energy security and environmental improvement. Another opportunity is growth of clean technology industries – for India, this could include electric 2-wheelers, solar power and smart buildings and grids.
Implementation issues	CCAP analysis identifies potential regulatory, economic and capacity barriers to achieving mitigation potential in selected sectors. Funding gaps are identified particularly for additional renewable capacity, improvements in power utility efficiency and industrial equipment. Ecofys suggests a range of additional measures and policies in order to deliver the ambitious mitigation scenario. The implication of all the studies is that much of the mitigation potential will only be achieved with significant policy reform and access to finance, but the impact upon mitigation potential by the absence of reform is not quantified. McKinsey cite very substantial additional investment requirements. Additional capital expenditure between 2010 and 2030 is estimated to be between €600-750, or 1.8-2.3% of forecast GDP during this period. Other barriers include lack of technical (skills) capacity, market imperfections and technology uncertainty (concerning performance and costs)

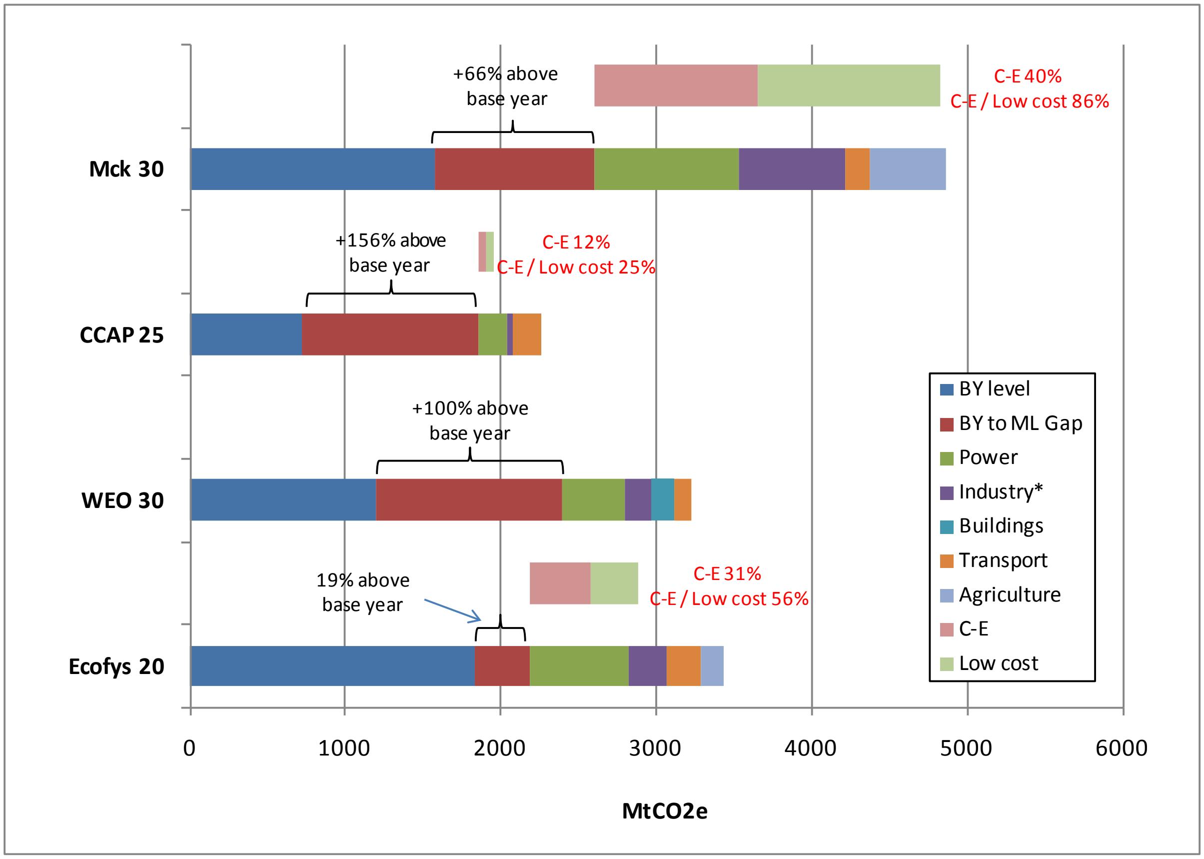


Figure A2.2. Comparison of mitigation totals for all sectors in India

Table A2.2. Comparison of key assumptions and results from India LCG studies

	Ecofys	IEA WEO 07	McKinsey	CCAP
Sectoral coverage	Complete	Power, Industry, Transport, Buildings	All sectors	Power-gen., transport, industry (cement, iron & steel, paper), residential / commercial.
Analysis target	2c above 1990 (400ppm by 2100)	Stabilisation 2020s and 19% reduction 2030 450ppm High Growth	None. Opportunities for enhancing sustainable growth and energy security	Technical Potential
Mitigation measures	Not clearly defined. C.40 policies	Not clearly defined (Full report unavailable)	200 (at costs less than €100/tCO2	18
Base Year	2005	2005	2005	2000
Analysis Year (for mitigation / potential costs)	2020	2030	2030	2020 (Costs/GHG Potential) 2030 (Projection)
GDP growth	Based on national studies (unstated)		7.5%	8%
Population growth	Based on national studies (unstated)		1.1 billion (2005) rising to 1.47 billion in 2030	1.14%
Discount rate	Assumptions not stated.		8% societal rate	10%
Mitigation potential				
Baseline emissions	3518	3300	5742	2259 selected sectors (2352 all sectors)
Total Mt CO_2 reduction	1336 (Ambitious reduced to 2182mt)	900 (Implied)	2602	402 selected sectors (392 including buildings)
% relative to baseline	-38% (2182/3518)	-27% (Alternative Scenario)	-55%	-18% All options
% relative to base year	+19%	+100%	+66%	+156%
-ve cost (*% of total*)	31% (407/1136)		40%	12% (All options)
<$20 cost (*% of total*)	56% (Co benefit scenario 750/1136)[33]		85%	25% (<$10/ton)

	Ecofys			IEA WEO 07			McKinsey			CCAP		
% of total mitigation	<0/tCO_2	<20/tCO_2	All	<0/tCO_2	<20/tCO_2	All	<0/tCO_2	<20/tCO_2	All	<0/tCO_2	<20/tCO_2	All
Power	8%	27%	48%	-	-	44%			36%	38	81 (<10/tco2)	44%
Industry*	11%	11%	18%	-	-	19%			26%		3 (<10/tco2)	11%[34]
Buildings	0%	0%	0%	-	-	17%[35]			13%			
Transport	4%	11%	17%	-	-	11%			6%			45%
Agriculture	8%	8%	11%	-	-	-			19%			
Forestry	0%[36]	0%	0%	-	-	-						

[33] Costs not specified. Ambitious target includes measures up to c.$100/$tCO_2e$
[34] Cement, iron and steel, pulp and paper
[35] Includes all end use energy efficiency in buildings and appliances
[36] LUCF Emissions kept at 0 from 2003 levels due to lack of data

Brazil

Studies reviewed include those from McKinsey (2009b), CCAP (2009d, 2009c, 2006b, 2006d) and a summary of the RECCS (FCO/DFID 2009)[37].

The summary findings from the synthesis are as follows:

Mitigation potential	Due to different analytical approaches, comparing studies is again difficult. The real focus on mitigation potential in all the analyses are on options for increasing biofuels, and in RECCS and McKinsey analyses reducing deforestation. As shown in Figure (energy sectors only), the McKinsey analysis also suggest significant potential in industry. CCAP / McKinsey analysis show that potential in energy sectors results in 2030 levels ~50% higher than base year emissions (of energy sector). Accounting for forestry and agriculture emissions and potential, emissions can be reduced to near ~60% of base year emissions.
Cost-effective (C-E) potential	Both the CCAP and McKinsey studies put cost-effective potential at ~20%. As shown in Figure A2.3, forestry increases low cost potential significantly. RECCS analysis also indicates relatively low incremental costs of reducing deforestation.
Costs and wider economic impacts	All studies consider wider impacts. The RECCS looks at the small impacts of carbon tax, estimating low impacts (less than 0.1% at $50 per tonne, and 2% reduction in emissions) due to no modelling of technological change. McKinsey suggest that to cut GHGs by 70%, €5.7 billion per annum would be required to curb deforestation, and €8 billion per annum by 2030 for other measures. CCAP suggest net benefits although no formal modelling undertaken. Only the RECCS comprehensively assessed co-benefits (although all analyses recognise them) or considers linkages of mitigation options to impacts / adaptation.
Implementation issues	The RECCS and CCAP analyses focus on implementation issues in detail, particularly for biofuels and deforestation – although how this might affect mitigation potential is difficult to determine. All analyses highlight and discuss the issues around setting up a system to reduce deforestation.

[37] It is not clear who the lead technical contributor on the final study is; hence this has been referenced as UK Government report for time being.

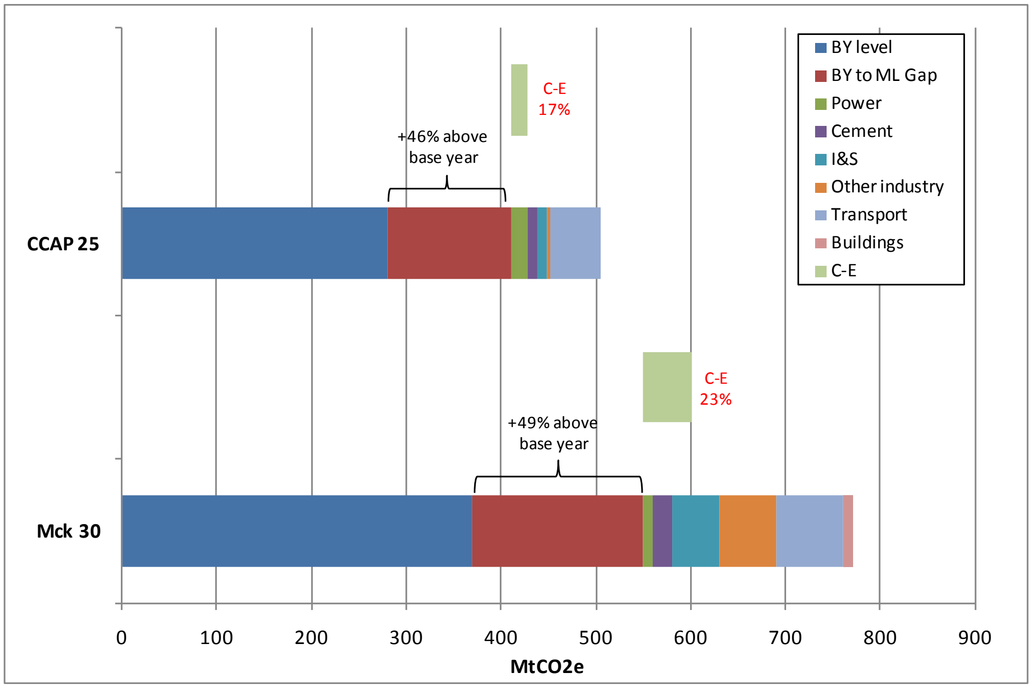


Figure A2.3. Comparison of mitigation totals for energy sectors in Brazil (forestry reported separately in figure below to ensure comparability)

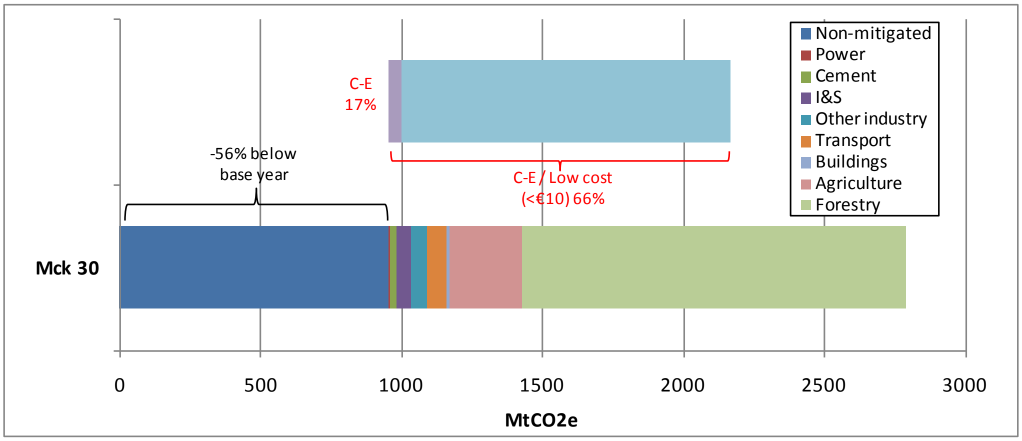


Figure A2.4. Comparison of mitigation totals for all sectors in Brazil (McKinsey analysis)

Coming to conclusion on actual mitigation potentials for the region is again difficult; what does emerge is the relatively low costs of reducing deforestation but the potential difficulties associated with implementation. In addition, Brazil has the options to ensure that relatively low carbon power and transport sectors remain low carbon in future years.

Table A2.3. Comparison of key assumptions and results from Brazil LCG studies

	McKinsey	**CCAP**	**RECCS**
Sectoral coverage	Complete	All energy sectors except some industry subsectors. Forestry not included in mitigation analysis, and agriculture on partially. Waste not covered	Biofuels (transport), Forests (reduce deforestation)
Analysis target	70% reduction (based on global reduction to achieve 2°C stabilisation.	No specific target	Potential for mitigation from these sectors
Mitigation measures	200 (based on global MAC curve)	8 (with no buildings measures considered)	Biofuels, reducing deforestation
Base Year	2005	2000	2005 (for biofuels analysis)
Analysis Year (for mitigation / potential costs)	2030	2020 (although projections to 2025); not all measures are costed	2035 (for biofuels analysis)
GDP growth	3.5% to 2015; 2.8% thereafter	4.05-4.26%	Based on A2 / B2 SRES scenarios used in climate impacts modelling
Population growth	0.9%	0.7-1%	
Discount rate	4%	Unclear	
Mitigation potential			
Baseline emissions	770 (2790 all sectors)	505	
Total Mt CO_2 reduction	220 (1840 all sectors)	94***	92-203 from biofuels (uncosted)
% change from baseline	-29% (-66% for all sectors)	-19% (in 2025, including non-costed measures)	For forestry, 95% at $50/t$CO_2$, 70% at $3t/$CO_2$ (displacing livestock)
% level relative to base year after reductions	+49% (-56% for all sectors)	+46%	
-ve cost (*% of total*)	23% (6% for all sectors)	17% (in 2020); (energy sector only)	
<$20 cost (*% of total*)	63% at <€10/tCO_2 (all sectors)		
Costs			
Total (*units*)	€5.7 billion (reduce forestry); €8 billion for all other measures	Not reported (some measures not costed)	Up to $2.6 billion per annum for forestry
% of GDP	1% (-ve costs not included)		

	McKinsey[38]			**CCAP**			**RECCS**		
% of total mitigation	<€0/tCO_2	<€20/tCO_2	Total	<€0/tCO_2	<€20/tCO_2	Total	<€0/tCO_2	<€20/tCO_2	Total
Power			1%	10%		17%			
Industry*			7%	7%		26%			
Buildings			1%						
Transport			4%			57%			
Agriculture			14%			****			
Forestry			74%**						

* CCAP ‘Other Industry’ only includes pulp and paper emissions while McKinsey include all other industries
** Increase to 2300 if extensive reforestation of degraded areas is taken up
*** CCAP potential in 2025 estimated based on comparison of ‘Recent policy’ baseline versus additional measures
**** Assessment only of livestock enteric emissions, evaluated on basis of food supplements used

[38] In the McKinsey analysis, average mitigation costs are relatively cheap (at an average €9/tCO_2e) compared to world average of €16, primarily due to low cost afforded to reducing deforestation.

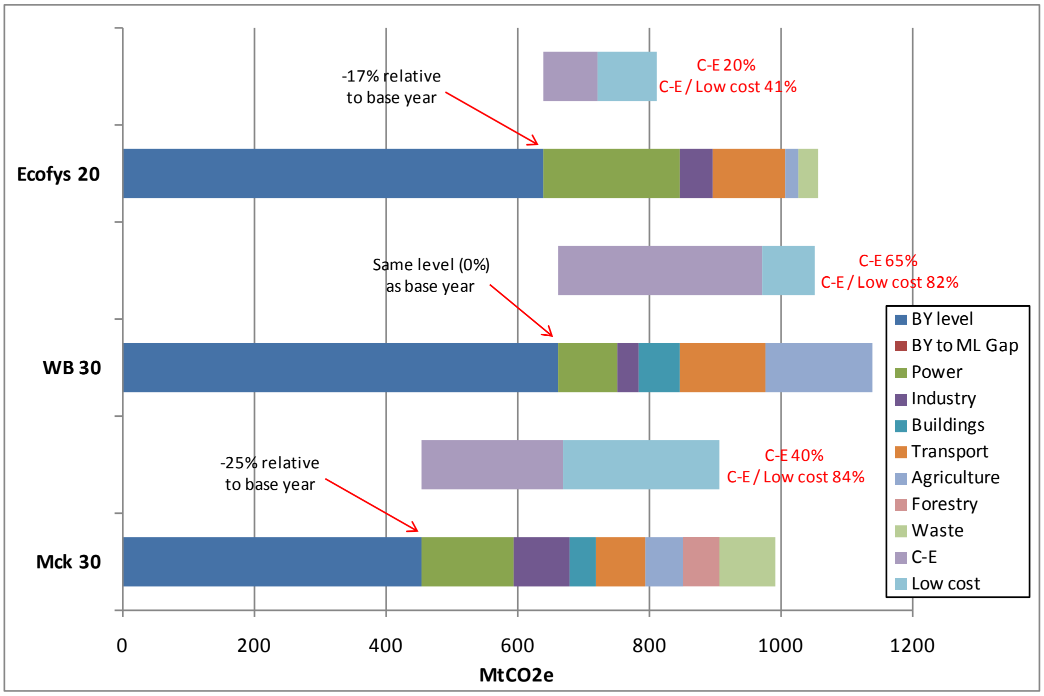
Mexico

Studies reviewed include those from Centro Mario Molina / McKinsey (2008), World Bank (2009a) and Ecofys (2008). There are a number of other studies which provide further context undertaken by Quadri (Ecosecurities), CCAP and PECC which provide further context, but which do not make explicit assessments of mitigation potential either at a sectoral or economy wide level.

The summary findings from the synthesis are as follows:

Mitigation potential	All studies estimate similar levels of mitigation potential, and estimate that total potential reduces emissions to or below (17-25%) base year emissions. However, the respective sectoral contributions differ, with relatively large contributions from power sector (Ecofys), agriculture (WB) and industry / waste (McKinsey). This is in part due to differences in sector categorisation.
Cost-effective (C-E) potential	The McKinsey analysis suggests very high percentage of –ve cost measures (40%), and indicates that ~80% can be afforded at <$30/t$CO_2$. Ecofys put –ve cost measures at 20%, whilst reductions including co-benefits (which may be assumed to be low cost measures) are 40% of potential.
Costs and wider economic impacts	McKinsey identifies the average cost of reaching full mitigation potential at only $2 per tco2e, with a net cost of $2.8bln per year. This is higher than the World Bank assessment of a net cost of $2.2bln over the entire analysis period and an average mitigation cost of -$19/tco2e. Both McKinsey and the World Bank study undertake macro economic analysis suggesting a net benefit to the economy, based on a shift from household consumption to capital investment. McKinsey estimates the benefit of an improvement of between 0.5-1.5% of GDP and an increase of 500,000 jobs. The World Bank estimates increased GDP benefits of up to 5% by 2030, although these benefits are not evenly distributed across sectors.
Implementation issues	All the studies identify implementation issues in terms of required policy and regulatory reform. The World Bank identifies high up front financing costs, electricity pricing reform and governance issues as key areas of reform. McKinsey provides a prioritised implementation road map based on an assessment of financing and regulatory barriers.

In summary, mitigation potential looks significant, with large opportunities in the power and transport sectors, but also in many other sectors. Much of this potential is estimated to be achievable at relatively low cost, but is predicated on ongoing regulatory and governance reform, and access to adequate investment capital.



* Low cost level: Mck <$30/tCO2, WB <$10/tCO2, Ecofys – Co-benefits

Figure A2.5. Comparison of mitigation totals for all sectors in Mexico

Table A2.4. Comparison of key assumptions and results from Mexico LCG studies

	McKinsey	**ECOFYS**	**World Bank**[39]
Sectoral coverage	All	All	electric power, oil and gas, stationary energy end-use, transport, and agriculture and forestry
Analysis target	50% by 2030 relative to BAU (Ambitious)	2C stabilisation	Growth maintenance
Mitigation measures	144	Multiple. Not specified	40
Base Year	2005	2005	2008
Analysis Year (for mitigation / potential costs)	2030	2020	2030
GDP growth	4.1% (2005-30)	Sources cited but not stated	3.6%
Population growth	1% (1.3% declining to 0.8% pa)	Sources cited but not stated	0.6%
Discount rate	4% (Social Cost of Capital)	Sources cited but not stated	10% (Private cost of capital)
Mitigation potential			
Baseline emissions	990mt (2030 BAU)	1055mt (2020 BAU)	1137 (2030 BAU)
Total Mt CO_2 reduction	535mt (reduced to 455mt)	417mt (Ambitious scenario, reduced to 638mt)	477 (Reduced to 660mt)
% relative to baseline	-54% (455/990)	-39% (638/1055)	-42% (660/1137)
% relative to base year	-15% (455/610)	-17% (638/770)	0% (660/660)
-ve cost (*% of total*)	40% (216/535)	20% (82/417) (No regret)	65%
<$20 cost (*% of total*)	84% (450/535) <$30/t cost	40% (173/417) (Co benefit)	82% (<10$)
Costs			
Total (*units*)	Average cost of +$2/tco2e 3% additional capital expenditure Net cost of $2.8bln per year (2030)	-	Average cost of -19$/tco2e $3bln per year new investment Net cost of $2.2bln for the period 2008-30
% of GDP	-	-	

	McKinsey Project Catalyst			**Ecofys**			**World Bank**		
% of total mitigation (Mt in brackets)	<0/tCO_2	<20/tCO_2	All	<0/tCO_2	<20/tCO_2[40]	All	<0/tCO_2	<20/tCO_2	All
Power	5% (26)	9% (48)	26% (140)	9% (38)	18% (74)	50% (209)			19% (91)
Industry*	8% (41)	9% (47)	15% (82)[41]	4% (17)	4% (17)	10% (41)			6% (30)[42]
Buildings	5% (24)	5% (25)	7% (35)	0%	0% (0)	0%			13% (63)
Transport	8% (41)	12% (63)	14% (76)	5% (19)	16% (68)	26% (111)			27% (131)
Agriculture	3% (18)	7% (39)	11% (61)	2% (9)	2% (9)	5% (21)			34% (162)[43]
Forestry	0%	5% (29)	10% (55)	0%	0%	0%			-
Waste	12% (66)	14% (74)	16% (83)	0%	0%	7% (31)			-

[39] Numbers in WB report are currently inconsistent between Summary and body of report with regards to sectoral potential
[40] Co benefit (low cost plus economic benefit) – rather than <20$tco2e
[41] Excludes power generation for industrial use – included in Power.
[42] Oil and gas only
[43] Agriculture and Forestry

South Africa

The only study available for this review was the LTMS study undertaken by the University of Cape Town (ERC 2007, Winkler 2007).

Key results from the LTMS analysis are shown below:

Mitigation wedge	***Start Now***	***Scale Up***	***Use Market***
Gap closure (%)	43	64	76
Mitigation potential to 2050 (cumulative Mt CO_2 eq.)	11,079	13,761	17,434
Average abatement costs (R/tCO_2)	-13	39	10
Costs as % share of GDP	-0.5	0.8	0.1
% Increase on GWC energy system costs	-2.2	3.6	0.6

The summary findings from the review are as follows:

Mitigation potential	The analysis took an approach of assessing potential using policy defined mitigation wedges. For example, *Scale Up* extended the use of renewable / nuclear whilst *Use Market* considered use of economic instruments, lumping together mitigation additional potential realised at a given carbon price. Mitigation potential by 2050 is significant, and under the most ambitious can close the gap to *required by science* targets by 76% (at low cost).
Cost-effective (C-E) potential	This appears to be fairly significant given the low cumulative costs projected under all mitigation wedges;[44] this is in large part due to limiting uptake in the baseline, which is a high unconstrained scenario.
Costs and wider economic impacts	Significant emission reductions can be achieved without significant increases in costs, indeed at a net saving. However, as the study caveats, this is compared to a *growth without constraints* case that has none of the energy efficiency potential taken up and no near term policy for reducing emissions. Moving to a lower carbon pathway, costs increase due to the prescribed uptake of renewable and nuclear power – but costs are still lower than 1% of GDP. The Use Market case has the positive costs, although these are low. In this case, the available energy efficiency levels and lower carbon options available are increased. It is probable that the costs to implement such large scale efficiency savings from a policy or consumer perspective are not fully costed or underestimated. The economy-wide assessment focused on the long run economic effects of energy efficiency in productive sectors, and changes in the energy supply fuel mix. Concerning efficiency gains, they have a small but positive overall production effects in the economy. Output and employment losses in the coal mining and electricity generation sectors are generally offset by gains in other sectors that benefit from lower production costs, resulting in unambiguously positive but small employment effects. Household welfare effects are also small but positive, with the distribution of gains depending on the type of energy efficiency modelled. Distributional effects are too small to raise great concern about the socio-economic implications.
Implementation issues	As a technical scenario study, the LTMS does not give much consideration to policy measures and barriers.

LTMS analysis indicates that the potential costs implications of a low carbon growth path are not excessive (less than 1% of GDP), with significant opportunities for win-win measures which are negative cost. The study actually goes further than that and suggests that the gap between the two pathways could be closed by 43%, and at negative cost. The main caveat here is that this is

[44] Individual measures are listed but not presented in an easily digestible way to determine sector potentials.

compared to a very high emission baseline, not a realistic baseline that could already include a greater proportion of energy efficiency potential.

Indonesia

The only full study reviewed was the RECCS for South East Asia (ADB 2009); data from a DNPI (2009) presentation was used for comparison, based on McKinsey work developing an Indonesian mitigation cost curve.

The summary findings from the synthesis are as follows:

Mitigation potential	Mitigation potential for energy using sectors is similar in both the RECCS and McKinsey analysis (see Figure excluding forestry, peat and agriculture). McKinsey analysis suggest significantly more can be achieved through forestry and peat measures, and at relatively low cost (<€20/tCO_2), and can reduce levels significantly below the base year.
Cost-effective (C-E) potential	Cost-effective potential for sectors is similar, albeit a bit higher in the RECCS analysis, primarily based on energy efficiency measures.
Costs and wider economic impacts	An analysis was undertaken by the RECCS to assess the potential funding requirements of mitigation action to achieve the 50% global cut relative to 1990 levels. It was estimated that the 4 countries in the analysis would be required to make cuts of 3,600 $MtCO_2$ eq., or 10%[45] of non-Annex 1 country requirement. The non-Annex 1 country requirement was estimated to be 23% below 1990 levels based on a developed country target of 80%. An average mitigation cost of $10/$tCO_2$ equated to $36 billion, or $54 billion at $15/$tCO_2$. Whilst a simplistic analysis, this was undertaken to show the level of investment required. However, it would be useful to see compared to GDP, and discounted back to take account of how investment over the long term tends to be viewed. The full McKinsey analysis is not yet available so it is not clear what the aggregate cost estimates are.
Implementation issues	In the RECCS analysis, there is some discussion on the barriers to implementing different options in agriculture and forestry sector in particular, and of the co-benefits (although no quantitative assessment). For the energy sector, the issue of barriers and / or co-benefits are not integrated into the analysis, in respect of adjusting mitigation potential etc. In the McKinsey analysis, this has yet to be seen in full, so it is not possible to say.

[45] The four countries in the analysis account for 10% of non-Annex 1 emissions, and would hence take on 10% of the required emission reduction.

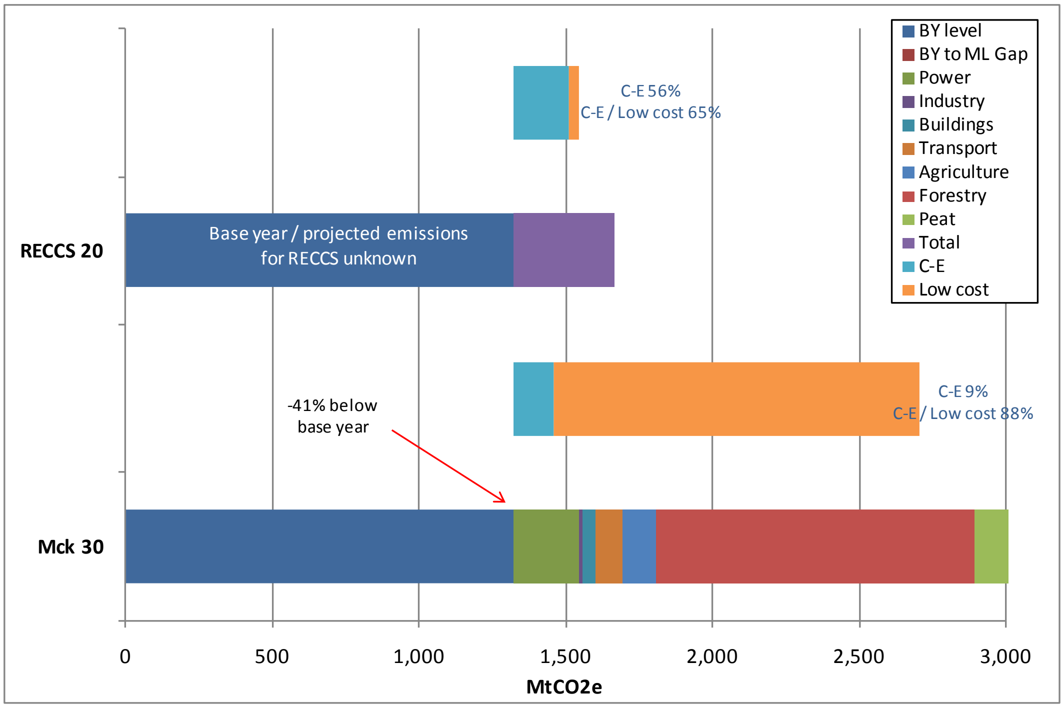


Figure A2.6. Comparison of mitigation totals for all sectors in Indonesia

Reducing emissions from degradation of forestry and peatland is going to provide a major opportunity to move to a lower carbon future path. Combined with energy efficiency measures, low carbon growth could be achieved, although there are significant implementation issues to capture this potential.

LCG Study comparability

Making comparison between studies has been challenging due to issues of comparability, which are summarised below.

Issues of LCG Study Comparability

- **Sectoral coverage**. As mentioned above, some assessments include all sectors (McKinsey) while others focus on specific sectors (CCAP / RECCS Brazil). This is often observed with energy modelling analyses that do not deal with agriculture and forestry sectors.
- **Coverage of options**. There are key differences in the assumptions and selection of potential mitigation technologies that may be available. McKinsey assumes potential technologies emerging over a 20-25 year time horizon, while the WB studies are limited to those technologies likely to emerge over the next 5 years. A shorter time horizon will have the result of reducing potential abatement potential and raising the MAC, but will negate some of the uncertainty in technology and price forecasting. Assumptions are made about the rate of technology improvement and cost that exclude improvements in the abatement potential of a technology once implemented. In addition, some studies include a wide range of options (McKinsey) while others do not (CCAP India / Brazil).
- **Sectoral overlap.** Sectors are often not clearly defined in the studies, particularly in relation to power generation for industrial and direct residential use and end use efficiency options.
- **Baselines.** Mitigation measures included in the baseline may differ (depending on the base year) affecting mitigation potential and different projection drivers (e.g. GDP, population) may have been assumed.
- **Discount rates**. Studies are not agreed on the type of discount rate to apply. McKinsey seems to apply a lower discount rate (4%), reflecting the social cost of capital and assumption of government finance, while the WB studies apply a higher discount rate (closer to 10%). DFID considers that 10% is what should be used to represent societal discount rate in many developing countries. Higher commercial discount rates result in the majority of interventions being more expensive as energy efficiency interventions often have large initial capital costs with long term benefits. The higher discount rate reduces the present value of the future benefits and causes the intervention to appear more costly. The societal discount rate is used in most analyses, correct for Government appraisal where the concern is to allocate resources most efficiently across the economy. Sensitivity analysis to consider the private sector view of investment costs would also be useful.
- **Level of detail**. McKinsey studies offer a very high level economy wide overview, with little detail as to the underlying analysis. The CCAP studies present in-depth analysis on specific sectors (particularly in Phase II), but do not allow for macro-economic analysis or country level comparisons and are better viewed as sectoral level case studies. The World Bank studies offer a hybrid view with significant sectoral detail, but also an economy wide perspective. Full tabular outputs or underlying data are often not presented, making it difficult to draw direct comparisons and data often has to be inferred from the report text.
- **Minimum abatement potential**. The studies apply different thresholds for inclusion of interventions in the analysis. The WB study applies a minimum threshold of 1-5 $MtCO_2$ eq. for inclusion in its analysis, whereas McKinsey tend not to set any threshold. Setting a minimum threshold reduces the number of potential interventions and will reduce the overall abatement potential somewhat. It is also likely to reduce the MAC by identifying high volume lower cost interventions.
- **Maximum MAC**. The studies apply different thresholds for the maximum marginal abatement cost associated with an intervention for it to be considered. For example, McKinsey considers all options up to $90//tCO_2 eq. while the Mexico WB study places a limit of only $25/tCO_2 eq. Applying a lower MAC limit reduces the abatement potential, but provides a clearer view of lower/negative cost mitigation options.

Appendix 3. Case Study 1: Mexico: Embarking on a Low Carbon Growth Path

Mexico is one of the leading developing countries in promoting a low carbon future, believing that robust mitigation goals are not incompatible with strong economic growth. At the 2008 Poznan Climate conference, Mexico stated that it wanted to reduce 2002 GHG emission levels by 50% by 2050.

Recently the Government launched the Special Climate Change Programme (Programa Especial de Cambio Climático (PECC)), proposing a range of initiatives to reduce carbon emissions, and establishing a low-carbon development scenario (Comision Intersecretarial de Cambio Climatico 2009). At the Copenhagen Summit in December 2009, Mexico re-iterated its commitment to reducing GHG emissions, stating that *Mexico aims at reducing its GHG emissions up to 30% with respect to the business as usual scenario by 2020, provided the provision of adequate financial and technological support from developed countries as part of a global agreement.*[46]

Mexico has therefore been taken as a case study country, to review the evidence of impacts of a low carbon growth pathway, particularly concerning how such a strategy impacts on wider growth. In addition to reviewing the evidence concerning macroeconomic impacts, evidence at the individual sector level has also been reviewed to identify the *no regrets* opportunities, and the potential for abatement.

The following questions have been considered in the case study analysis:

- What are the low carbon growth opportunities for Mexico at a sector level?
- Are the levels of abatement potential for sectors, and estimates of cost-effectiveness consistent between studies?
- Do the sector level findings support economy wide level findings on the impact of a low carbon pathway?
- Are the insights for Mexico relevant for other countries, and transferable to inform low carbon strategies in other developing countries?
- Is there methodology good practice that can be highlighted to make assessments more robust?

A key question emerges as to whether Mexico is in a unique position to embark on a low carbon growth strategy and what insights this case study provides for other developing countries.

[46] Submitted letter can be found at the following website – http://unfccc.int/files/meetings/application/pdf/mexicocphaccord_app2.pdf

Table A3.1. Comparison of key studies reviewed for Mexico Case Study[47]

	Centro Mario Molina (2008)	World Bank (MEDEC) (2009)	PECC (2009)
Objective	Assess the opportunities and costs of reducing emissions to an emission level considered sustainable by the science	Review opportunities that will put Mexico on a lower carbon growth path, which are high impact-low cost; therefore not guided by science	Set out a preliminary vision of longer term emission reductions consistent with science-determined sustainable levels
Mitigation only	Yes	Yes	Yes
Primary approach	Cost-effectiveness (using McKinsey MACC analysis); excludes policy / transaction costs	Cost-effectiveness (using MACC) although inclusion of some wider benefits e.g. time savings but not health external costs; excludes policy / transaction costs	
Sectoral coverage	All	Power, oil and gas, stationary energy end-use, transport, and agriculture and forestry	All
Analysis target	Ambitious. 50% by 2030 relative to BAU – on pathway to 2tCO_2 / capita by 2050	Significant reductions realised although not tied to any specific target	Ambitious. 50% reduction if 2002 levels by 2050 (consistent with 450 ppm stabilisation)
Mitigation measures	Fully or near commercial, and less than \$90/tCO_2 (144 options)	5 Mt CO_2e potential per annum, costing less than \$25/t CO_2 and feasible in the short or medium term (40 options)	Groupings of measures cited at different costs / potentials
Transparency of option assumptions	Low	High (Appendix C)	Unclear
Base Year	2005	2008	2002
Analysis Year (for mitigation / potential costs)	2030	2030	2050
GDP growth	4.1% (2005-30)	3.6%	3.5%
Population growth	1% (1.3% declining to 0.8% pa)	0.6%	Stabilising at 122 million in 2040s, (current level of 110 million)
Discount rate	4% (Social Cost of Capital)	10% (Private cost of capital)	
Other study analyses	Macroeconomic impacts (using E3MG)	CGE modelling of macroeconomic impacts	
Projections	IEA WEO 2007 (plus other sector specific sources)	LEAP model used	Internal analysis
Funding			Mexico Government

[47] Not all of the studies reviewed for Mexico have been included in this Table as not very comparable. For example, the RECCs study (Galindo et al 2009) does not undertake a full mitigation analysis, whilst the CCAP analysis only focuses on two industrial sectors.

Low Carbon Growth Studies reviewed for Mexico

There a number of different studies that have been undertaken for Mexico, assessing the economics of climate change. These include:

- The World Bank MEDEC study, focusing on mitigation opportunities across all economic sectors that are low (or negative) cost, and have a significant impact
- The Centro Mario Molina (CMM) study, including analysis by McKinsey, focuses on mitigation opportunities across all sectors, to reduce emissions to the pathway necessary to meet a target of 2 tCO_2 per capita
- Special Climate Change Programme (*Programa Especial de Cambio Climático* (PECC)) focuses on mitigation in 2009-2012 but with a longer term view of reducing emissions by 50% relative to 2002 levels. The long term scenario does not develop cost estimates, although does reference the Centro Mario Molina and MEDEC studies.
- The RECCS (by Galindo et al 2009), assessing the economics of climate change, including impacts / adaptation and mitigation. The RECCS assesses the economic implications of meeting the long term target stated in the PECC programme.
- CCAP sectoral analysis (2009, 2007) which reviews unilateral abatement measures in selected sectors identified by the Mexican government, provides an in depth framework for setting mitigation targets within the oil refining and cement sectors.

A comparison of the first three (main) studies are shown in Table A3.1.

Economy wide impacts of a Low Carbon Growth Strategy

Mexico's Low Carbon Strategy for the next four years is set out in the *Programa Especial de Cambio Climático* (PECC). In addition to the many initiatives described, this document also discusses the longer term projected emissions and the issues associated with achieving the long-term aspirational goal of reducing emissions by 50% in 2050 (relative to 2002 levels).

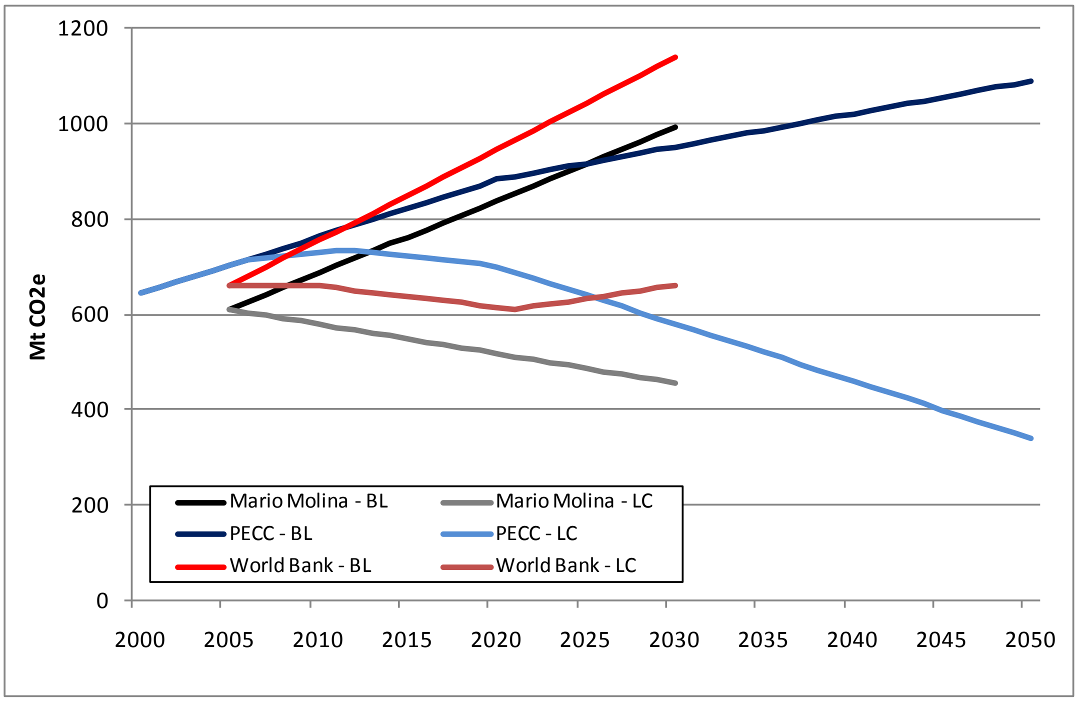
Based on average GDP growth of 3.5% and population stabilising at around 122 million in the 2040s, (compared to current level of just under 110 million), emissions are projected to increase to 1090 $MtCO_2e$ by 2050, an increase of 70% relative to base year levels. The Mexican government are hoping to reduce this projected emission level by 70%, which would mean a level around 50% below 2000 emissions. In per capita terms, this means emissions of 2.8 tCO_2 / capita, compared to 8.9 tCO_2 under the baseline. The near term action in the PECC will help to move Mexico on the required pathway, reducing emissions by 6% relative to the projected baseline (see Figure A3.1 below).

There is an emerging body of evidence that suggests Mexico can move to a low carbon pathway whilst maintaining strong economic growth. This has inevitably helped inform policy makers, and influenced thinking in respect of opportunities for a lower carbon future, as set out in the PECC. The evidence suggests that costs of low carbon options are not prohibitive for two key reasons: 1) mitigation potential is significant, and on average does not add significant incremental costs[48] and 2) moving to a lower carbon economy generates significant economic opportunities.

Two studies have undertaken useful economic analyses of the costs of moving to a low carbon pathway. Centro Mario Molina (2008) (abbreviated to CMM in this report) highlights significant abatement opportunities in 2030, reducing emissions by over 50% in 2030 relative to the baseline. CMM's bottom-up analysis (based on a MACC approach developed by McKinsey) suggests that average costs of abatement in 2030 will be approximately $2/$tCO_2$. This low cost reflects that 216

[48] Low carbon investments tend to be judged against the alternative (higher carbon) investment that would have been made in the baseline. Therefore, low carbon investments are usually instead of, not additional to investments required in the baseline projection.

$MtCO_2e$, or 40% of total potential (535 $MtCO_2e$) can be achieved at negative cost. Increasing investment needs are estimated to be US$7.3 billion / year (2011–2015) rising to US$18 billion (2026–2030), or 2.8-3.1% of total economy wide investment. Crucially, these reduce to $4.9 and $2.8 billion if netted against energy and operating cost savings. This illustrates the significant potential for energy efficiency savings and low cost abatement opportunities.



* In the legend, *BL* refers to *baseline*, and *LC* refers to *low carbon*

Figure A3.1. Projected GHG emissions in Mexico under different study scenarios

A top-down macroeconomic analysis has also been undertaken by E3MG as part of the CMM study. The findings of the analysis are that large emission reductions do not harm growth prospects; in fact growth in GDP increases by up to 1% relative to the reference case, and could create half a million new green jobs. There are some distributive effects, with job losses in some sectors; however, the impact is net positive. A small reduction in consumption due to increased prices is largely offset by overall growth in consumption in future years. In 2030, household consumption is expected to be more than double current levels. In other words, the cost is very small, with growth in spending per household of 3.18% per annum in the low carbon scenario compared to 3.22% under the reference case.

Growth is not negatively affected for a variety of reasons. Firstly, energy costs are a small proportion of total economic costs. Additionally, low carbon technical measures are estimated to lead to small incremental cost. Finally, borrowing of capital occurs over time, therefore not affecting economic consumption significantly. The analysis is premised on early action, starting investing in low carbon technologies now. This is crucial to ensuring lower costs, due to avoided lock-in to higher carbon technologies and the need for additional and disruptive investments in future years. Early action and a move away from fossil-based energy system will also lower reliance on potentially higher cost energy in the future, leading to some comparative advantage.

The second study by the World Bank (Johnson et al 2009) uses analysis under the MEDEC (México: Estudio sobre la Disminución de Emisiones de Carbono) study to determine economic costs of a low carbon strategy. Whilst only considering high potential, low cost measures, the analysis points to similar reduction potential as Centro Mario Molina (CMM 2008) in 2030, of 42%. 82% of the potential from interventions assessed is below the \$10/t CO_2e cost level. 65% of reductions (26 of the 40 options assessed) can be achieved at negative cost. The aggregate costs are put at \$64 billion between 2009 and 2030, or about \$3 billion a year, equivalent to about 0.4% of Mexico's GDP in 2008. The \$3 billion value is similar to the CMM (2008) estimate, where financial savings are also accounted for.

The CGE model developed by Boyd and Ibarrarán (2008) was used to assess the macroeconomic impacts of the low carbon scenario. Implementation of the options was estimated to increase the overall level of GDP by as much as 5% in 2030. While this appears high relative to the E3MG estimate discussed above, a key factor in the observed positive impact must be the level of energy savings achieved through negative cost measures. Agriculture and forest sectors are estimated to be the biggest winners (note in this analysis this includes biofuels / use of biomass products) whilst welfare gains were greatest for the lowest decile groups, suggesting a progressive rather than regressive strategy.

Another important contribution to the economics of climate change evidence base for Mexico is the RECCS (Galindo 2009). Whilst the focus is on impacts / adaptation, a simple approach is taken to determining mitigation costs, estimated by assuming a specific carbon price multiplied by the amount of reduction (50% by the year 2050 and 2100 relative to 2002). At a 4% discount rate, costs for the 2100 target are between 0.7% GDP using \$10/tCO_2e and 2.2% using \$30/tCO_2e. In 2050, they are 0.56% and 1.75% respectively. The analysis does mention that these cost estimates probably represent the upper limit, given that no cost minimization was applied in the analysis e.g. using cost curves or estimating cost reductions through innovation. No analysis is undertaken at a sectoral level, although the MACC analyses reviewed in this study are cited.

It is not clear whether the aggregate economic costs for the longer term objective for 2050 are estimated in the Mexican climate strategy (PECC, in Comision Intersecretarial de Cambio Climatico 2009), which focuses on the 2009-2012 period. Concerning the longer term objective, the focus of the report is on which sectors will contribute to abatement. It does however note significant potential for negative and low cost measures, based on a range of analyses, including the CMM / MEDEC studies, and a report by Quadri (2008) *El Cambio Climatico en Mexico y el Potencial de Reduccion de Emisiones por Sectores* (although this has not yet been sourced). This is another cost curve analysis, reproduced in Galindo (2009), showing similar significant potential in 2020, again much of which is negative costs as seen in the CMM / MEDEC analysis.

At the economy level, the studies appear to point towards relatively low incremental costs associated with necessary investments. In fact, benefits to growth are observed. Financial mechanisms that incentivise the move to a low carbon growth pathway through the use of a carbon price will make low carbon investments more attractive, and again reduce any foreseen impacts on growth. The issue here will be about the type of mechanisms available to provide incentives, and then access to such finances at the sectoral level.

Finally, the costs of domestic implementation will be affected by global action, needed to provide the markets and mechanisms for ensuring finance, political impetus and incentives to reducing GHG emissions. An analysis funded by the Climate Group (using analysis from Cambridge University's E3MG model) highlights the importance of global agreement and collaborative action. The focus of the analysis is to illustrate how collaborative action globally can reduce the cost of a low carbon transition. If Mexico was to return to 2010 or 2015 emission levels in 2020, comparable action was undertaken in other developing countries, and the developed world adopted stringent targets (30% below 1990 levels), this would have a net positive impact on GDP and jobs; GDP increases by between 0.35-0.55%. This is because development is accelerated by a greater technological change towards low-carbon employment-intensive technologies and away from obsolete fossil-fuel combustion.

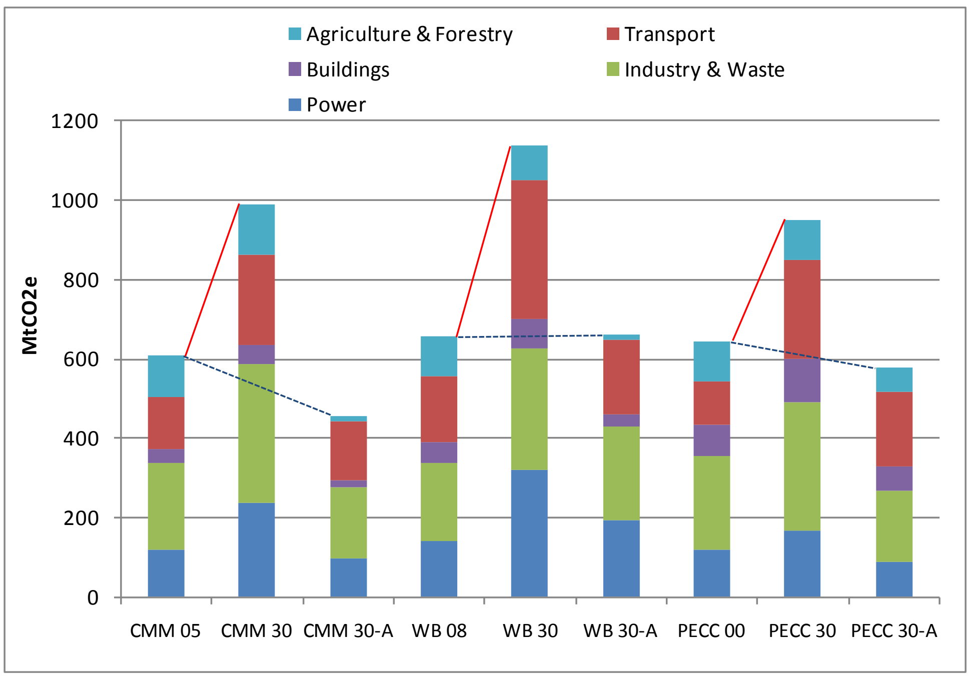
Whilst the uncertainties mean such values need to be viewed cautiously, the minimum insight is that growth is not negatively impacted. The report also notes that developing country growth will be contingent on adequate support – technological, institutional and financial – being provided by industrialised countries, but such support is not a "lost" transfer; rather it will enhance growth in global terms.

Low carbon options by sector

This section of the report assesses which sectors have greatest potential for mitigation opportunities and at what cost, and therefore impact most on the macro-level findings. That is, this section assesses the extent to which the studies similar aggregate findings are consistent at a sectoral level. The review also highlights measures that could be important for other developing countries in moving towards a low carbon pattern of growth.

For the three main studies for which low carbon pathways are assessed, the emission levels by sector for the base year, 2030 baseline and 2030 low carbon pathway are shown in Figure A3.2 below. The red lines indicate the baseline trend, compared to the low carbon trend, illustrated by the blue lines. All three studies show emissions returning to base year levels by 2030 under a low carbon pathway.

Taking account of the different baseline assumptions and measures considered in the analyses, reasonable consistency can be observed at the aggregate level. However, some important differences can also be observed in the relative contribution to emissions and reductions at a sectoral level.



* 30-A cases represent the low carbon growth (Abatement) case in 2030; CMM 30-A includes reduction from waste sector

Figure A3.2. Current and projected emissions for Mexico by study[49]

[49] PECC estimates are taken from published graphs, and are therefore subject to some additional uncertainty

At the end of this section, a more detailed review by sector of the types of measures considered, and their potential and costs is provided, particularly focusing on the MEDEC and CMM studies. In summary, the CMM analysis shows the biggest contributors to emission reductions are the power sector (26%), waste management (16%) and transport (through improved efficiency, decarbonising fuels, improving public transport, 14%). The MEDEC study put the following four sectors as being highest priority for realising emission reduction potential (% contribution to mitigation in brackets) – transport (27%), electric power (33%), forestry (16%), and energy-efficiency sectors (24%).

There are therefore some key differences between the two studies leading to sectoral differences in reduction potential. The baselines differ, with the MEDEC study estimating significantly higher growth in transport, and therefore reduction potential. The MEDEC study also shows significant emissions from waste and industrial processes but does not investigate any abatement options (as reflected in Figure A3.2), whilst the CMM analysis shows significant potential for reductions from improved waste management. Finally, forestry is considered a higher emitting sector in the MEDEC study, with afforestation leading to higher emission reductions relative to the 2030 baseline. Conversely, agriculture is more significant in the CMM analysis.

The PECC (CICC 2009) strategy states that the following sectors offer the most potential - energy (146 $MtCO_2e$, incl. electricity generation, oil and gas), industry (77 $MtCO_2e$ incl. energy and processed-based emissions) and transport (51 $MtCO_2e$). It is therefore relatively consistent with the above analyses, again with differences due to baseline assumptions and measures considered. Due to lack of detail in the PECC, the sector options in this study are not considered in detail in the following sections.

All three studies suggest large potential for negative cost measures, between 40% and 60%, whilst low cost (<$20/$tCO_2e$) measures typically achieve up to 80% of the available reduction potential. This potential enables Mexico to get back to or below base year emission levels.

Figure A3.3 provides a useful illustration of the types of measures included in the two assessments reviewed in detail. It illustrates that negative and low cost measures dominate, driving the conclusions about such a strategy having relatively low costs. These negative and low costs are dominated by energy efficiency options, forestry measures (enhancing sinks) and cheaper renewable / shifting to low carbon fuels (decarbonising energy). That is, the similarity between the aggregate findings of the World Bank and CMM studies tends to be born out at a sectoral level.

In the World Bank study there is a significant proportion from mode shift; this is made up of moving to rail freight and enhancing public transport systems. The inclusion of mode shift in the Mexico MACC reflects that such measures can be appraised using this framework, although would be more difficult to include in global MACCs, as costs and potential are very sector specific. Potential from higher cost measures include advanced technologies such as CCS and more expensive renewable options, such as solar PV.

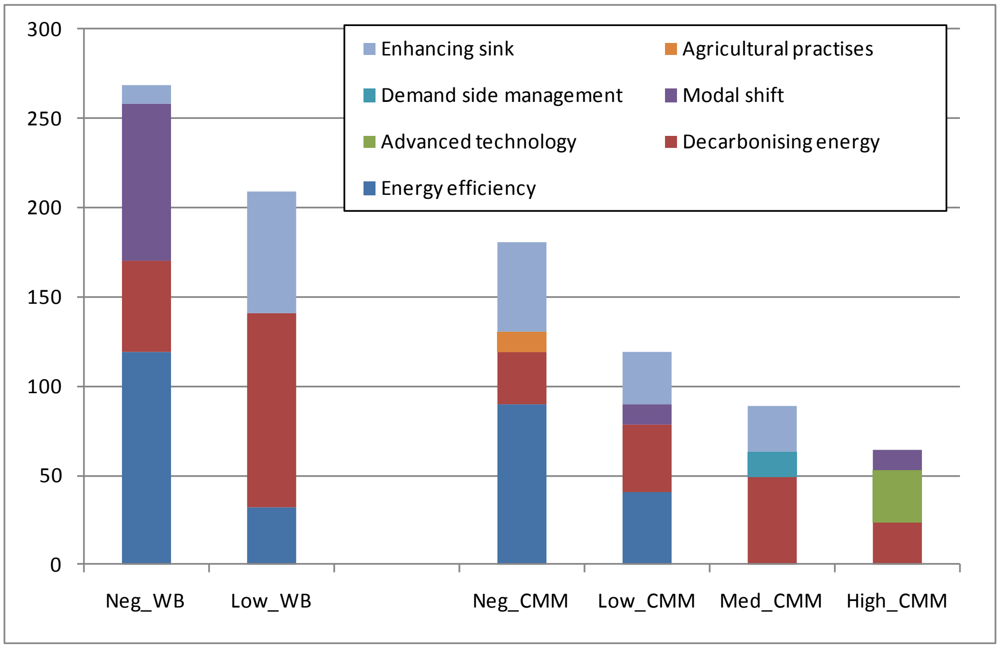


Figure A3.3. Abatement potential in 2030 in Mexico by measure type (CMM 2008, WB 2009[50])
Cost categories are as follows: Negative (<$0), Low ($0-25), Medium ($25-40) and High (>$40).

In addition to all sectors playing an important role in a given reduction strategy, the data also suggests that the range of technical measures needed is significant. This will of course be true for the types of policy mechanisms that will be required to implement such measures.

Realising Low Carbon Growth in Mexico

For Mexico to realise low carbon growth, three key areas need appropriate consideration – effective implementation, adequate financing and co-benefits assessment.

Implementation of mitigation options

Effective policy implementation will be crucial for Mexico to move towards a lower carbon pathway. The PECC is an important programme for taking this forward in the near term, whilst further work is needed to develop the strategy further for the medium / longer term pathway. Concerning implementation, the analyses seem to focus on three areas – timing of action, required policy mechanisms and overcoming barriers.

The CMM (2008) analysis considers the issue of implementation and its timing. While it is imperative that countries start now, a range of issues need to be considered to determine the timing of action. Two factors are highlighted: current costs and ease of capture. The former concerns whether to wait for options to become cheaper in future years, and then implement. The latter includes a range of criteria (such as requirement for and access to finance, institutional capacity and political feasibility) prioritising those options that are easier to capture now.

Applying this approach to the Mexican situation results in three implementation stages:

[50] The World Bank study only considers negative and low cost measures

- Do it now, no regrets (22% reduction from baseline in 2030). Includes measures that are no regret and easier to implement
- Start now, then accelerate (24% reduction). Measures are low cost and have low-moderate barriers to implementation
- Explore now, capture over time (post-2015, 9% reduction). Options that have greater impact over longer time frame, which tend to have higher costs (e.g. may not be fully commercial)

From a cost perspective, timing issues may be less of an issue in the World Bank analysis as all options are negative or low cost. However, they do propose that priority should be given to options with significant potential, strong rates of return and co-benefits, have been demonstrated at a commercial scale and have lower investment costs (to avoid financing problems).

PECC take a similar approach to CMM (2008) splitting abatement potential to 2030 into four different implementation groups, as shown in the Table A3.2 below. It suggests a similar schedule for implementation, starting with options that are lowest cost and can realise the highest reductions (although take less account of other 'ease of capture' factors). The timing of implementation issue is key, and will affect the costs associated with a lower carbon pathway; start too soon and potentially incur higher costs or delay and miss cost-effective opportunities for intervention or risk lock-in to higher carbon investments.

Table A3.2. Packages of measures for realising emission reductions in 2030 under PECC

Group	Impact of measure	Cost range ($/t$CO_2$e)*	Potential in 2030 (MtCO_2e)	Implementation timescale	Key sectors / options
1	>3 MtCO_2e /yr	-33 - -54	177-202	Immediate	Energy efficiency in buildings and industry, public transport
2	<3 MtCO_2e /yr	-24 - -65	10-46	Near term	Transmission and distribution of electricity, light duty vehicles, tillage practises
3	>3 MtCO_2e /yr	4-13	167-187	2015-2025	Forestry measures, Renewable generation
4	<3 MtCO_2e /yr	7-17	7-12	Post-2020	Biodiesel, CCS, Smart Grid systems

* Average cost of package of measures

Specific policies considered to implement different options are varied; the effectiveness of different policies will be determined by their structure and delivery, information not provided by these analyses nor in the remit of this study. Some broad policies can be identified that appear particularly important in the Mexico situation but which will also be relevant for other developing countries.

- Mechanisms to encourage renewable energy investment e.g. for example feed-in tariffs
- Removing of energy subsidies so as not to distort price signals
- Implementing minimum efficiency standards for energy using technologies (appliances, vehicles)
- Urban planning and public transport
- Forestry programme to protect forests (reduce deforestation) but also to increase forest cover (afforestation)

More detail on policies measures can be found in later in this section, including assessment of the barriers. Barriers vary across different sectors of the economy. In agriculture / forestry, there are issues concerning permanence of mitigation, property rights and enforcement. In the building sector, barriers include lack of consumer awareness, principal agent problems and subsidies for high carbon fuels. Barriers across all sectors include high upfront costs, sector inertia (including consumer preferences) and a distorted pricing system for energy due to subsidies.

A discussion of the specific barriers facing uptake of renewable generation in Mexico is provided in the Box below.

Overcoming barriers to renewable generation in Mexico

Mexico has significant potential for increasing renewable electricity generation. Lokey (2009) states that the CDM mechanism could be utilised much more for financing such projects but barriers to uptake exist. She argues that CDM opportunities are significant, given the high carbon intensity of electricity, but are not being realised due to the culture of and laws directing the state-run companies with control of the majority of power generation and transmission, Comision Federal de Electricidad (CFE).

The main hurdle is that priority under the current planning structure is given to the lowest levelised cost generation, which is fossil-based. The carbon benefits of renewable are not included in the levelised cost assessment. According to federal law, the CFE must develop new capacity additions that will provide the cheapest electricity for citizens.

IPPs account for less than 20% of generation. Barriers to development by private sector operators are many; for example, land leases are required for new projects which are difficult to obtain due to lack of land deeds showing legal ownership. Agreeing additional capacity charges and agreeing tariffs is again a long process that disincentivises new investment. Government subsidies to the state sector also make it harder for the private sector to compete.

Previous laws opening up the market have not appeared to have worked well. New legislation is being introduced - Law for Utilization of Renewable Energy. This law allows for renewable benefits to be included in levelised cost estimates, and sets out a goal for renewable generation accounting for 12% of the generation mix (excluding hydro).

Huacuz (2005) also notes the barriers to large uptake of renewable generation technologies, and suggests a number of important factors in facilitating increased penetration.

- A policy and regulatory framework that levels the playing field, allowing mature renewable energy technologies to compete with fossil alternatives. An important initiative could be a ‘‘Special Regime’’ that *recognized the non-energy values of green power by rewarding renewable energy projects with fiscal and other economic incentives, fast track permitting, fair buy-back prices and long-term contracts, public information campaigns, capacity credits and so forth.*
- Adequate and effective institutional and technical capacity to support technology development, transfer and deployment
- Financing mechanisms to facilitate market development and to help advance pre-commercial renewable energy technologies to the market.
- Coordination of energy issues with other government sectors, to allow renewable technologies to be considered in infrastructure projects
- Mechanisms to assure participation of the private and social sectors in the development of energy projects
- Effective coordination among stakeholders interested in the promotion of renewable energy

Sourcing investment

Mexico will require significant investment for continued economic growth, whether low carbon growth or not. This will be to fund new roads, electricity generation plants and housing, for example. A low carbon growth pathway requires additional levels of investments above the reference growth case, although in many cases these may be more cost-effective over the lifetime of the technology.

Sourcing this additional finance now is critical to the notion of 'starting early'. Investment routes include the domestic private and public sector (also providing incomes for domestic sector investment). If able to position itself as a leader in clean technology development, increased foreign investment could be sourced. Financial institutions could also be important, such as the World Bank, which has sources of funding for emission reduction-based projects.

In October 2009, the World Bank approved a US$1.5 billion loan aimed to develop public policies to support the stimulus of the economy while strengthening the framework for long-term sustainable growth.[51] Regulatory, monitoring and financial frameworks will be set-up to help ensure low carbon evolution of urban transport and energy sectors. The objective is that such investments will stimulate the economy in the short term, while improvements in urban mobility and energy efficiency will increase productivity and further growth in the medium term.

Future carbon markets are also important. CMM (2008) state that McKinsey estimate the size of the CDM market at around 1500 Mt CO_2e by 2030, and worth US$2 billion per year assuming a US$50 carbon price (based on share of developing world abatement potential). This and other financing mechanisms, such as REDD+, will be increasingly important.

Raising capital for investment is crucial for any developing country to embark on a low carbon pathway in the near term. There are a range of emerging mechanisms that developing countries need to access; to benefit, Mexico will need to input into how such mechanisms are set up, and invest in institutional capacity to enable access.

Maximising co-benefits

The benefits of a low carbon pathway should not only be appraised on the basis of monetary costs or savings but on the less easily monetised co-benefits. This is good practice in appraisal of strategy because it allows for wider assessment of other policy impacts, hence reinforcing the argument or not concerning a move to a lower carbon growth pathway. The Mexico analyses note the following policy co-benefits of low carbon options:

- *Energy security*. The analysis by CMM (2008) estimates 27% reduction in oil consumption by 2030. This means less reliance on foreign imports, and reduction in future payments for an increasingly expensive commodity.
- *Health / welfare*. Greater agricultural productivity results in higher incomes, reduced traffic congestion improves economic productivity, reduces fuel consumption and improves urban environments, whilst a shift away from fossil fuels leads to cleaner local environments, and reduction in health impacts. Protecting forests safeguards economic sectors reliant on wood-based products, biodiversity and the welfare of forest-based communities.
- *Political leadership*. Mexico can leverage its position as a low carbon leader in future climate negotiations and in attracting foreign investment.

Concerning the above point on health and welfare, the World Bank analysis estimates the time benefits (due to less congestion) and reduction in external costs (due to less air pollution damaging health) associated with transport measures. For specific measures they are considerable.

[51] World Bank website, http://beta.worldbank.org/node/5039

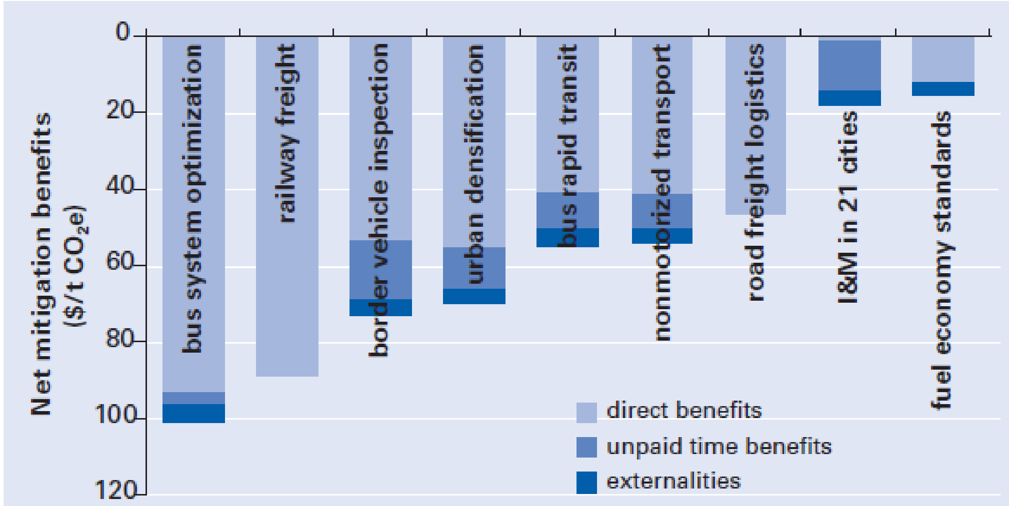


Figure A3.4. Externality and Time Costs for MEDEC Transport Interventions (Source: Johnson et al. (2009))

Key Insights from the Mexico Review

The evidence reviewed for this case study suggests that costs of moving a significant way towards a low carbon economy are not prohibitive so long as the opportunities are pursued in a phased manner, reflecting their cost, technological maturity and ease of implementation. There is estimated to be significant mitigation potential that on average does not add significant incremental costs. That is not to say that financing the additional costs will not be challenging.

In addition, a move to a lower carbon economy generates certain economic opportunities, although these tend to be less well elaborated than the abatement opportunities in the various studies. The key question is whether this overall finding is specific to Mexico, or is also applicable to other developing countries, considering a future lower carbon pathway.

Therefore, it is important to note on what basis a low carbon growth pathway in Mexico is possible, and at limited additional cost:

- The analyses are premised on action being taken early, avoiding lock-in to high carbon technologies. Introducing lower carbon technologies after investment in high carbon technologies in later years, possibly in the face of mandatory targets, would be significantly more expensive. Examples of early action include investing in low carbon electricity generation to meet rapidly increasing demand, ensuring minimum efficiency standards for appliances and securing reductions in deforestation.

- It also requires that policy be implemented consistently over many years – investors need confidence that there will be stability in the policy framework

- Economic and population growth rates are not as high as forecast in other developing countries. As these are the primary drivers of growth in carbon emissions, the fact they are lower will make a shift to a lower carbon pathway relatively easier.

- Analyses highlight significant amounts of energy efficiency potential across all sectors, resulting in large cost savings to the economy. However, the analyses do not highlight the difficulties associated with implementing such measures. The lack of consideration of policy and transaction costs in implementation is a key area for further study in the cost assessment. Policies to realise the potential of such measures are likely to push the costs of these measures up significantly.

- In addition to negative cost options, there are a range of options in the low cost range ($0-20 / tCO_2e) that also ensure a move to a low carbon pathway is not prohibitively expensive. Importantly, Mexico can go a long way to establishing a low carbon pathway primarily on the basis of relatively cost-effective options.

- All sectors of the economy provide either negative and / or low cost options. Only by tapping this reduction potential across all or most sectors can significant reductions be achieved. Sectors contributing the most potential include power generation, transport and other energy end use sectors.

Two relatively comparable analyses (CMM 2008, Johnson et al. 2009) using different data and modelling approaches increases the confidence in the robustness of this analysis, and the insights that emerge. While the full stated potential is unlikely to be realised,[52] if it can be to the 60-70% level by 2030 then this will still put Mexico on a strong low carbon emissions trajectory. In addition, Mexico's Climate Change Programme also recognises that a low carbon pathway similar to that in the above analyses is achievable (although it is unclear the extent to which PECC has undertaken new analyses or primarily used existing assessments from CMM / WB).

The analyses considered are also conservative in the type of measures they consider i.e. relatively low cost options, and in the World Bank analysis, only those interventions that provide significant reduction potential. Limited consideration is given to 'leapfrogging' technologies, including technologies that may appear expensive now but may not be in 2030. In addition, the assessment of the impact of behavioural change is limited; social awareness of the climate change issue could affect patterns of consumption whilst price effects may also result in changing consumption, for example of fossil fuels.

Options considered in the analyses are all near or fully commercialised. Therefore, the risks associated with technical feasibility of options, or cost overrun, are low. In addition, due to the co-benefits (discussed below) and many cost saving (no regret) measures, the risks of wasted investment are minimised in the absence of strong domestic and international targets in the future. From a political perspective, risks are also low.

Finally, the benefits of carbon finance in reducing costs are not reflected in the cost curve analysis. If for example a given project raised $30 per tonne CO_2 abated in carbon financing, this could in affect be included in the cost curve, lowering the marginal cost of the measure by $30 per tonne CO_2. Clearly this is simplistic as accessing this finance will incur transaction costs. However, it does illustrate that if financing can cover incremental costs associated with low carbon options across different sectors, this could further reduce any additional cost burden associated with a lower carbon options.

The key challenge for Mexico and for other developing countries is <u>implementation</u> to realise what appears a low cost strategy, which the economic evidence appears to point to. Effective implementation is difficult for a range of reasons including lack of international support, limited access to financial capital or carbon markets, or limited institutional capacity to drive the strategy

[52] The level of reduction potential shown in the cost curve analysis is not likely to be realised in reality. This is recognised in the CMM (2008) study, stating that *even with well designed government policies and business strategies, it is unlikely that the full potential will ever be captured. Technical potential rarely translates fully to real-world action, even if there are strong economic incentives, as the existence of many opportunities on the left side of the cost curve shows.*

forward. Johnson et al. (2009) state that the greatest challenges in realising low carbon interventions are *financing the often larger upfront costs of low carbon interventions and putting in place supportive policies and programs.*

While the costs may not appear prohibitive, this shift to a low carbon economy is going to be challenging, requiring strong implementation of the strategy and international support. Figure A3.5 shows the low carbon pathway published in the PECC, illustrating the scale of the challenge, with significant reductions required across most sectors, particularly electricity generation, transport, industry and waste sectors (*Desechos*).

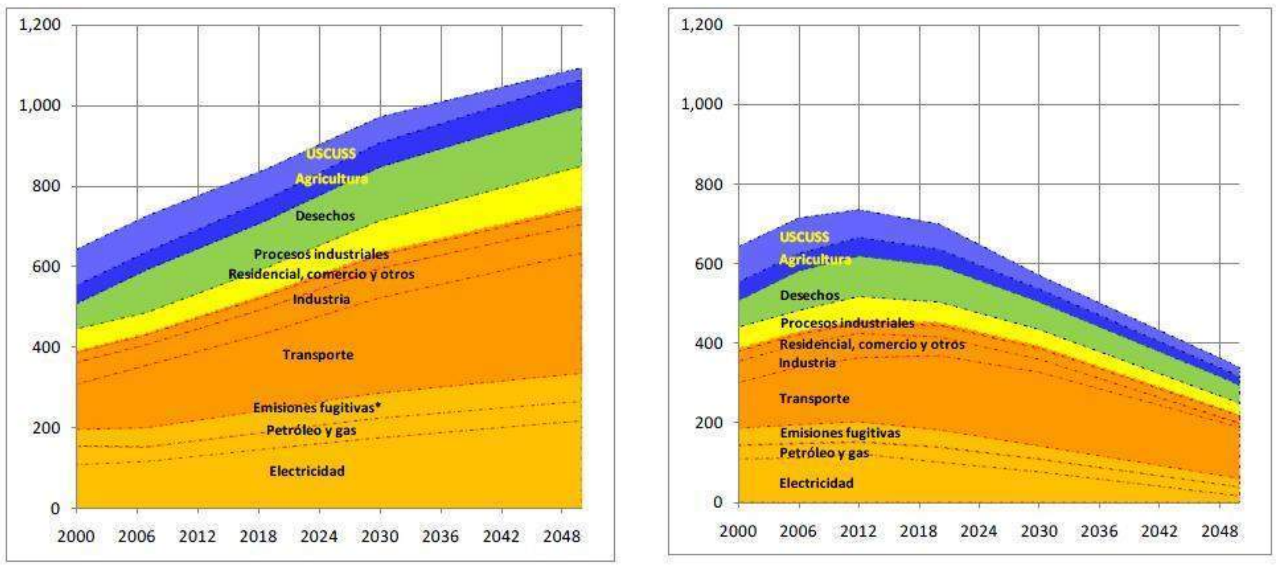


Figure A3.5. Reference and low carbon projections for Mexico by sector, 2000-2050 *(Source: Comision Intersecretarial de Cambio Climatico 2009)*

In summary, the evidence base suggests that Mexico has significant opportunity for low carbon growth across all sectors of the economy. In addition, the costs of different options tend to be low; fed into macroeconomic models, the resulting analysis indicates that even challenging low carbon objectives can be met without compromising growth. This is broadly consistent with what is seen in other developing world analysis, as reviewed in other outputs under this project. In addition, the studies reviewed in this case study are broadly consistent, although there are clear differences in baseline emission assumptions and mixes of measures at the sector level.

The insights from this case study are very relevant to other developing countries; however, differences in other regional and national circumstances do need to be considered, as do the issues around implementation which may also differ significantly. Finally, key uncertainties exist that should be better reflected in the analysis and / or wider evidence base. Some recommendations on developing the approaches to low carbon growth studies have therefore been made in section 6.

Key conditions for achieving low carbon growth in Mexico

A number of conditions emerge that appear to be important for Mexico to achieve low carbon growth objectives:

- **Start now to avoid more costly action in the future**; if investments are to be low carbon (and climate resilient) this has to be taken into account now to prevent lock-in to higher carbon technologies and the potential re-investment under any future agreements that cover developing countries.
- A **robust strategy needs to in place, backed by strong political will**. Evidence of low carbon growth potential is important but will never be achieved without strong political backing, and the right policies in place that provide the long term stable framework for investment.
- An **economy wide view of mitigation opportunities** is required, with all sectors contributing if significant reductions are to be realised. Opportunities, particularly those that are low cost, are not restricted to specific sectors but available across all.
- **Timing of options** in important to ensure technologies are implemented at the cost-optimal time.
- **Accessing capital** by providing the necessary political signals and having the necessary institutional capacity in place. Finance is key to delivering a strategy.

Annex to Mexico Case Study: Review of potential by sector, and policies and barriers

Power Sector

The power generation sector in Mexico is primarily fossil-based, comprising the following generation shares - 35% gas, 27% oil and 15% coal. The remaining generation is primarily from hydro but with some contribution from geothermal and nuclear. Under the baseline, the MEDEC study assumes a different mix in future years, with a higher proportion of coal generation, and therefore higher emissions in 2030 than observed in the CMM baseline.

By 2030, both studies expect the relative contribution of the power sector to overall emissions to be of comparable magnitude (24-28%), with the World Bank study estimating higher absolute emissions from the sector by 2030. The absolute abatement potential within the sector is also broadly comparable (129-139Mt CO_2e). The abatement potential within the sector represents a reduction of 58% over the reference scenario under the CMM analysis and 41% under the World Bank study. This indicates that significant decarbonisation of the power sector is needed to meet ambitious future reductions, as being considered for Mexico.

The comparability between studies masks a significant difference in the number of abatement options underlying each of the studies and the individual potential of these options. The CMM study outlines a broader set of abatement options with lower potential while the WB study has a smaller number of abatement options as a result of screening for negative/low cost options and near term implementation potential. As a result, where the two studies assess the same technology options, the WB often estimates the abatement potential of the technology to be significantly higher than the CMM study.

The CMM analysis identifies geothermal and hydro as potentially negative cost technologies, with the majority of other options representing medium or high cost pathways. The WB analysis draws relatively similar conclusions about the abatement cost of technologies (albeit with a much narrower scope), although there is some divergence between the studies as to which are low cost or negative cost.

Table A3.3. Abatement opportunities in the power generation sector (Values in Mt CO_2e unless otherwise stated)

	CMM (2008)	WB (2009)**
Sector Emissions (Base)	121 (2005)	142 (2008)
Sector Emissions (2030)	240	322
Sector emissions contribution (2030)	24%	28%
Reduction Potential (2030)	-140	-129
% Emissions relative to reference year	-58%	-40%
Contribution to total abatement in 2030	26%	27%
Key options*		
Biogas	-	Low cost (4%)
Geothermal	Negative cost (7%)	Low cost (37%)
Small Hydro	Negative cost (11%)	Low cost (7%)
Replace new coal build with gas	Low cost (1%)	-
Oil to gas shift in power	Low cost (15%)	-
Increased efficiency in utility	Low cost (1%)	Negative cost (5%)
SCADA (Smart Grid)	Medium cost (10%)	-
DSM and consumption reduction	Medium cost (1%)	-
Nuclear Power	Medium cost (9%)	-
Coal CCS w/ enhanced oil recovery	Medium cost (0%)	-
Gas CCS w/enhanced oil recovery	Medium cost (0%)	-
Wind	Medium/High cost (20%)	Low cost (18%)
Solar PV	Medium cost (6%)	-

Solar CSP	High cost (14%)	-
Gas CCS new build	High cost (1%)	-
Coal CCS retrofit	High cost (2%)	-
Gas CCS retrofit	High cost (3%)	-
Biomass (Direct and cofiring)**	High cost (0%)	Negative/Low cost (29%)

* Cost categories are as follows: Negative (<$0), Low ($0-25), Medium ($25-40) and High (>$40). All costs are in $/t$CO_2$e.
** Biomass direct and cofiring data taken from agriculture section in report

Abatement Options

The focus of the 17 different options cited by CMM (2008) focus on increasing the share in the power mix of renewables and potentially nuclear, improving grid and generation efficiency, and in the longer term applying carbon capture and storage technology (CCS).

The World Bank analysis (Johnson et al 2009) selects a much narrower range of technologies, representing low and negative cost options (<$25t CO_2e). Solar PV was not analysed due to high technology costs whilst nuclear was excluded due to security and environmental constraints. Large hydro rehabilitation was excluded due to lack of appropriate data. CCS options were excluded on the basis of the immaturity of the technology and the lack of implementation options in the short term.

Barriers to Take-up

CMM (2008) identifies barriers for selected technology options that may impact upon realising the abatement potential identified: The main cross cutting issue is the lack of incentive for CFE to switch from fossil fuel generation to other options with potentially higher up front capital costs per MW installed. Technology specific barriers include, potential competition for skills and technology between geothermal and oil exploration, a global shortage of small hydro and wind turbines. Solar PV is limited by intermittency and storage issues, high costs and difficulty in developing suitable sites.

The World Bank analysis (Johnson et al 2009) splits the barriers into those experienced by large scale and small scale projects rather than by particular technology. Those that prevent deployment of large scale low carbon alternatives include power sector planning using low fuel price assumptions, use of least cost technology approaches, failure to account for co-benefits and full costs (environmental externalities, diversification, risk reduction and security of supply). Particular barriers for smaller technologies include exclusion from power procurement bidding processes, a lack of contracting and power purchase procedures, partial payments, licensing issues and transmission capacity issues. Some specific issues are identified for small hydro, in particular relatively high capital costs, licensing uncertainty and competition for water supplies with agriculture and fisheries.

Policy Initiatives

A number of policy initiatives for this sector are discussed in the different studies for delivering emission reductions (listed below). The WB study focuses primarily on structural reform to encourage CFE investment in higher cost renewables, such as portfolio planning, better risk management, and improved licensing/grid connection procedures. The CMM study also identifies the need for financial support for higher cost renewable alternatives, but also focuses on the need to ramp up domestic production and export of small hydro and wind turbine production, and the need to balance intermittency with investment in smart grids.

While both studies address improvements in utility efficiency (T&D losses, generation efficiency in existing plant), only CMM (2009) addresses the impact of the (passive) demand side management (DSM) benefits arising from smart grid technology and improved metering. Even so, the abatement potential identified is relatively modest (0.7 Mt CO_2e). There is potential for a more proactive assessment of utility-led DSM options to reduce peak load.

A further issue is that neither report appears to consider the electricity demand reduction implications of abatement measures in other sectors. In both studies, abatement cost analysis is undertaken against a static electricity demand forecast for 2030, based around the substitution of technologies, rather than optimising supply against potential demand changes.

Objective	Barriers	Policy option
Large scale RE	Low fuel price planning scenarios No use of portfolio planning No consideration of ex plant infrastructure costs and co-benefits Social issues for large hydro	Use higher fuel price scenarios for electricity sector planning Integrate volatility risks and assess diversification benefits Include environmental externalities, infrastructure costs and carbon costs
Small scale RE	Only large scale projects in bidding Lack of contracting procedures Renewable generators/cogen paid marginal costs and no capacity charges Licensing issues Transmission bottle necks	Allow small scale RE and cogen projects to supply partial capacity requirements Develop PPAs for small projects Develop payment system to reward capacity, risk reduction and externalities Streamlined licensing procedure Expand transmission capacity in areas with large RE potential
Geothermal Power	No incentive to switch for CFE Drilling technologies offer competition to oil and gas sector	Fiscal incentives and obligations
Hydro Power	Lack of capacity for small turbines High capital costs and low incentives Social impact issues for large hydro	Partnership with manufacturers Fiscal incentives and obligations Improve negotiation mechanisms
Wind	Supply chain bottleneck for turbines Lack of incentives to switch for CFE	Domestic manufacturing capacity and technology transfer Fiscal incentives and obligations
Solar	Rate of new site development Intermittency and storage issues Available land High costs of generation Lack of incentives to switch for CFE	Introduction of smart grid technology to address intermittency
Smart Grids	Access to technology Lack of awareness in T&D operators Capital investment to upgrade grid and install meters Lack of consumer awareness	Public/Private R&D partnerships Technology transfer in UNFCCC Government subsidy Raising T&D charges
CCS	Public concerns over integrity Lack of legal framework Technology immaturity Commercial immaturity and risk	Public awareness campaign Develop regulatory frameworks Fund demonstration plant
Nuclear Power	High Capital Costs and overruns Public concerns on waste Long payback increases risk Supply chain and personnel bottlenecks Lack of capacity	Streamline planning Standardise designs Public/private finance Government Underwriting Waste disposal planning Regulatory authority Remove fossil fuel subsidies Fiscal incentives and obligations Supply chain management Training

In summary, while the WB study (2009) excludes many potential measures on the basis of high costs or long technology lead times, both studies conclude that it is possible to decarbonise the electricity sector to a considerable extent at low or negative cost. Both studies indentify geothermal, small hydro and utility efficiency as the key short term measures. CMM (2009) also recognises the commercial opportunities in developing Mexico as a low cost manufacturing base for wind and hydro turbine technology to supply the North American market.

Transport

Across all studies, the transport sector is the source sector growing most rapidly in future years. The baseline in WB (2009) assumes that vehicle numbers will grow from 24 million in 2008 to more than 70 million in 2030. It is this growth that leads to emissions more than doubling by 2030. The CMM (2008) analysis assumes more conservative growth, probably due to assumed baseline efficiency improvement in new vehicles and the exclusion of air, rail and shipping sectors.

It is clear from the data that moving to a low carbon growth pathway is going to be difficult without addressing transport emissions, due to their significant growth in future years.

Table A3.4. Abatement opportunities in the Transport sector (Values in Mt CO_2e unless otherwise stated)

	CMM (2008)	WB (2009)**
Sector Emissions (Base)	131	167
Sector Emissions (2030)	225	347
Sector emissions contribution (2030)	23%	31%
Reduction Potential (2030)	-76	-155
% Emissions relative to reference year	-34%	-45%
Contribution to total abatement in 2030	14%	35%
Key options*		
Vehicle Efficiency improvement	Negative/Medium cost (50%)	Negative cost (27%)
Sustainable Biofuels	Low cost (20%)	Low Cost (16%)
Public Transport investment	Low/High cost (30%)	Negative cost (36%)
Road and Rail Freight logistics	-	Negative cost (21%)

* Cost categories are as follows: Negative (<$0), Low ($0-25), Medium ($25-40) and High (>$40). All costs are in $/t$CO_2$e.
** WB figures include abatement potential from Biofuels (Sugarcane Ethanol, Sorghum Ethanol, Palm oil biodiesel) to ensure comparability with CMM study.

<u>Abatement Options</u>

CMM (2008) sets out a detailed and phased set of packages in relation to improving efficiency in both light (LDV) and heavy (HDV) duty vehicles. These include improvements in ICE engine efficiency, hybrid and electric vehicle technology and downsizing. They get increasingly expensive as they become more stringent, therefore explaining the relatively high abatement costs associated by 2030. Also identified are switch to sustainable biofuels and expansion of public transport (increased bus use, and electric vehicles).

The World Bank analysis (Johnson et al 2009) looks at improvement in engine efficiency through better inspection regimes and higher fuel economy standards. The WB report does not consider the introduction of hybrid or diesel technologies (due to high mitigation costs). Vehicle efficiency is reviewed in considerably less detail than the CMM study. Also included is the expansion of public transport (to include better urban planning) and expansion of low carbon freight (an area not included in the CMM study). Demand management interventions (parking, congestion charges) were also not considered. Biofuels abatement potential are estimated, but as part of agriculture sector, rather than within transport. This includes, Sugarcane ethanol, sorghum ethanol and palm oil biodiesel, but excludes Jatropha due to high mitigation costs.

<u>Barriers and policy responses</u>

The CMM (2008) study identifies a number of barriers and possible policy responses. These are listed below and mostly relate to the generic issues with costs and availability of emerging clean transport technologies. Land access is identified as a specific issue for Mexico in relation to biofuels consumption. The World Bank (2009) study focuses more on institutional issues such as lack of coordination between different departments at various levels of government, and the lax vehicle emissions inspection and enforcement regime.

Objective	Barriers	Policy option
Improve transport planning	Lack of coordination between agencies (urban, environment, transport) and local, state, federal Incumbent operators and concessions create complex environment Lack of demand studies for mass transit optimisation planning Lack of enforcement of vehicle emission standards	Improve agency coordination. Integrated planning Undertake demand planning for rapid transport Improve inspection regime Increase awareness of health benefits
LDV efficiency	Increase in prices reduces potential demand for new vehicles	Tougher fuel efficiency standards Consumer education Reduction in fuel subsidies Additional funding, capital subsidies, finance subsidies, reduced tax
Increased bus use	Public preference	Increase costs of car transport Remove fossil subsidies, increase taxes Increase vehicle/road taxes Road charging Subsidies for public transport Integrated transport planning
Expand electric transport systems	Long and complex planning process High capital requirements	Streamline planning processes Access private sector capital through PPPs or debt underwriting
Develop alternative power trains	Poor battery technologies for storage High capital costs New charging infrastructure	
Use of Biofuels	Competition for land in Mexico and inefficiency of sugarcane industry Political difficulties to import biofuels from Brazil Need to reengineer fuel distribution networks and vehicle fleet	Move to second generation Biofuels

The WB (2009) study estimates the abatement potential of the transport sector at twice the size of that estimated by CMM (2008), despite excluding a number of technology developments related to new electric vehicle technologies and longer term emission standards.

Nonetheless, both studies conclude that the significant abatement potential associated with the transport sector by 2030 can be met at relatively low cost. This will be primarily achieved through improvement of vehicle efficiency by the introduction of minimum standards and improved maintenance and inspection regimes. Both studies also identify the benefits of increased investment in public transportation systems, with WB (2009) stressing the importance of integrated urban planning in relation to transportation emissions.

Industry

The industrial sector is the second-largest energy end-user in Mexico (after transport), accounting for about 27% of final energy consumption. The largest energy users include cement, iron and steel, chemicals and petrochemicals, mining, and food and tobacco, accounting for about half of all energy use (and most of the higher carbon fuels). It is important to note that cement and iron and steel sectors have less associated abatement potential due to being highly efficient in global terms.

Table A3.5. **Abatement opportunities in the Industry sector** (Values in Mt CO_2e unless otherwise stated)

	CMM (2008)	WB (2009)**
Sector Emissions (Base)	219	199
Sector Emissions (2030)	347	304
Sector emissions contribution (2030)	35%	27%
Reduction Potential (2030)	-85	-68
% Emissions relative to reference year	-24%	-22%
Contribution to total abatement in 2030	16%	14%
Key options*		
Oil and Gas Reduced Flaring	High cost (6%)	-
Oil and Gas cogeneration	Negative cost (6%)	Negative cost (55%)
Oil and Gas CCS	High cost (13%)	-
Oil and Gas EE	Negative/Low cost (10%)	Low cost (5%)
Oil and Gas methane	Negative/Low cost (9%)	Negative cost (2%)
Sugar cogeneration	Negative cost (4%)	Low cost (12%)
Other industry cogeneration	Negative cost (7%)	Negative cost (13%)
Various Industrial EE	Negative/Low/Medium cost (23%)	Negative cost (12%)
CCS Iron and Steel, Chemicals and Cement	High cost (11%)	-
Process Improvements	Negative/Low/Medium cost (6%)	-
Fuel Shift	Negative cost (5%)	-

NB. Above estimates include waste sector emissions (for both studies), but not abatement potential as this is available for CMM only.
* Cost categories are as follows: Negative (<$0), Low ($0-25), Medium ($25-40) and High (>$40). All costs are in $/t$CO_2$e.
** WB splits industry abatement opportunities into oil and gas abatement opportunities and industrial end use efficiency (which includes cogen and industrial motors). In the report, the base year and reference year emissions include all emissions from end-use fuel consumption for heat and all emissions arising from waste and industrial processes. The emissions and opportunities relating to non-industrial energy use have been estimated by the authors, and are not included in the above values.

Abatement Options

There are in excess of 40 individual abatement options identified by CMM (2008). These focus on a number of key sectors where the largest abatement potential can be found, namely cement, chemicals, iron and steel, and oil and gas.

- *Cement:* Increased share of waste and biomass as kiln fuel, use of CCS in new builds and for retrofits, and waste heat recovery for electricity generation.
- *Chemicals:* Opportunities identified include motor efficiency, adipic acid reduction, nitric acid reduction, fuel shift, CCS for ammonia and direct emissions, process intensification, catalyst optimisation, cogeneration and ethylene cracking
- *Iron and steel:* Cogeneration from blast furnace gas, direct casting, smelt reduction, general energy efficiency, CCS, coke substitution with biomass
- *Oil and gas (upstream):* EE from improved behaviour, maintenance and process control, energy efficient retrofit, energy efficiency new build, reduction of continuous remote flaring, CCS
- *Oil and gas (midstream and transport):* Replacing compressor seals, improved compressor maintenance, improved maintenance of distribution network, improved planning and system optimisation
- *Oil and gas downstream refining:* EE behavioural change, improved maintenance and process control, EE investments in process units, cogeneration, CCS

The World Bank analysis (Johnson et al 2009) takes a more limited view of the oil and gas sector than the CMM study. For example, it does not consider gas flaring and venting (this is included in the baseline due to aggressive national action already underway). Other methane mitigation opportunities in oil storage are not considered due to lack of reliable cost and potential data. More general energy efficiency opportunities are also excluded due to lack of cost benefit analysis. Industrial motors are included, but this represents a much narrower industrial energy efficiency focus than the CMM study. For cogeneration, biomass gasification is excluded, and calculations made on the basis of a standard boiler and vapour turbine. Water pumping and pressure recovery opportunities using hydraulic turbines are also excluded due to lack of data.

CCAP (2009), whilst not analysed here in significant detail, develops an detailed methodology for abatement potential calculations in the cement and oil refining sectors. Low cost, high volume opportunities are identified for both industries. Both sectors are analysed over the period 2007-2020 with oil refining offering 23% abatement potential vs. industry benchmarks and cement offering 22% for selected abatement options.

For the cement sector, the analysis analysed a number of abatement options for technical and economic potential and identified energy efficiency (high cost), cement blending (low cost), and wind power (negative cost) as those with the most abatement potential. For the oil refining sector, cogeneration and energy efficiency improvements are all considered to be low-negative cost.

<u>Barriers and policy responses</u>

Beyond the generic barriers identified for low carbon development, the CMM (2008) report identifies relatively few specific barriers and policy responses in relation to the industrial sector, and these are primarily focused on CCS and relate to long term technology and public policy concerns.

Objective	Barriers	Policy option
Encourage Pemex to invest in mitigation	Oil and gas exploration are more commercially attractive than cogeneration to Pemex	Reform of investment frameworks
	High debt levels prevent commercial credit access	Regulatory reform
	Unfavourable conditions for sale of excess electricity to grid	Develop more favourable tariffs and PPAs
	Reliance on oil and gas revenues	Diversify budgetary sources and industrial base
	Investment restrictions by federal government	Allow private sector finance for cogen
CCS	Public concerns over integrity	Public awareness campaign
	Lack of legal framework	Develop regulatory frameworks
	Technology immaturity	Fund demonstration plant
	Commercial immaturity and risk	

The World Bank report instead identifies a number of national and corporate issues specific to Pemex, including the relative lower financial attractiveness of mitigation investments compared to petroleum exploration and the dependence of the federal budget on oil industry revenues. In addition, Pemex faces unfavourable conditions for the sale of surplus electricity from cogeneration to the grid, despite the low cost. Private sector investments cannot be made in gas leakage reduction or refinery efficiency due to legal structures.

CCAP (2009) identifies a number of specific barriers for the oil refining and cement sectors, as well as generic barriers such as high capital investment costs, restrictive legal framework and various non-cost financing constraints. Barriers specific to the cement sector include a lack of renewable energy support mechanisms, high costs of cement plant refit and lack of materials and technologies for cement blending. For the oil refining sector, the analysis is similar to that in CCM (2008) with a focus on regulatory and budgetary barriers that prevent Pemex from investing in non core activities and encourage oil production, rather than operational efficiency. CCAP (2009) is further refining policy options to deliver the envisaged abatement potential.

Industrial abatement opportunities offer a relatively small proportion of total abatement potential at the national level. Nonetheless, they are important for a small number of strategic industries that provide significant tax revenues, and face considerable international competitiveness challenges. Cogeneration across all industry segments and methane capture in the oil and gas industry are identified by both reports as areas of low cost potential. Targeted energy efficiency measures such as investment in high efficiency motors are also identified. Nonetheless, there are considerable policy challenges related to the high level of regulation and state ownership in these sectors. This may result in the abatement potential being considerably more challenging to achieve than the economic potential would indicate.

Buildings

CMM (2008) estimates that the buildings sector will contribute 5% of emissions in 2030 but could account for 7% of total abatement potential. The important factor concerning opportunities in this sector is that they tend to be negative cost. The World Bank analysis shows similar levels of abatement potential although lower energy efficiency potential; the accuracy of this comparison is difficult as the World Bank analysis also includes emissions from industrial energy use.

Table A3.6. Abatement opportunities in the Building sector (Values in Mt CO_2e unless otherwise stated)

	CMM (2008)	WB (2009)**
Sector Emissions (Base)	34	51
Sector Emissions (2030)	49	77
Sector Emissions Contribution (2030)	5%	7%
Reduction Potential (2030)	-35	-48
% Emissions relative to reference year	-71%	-62%
Contribution to total abatement in 2030	7%	10%
Key options*		
Energy efficiency	Negative cost (100%)	Negative cost (25%)
Renewable heat		Negative cost (51%)
Industry (cogen)		Negative / low cost (17%)
Industry (efficiency)		Negative cost (8%)

* Cost categories are as follows: Negative (<$0), Low ($0-25), Medium ($25-40) and High (>$40). All costs are in $/t$CO_2$e.
** Industry measures were included in this category called energy end-use (excl. transport); however, these have been excluded based on assumptions derived from the report

Options cited by CMM (2008) include energy-efficiency packages for new buildings, lighting controls, and switching to more efficient lighting (e.g. light-emitting diodes (LEDs)) and appliances. Solar water heating is also an option to replace gas water heaters on retirement. The World Bank analysis (Johnson et al 2009) cites similar measures.

Both analyses indicate significant barriers associated with such options, an important caveat in translating this potential to actual savings. CMM (2008) estimates that 24% of potential in 2030 is from energy efficiency options (across all sectors), and that these are not easily captured for a range of reasons.

- ‘Principal-agent’ problems—neither builders, owners, nor tenants of buildings have incentives to make efficiency investments
- Lack of information on options, and potential returns
- Irrationally high returns expectations
- Too small to be a priority
- Access to capital
- Energy subsidies and other distortions

A number of policy initiatives for this sector are discussed in the different studies for delivering emission reductions/ listed below. They focus on mandatory standards (for marketed appliances), removal of fuel subsidies and financial incentives to help private household or business investment.

Objective	Barriers	Policy option
Improving appliance efficiency	Subsidies Lack of consumer information	Mandatory efficiency standards Industry wide benchmarking Removal of electricity subsidies Consumer information (e.g. through labelling) Substitution programmes
Introduce LED lighting	Upfront costs Social inertia	Mandatory standards
Energy efficiency for new build	Principal agent problem Higher costs Enforcement Subsidies	Mandatory standards Financial support Removal of subsidies Training for local enforcement of code

This sector will be an important contributor to mitigation efforts in future years because it offers many negative cost opportunities. However, implementation will be key to actually realising this potential as the barriers are often significant. It is argued later in this report that barriers for this type of measure are in large part due to the underestimation of costs in the cost curve analysis. In addition, while not necessarily having the same level of capital to raise as for example a new power plant, implementation has to be undertaken across a wide range of stakeholders, and is therefore more challenging on that basis than a single infrastructure project.

Agriculture

There is a divergence between the studies concerning the contribution of the agriculture sector to emissions, both current and projected – and hence a large difference in assumed potential. CMM (2008) estimates the emissions contribution from this sector at 10% of total emissions, with a possible 11% contribution to abatement potential. It appears that estimates of emissions from this sector are sourced from US EPA[53]. Key options are listed in Table A3.7 below, and are more extensive than those cited in the World Bank analysis, which are limited to zero-tillage maize based on the criteria for including options in the analysis (Biofuels are mentioned but in this sector but have been considered in the transport sector).

Table A3.7. Abatement opportunities in the Agricultural sector (Values in Mt CO_2e unless otherwise stated)

	CMM (2008)	WB (2009)
Sector Emissions (Base)	77	33
Sector Emissions (2030)	101	33
Reduction Potential (2030)	-61	-2.5
% Emissions relative to reference year	-60%	-8%
Contribution to total abatement in 2030	11%	1%
Key options*		
Crop / Grassland management	Negative cost (50%)	Negative cost (100%)
Restoring degraded land / Reducing drainage	Negative / Low cost (31%)	
Enteric emissions (feed / vaccination)	Negative / Low cost (19%)	

* Cost categories are as follows: Negative (<$0), Low ($0-25), Medium ($25-40) and High (>$40). All costs are in $/t$CO_2$e.

Co-benefits for agricultural measures are cited in CMM (2008). Abatement measures can often increase agricultural productivity, boosting local incomes; Antimethanogen vaccines and feed

[53] Environmental Protection Agency (EPA; US) (June 2006) "Global Mitigation of Non-CO2 Greenhouse Gases", Report 430-R-06-005, Section III Waste, Section IV Industrial Processes, Section V Agriculture (available at http://www.epa.gov/climatechange/economics/international.html)

supplements for cows could raise dairy and beef productivity by 5 percent. Better cropland management can reduce use of fertilisers by making them more efficient and increase crop yields (by up to 11%). Increasing productivity can also reduce land requirements, reducing demand for forested land.

Carbon financing for such measures is difficult due to the problems with estimating carbon removal, although this is being closely studied in view of emerging mechanisms. Other barriers include lack of institutional capacity, poor information for famers, uncertainty of benefits or cultural barriers e.g. in Mexico, zero-tillage maize runs counter to the traditional use of maize stubble as forage for cattle. Agriculture is also very fragmented, with large numbers of stakeholders. Incentivising change and overcoming long standing practices across this large and diverse sector is challenging.

The uncertainty around abatement potential (highlighted in CMM 2008) and many barriers concerning implementation mean that policy needs to be creative, and co-benefits for (or from) other policy objectives, of which there are many, need to be emphasised (Smith et al, 2007).

Whilst there are some differences in the emissions baseline and potential between studies, there is consensus that this sector does offer negative or low cost options that will be important in moving to a lower carbon pathway. However, as with energy efficiency measures more broadly, it is probable that the costs are underestimates, not taking account of policy / administrative costs which could be significant, skewing the analysis towards a more optimistic outlook.

Forestry

The forestry sector in Mexico provides a significant level of abatement potential in 2030, according to the analyses reviewed. In the CMM (2008) analysis, forest emissions are kept at current emission levels. These differ significantly from the World Bank estimates,[54] which are significantly higher. From both these studies, emission reduction estimates are between 55-75 Mt CO_2e, and primarily from reducing deforestation and afforestation / reforestation (in equal measure). In the main, these measures are considered low cost.

The CMM reduction potential estimates are double the projected emissions, due to increased forest cover (from afforestation / reforestation), from 65 million hectares today to about 70 million hectares in 2030.

Table A3.8. Abatement opportunities in the Forestry sector (Values in Mt CO_2e unless otherwise stated)

	CMM (2008)	WB (2009)
Sector Emissions (Base)	29	67
Sector Emissions (2030)	29	54
Reduction Potential (2030)	-55	-75
% Emissions relative to reference year	-190%	-139%
Contribution to total abatement in 2030	10%	16%
Key options*		
Reducing deforestation	Low cost (53%)	Low cost (42%)
Afforestation / Reforestation	Medium cost (42%)	Low cost (48%)
Improved management	Medium cost (5%)	Negative cost (10%)

* Cost categories are as follows: Negative (<$0), Low ($0-25), Medium ($25-40) and High (>$40). All costs are in $/t$CO_2$e.

Two main options exist in the forestry sector: protecting existing stock through reduced deforestation / better management and increasing forest cover, through afforestation. Much of the

[54] CMM (2008) estimates by Richard A. Houghton (Woods Hole Research Center) at 29 Mt a year today based on FAO 2005 forest area data

recent discussions internationally have been how you set up a scheme that allows payment by developed countries for forest protection and enhancement. Further challenges are then how you implement such schemes on the ground, and monitor whether they are achieving the stated objectives. The encouraging aspect of this area of mitigation is that for reducing deforestation, measures appear to be relatively low cost, based on estimates of opportunity costs for foregoing alternative activities and keeping forest intact, and the cost of implementation and monitoring. Higher costs are observed for afforestation; in addition, the benefits of such a measure are longer to realise due to time it take for tree growth.

Key barriers (listed below) include resolving land ownership disputes, establishing the financing scheme, and ensuring permanence of any reductions associated with such measures. Like with agriculture, implementing such measures requires coordination across many different stakeholders, making such potential challenging to realise.

Objective	Barriers	Policy option
Reduce deforestation	Land tenure issues Conflicting forestry-agriculture objectives Absence of financing scheme Lack of monitoring Issue of permanence	Resolve tenure disputes Ensure permanence through institutional restructuring Support financing scheme in negotiation Enhance capacity for monitoring small-scale deforestation and enforcement
Promote afforestation, reforestation, and forest management	As for above option	Strengthening of existing programmes

Appendix 4. Case Study 2: East Africa - Exploring co-benefits of low carbon patterns of growth

East Africa is an interesting case study example for different reasons to those observed for Mexico. It is a low income region for which the challenges of establishing low carbon patterns of growth will be different, including costs of mitigation. It is a low emitting region, and therefore different from other countries considered in this stocktake, with particular vulnerability to climate change impacts, therefore making climate resilience additionally important. The objective of looking at this region was to see if there are specific opportunities / challenges for low income countries in taking forward a low carbon growth strategy.

This case study focuses on insights from a recently published RECCS report by SEI (2009b) on the economics of climate change in East Africa. It has been included because of the very different low income perspective it affords, with most studies reviewed in this stocktake focusing on middle income countries.

There are some key differences in challenges for low income countries concerning moving towards a low carbon patterns of growth as reflected in the East Africa study:

- Rapidly evolving demography, relating to population growth and urbanisation
- Different energy resource base and consumption profile, with high levels of biomass consumption and greater reliance on imported fossil fuels
- Large agriculture sector, making this an important emitter and therefore focus for mitigation options
- Low emissions from transport sector but with rapid growth in the near / medium term

Concerning political and economic capacity, differences again emerge:

- Access to capital can be difficult, particularly with less potential for funding from a relatively smaller private sector
- Institutional capacity often less able to deliver low carbon growth opportunities, or access opportunities for carbon financing

The important issue to flag here is that the challenges faced by LICs in pursuing a lower carbon pattern of growth are different. In addition, the priority is likely to focus on slowing rates of emissions growth in the near term (but allowing for absolute growth) but in later years moving to a situation where absolute cuts can be afforded and may be desirable (depending on international agreements in place). Therefore, any low carbon growth strategy is likely to be different from that adopted in a MIC.

The focus of the Kenya assessment (within the wider East Africa study) was to highlight key opportunities that could put Kenya on a Low Carbon Growth Path, and the potential costs. This was therefore not a comprehensive assessment of mitigation potential and costs but rather a case study approach across a selection of mitigation opportunities.

Mitigation opportunities and their co-benefits

The mitigation opportunities assessed for Kenya were assessed within a MACC framework, and are presented as such in Figure A4.1. Key opportunities that were assessed included improved efficiency of road vehicles, improved biomass stoves, geothermal generation, renewable generation distributed technologies and improved agriculture practices. From these selected mitigation options, it is clear that there are a range of opportunities that could be considered negative or low cost i.e. over 80% of the stated potential can be delivered at less than $20/tCO$_2$. This is with options discounted at 10%, which is much higher than typically seen in other MAC curve analyses.

From the selected low carbon options, there is the potential to produce savings of 22% relative to the baseline in 2020 (as shown in Figure A4.2). The inclusion of agriculture sector emissions results in an overall reduction of 13%. This is lower than the 22% reported above due to the high level of the emissions from this sector. It is likely that a comprehensive review of opportunities could result in significantly higher estimates of emission reduction potential (as seen in other countries in this stocktake) at similar costs of abatement.

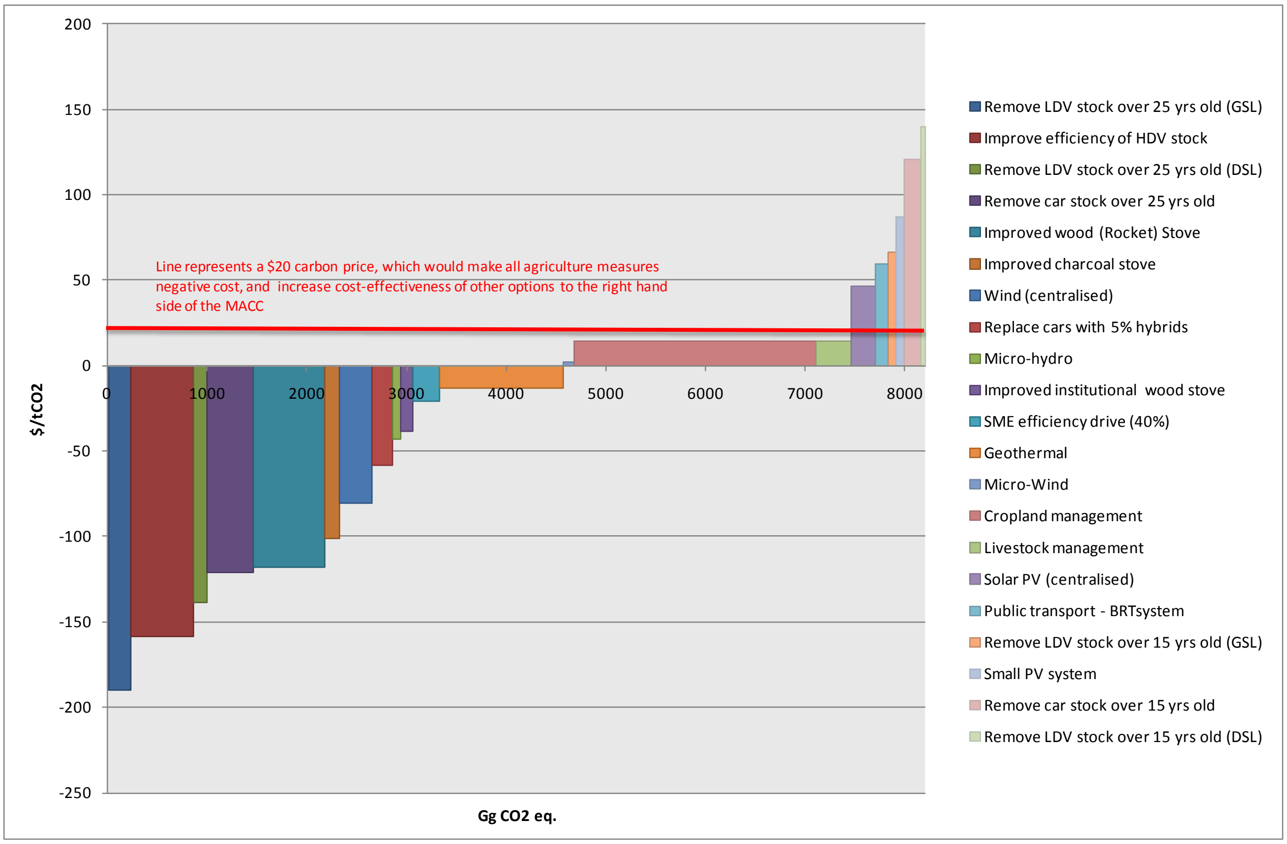


Figure A4.1. Indicative MAC curve of selected abatement measures for Kenya in 2020 (10% discount rate assumed). NB. 8000 GgCO$_2$e is equivalent to 8 MtCO$_2$e. (GSL refers to petrol, vehicles, DSL to diesel)

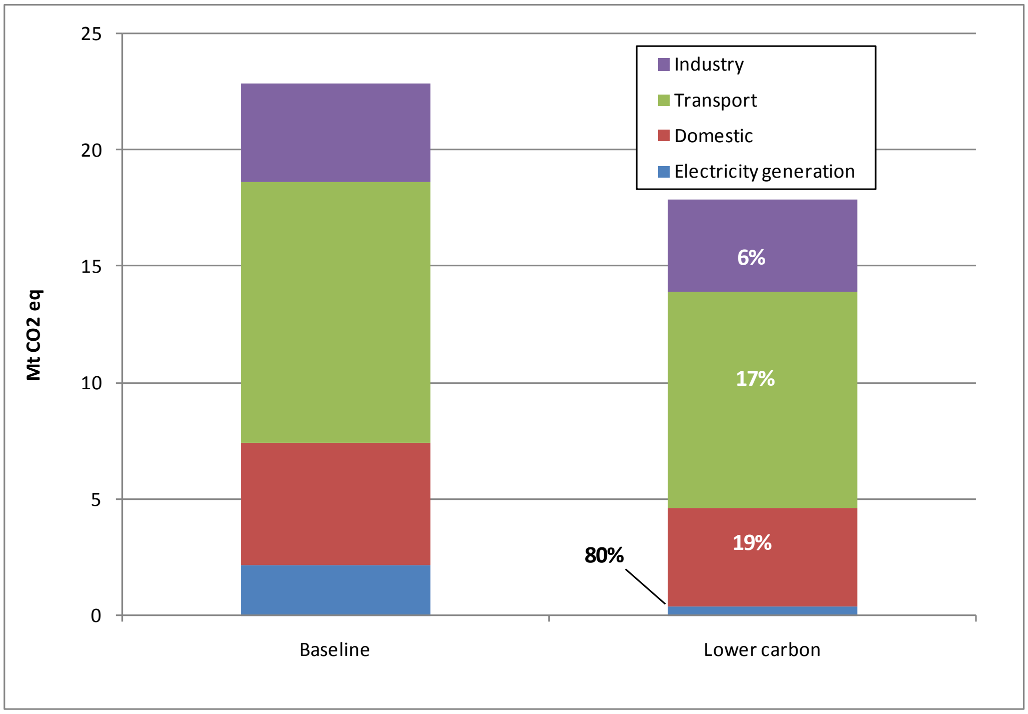


Figure A4.2. Kenyan emission in 2020 under the baseline and *lower carbon* case

* The % labels in the *Lower carbon* case denote % reduction by sector relative to baseline

With some of the lowest absolute and per capita levels in the world, it is unlikely that Kenya is going to be introducing mitigation measures simply as part of a low carbon strategy. Rather, Kenya may consider the co-benefits of introducing a lower carbon option when thinking through policy options in its development plan. The measures shown in the above cost curve are listed below in Table A4.1, identifying what the policy driver might be for introducing a given option, and the co-benefits of the measure if indeed the measure was being appraised for carbon mitigation. The potential co-benefits are significant across most of the measures.

Table A4.1. Low carbon options for Kenya and their co-benefits

Option	Policy driver	Co-benefits (as a GHG mitigation measure)
Expanding use of renewables (centralised)	Expanding capacity to meet future needs based on strong resource base	Reduce reliance on / payments for foreign fossil imports More cost-effective across many types Leverage carbon finance to fund investment Potential to build regional expertise, and export No air quality pollution
Decentralised generation from renewable	Rural electrification	Lower cost than alternative fossil generation Limit requirements for expensive grid expansion Sustainable energy for local economic growth No air quality pollution
Introducing improved stoves	Reduce biomass demand	Reduce indoor air pollution, and therefore health impacts Reduce fuel costs Protecting fuel Saving economic / leisure time (wood collection)
Improving efficiency of road transport fleet	Reducing reliance on fossil fuel imports	Reduce reliance on / payments for foreign fossil imports Reduce costs of vehicle use Reduce air pollution Reduce road traffic accidents (due to newer cars)

Planned public transport scheme for Nairobi	Meeting urban transport demand	Reduce congestion Reduce air and noise pollution levels Save travel time / enhance productivity Reduce road traffic accidents
Tackling energy inefficiency in SMEs	Reducing industry fuel costs, increasing competitiveness	Reduce fuel costs, enhance competitiveness Enhance energy security Reduce air pollution
Improve livestock and cropland management	Improve agriculture productivity and reduce land degradation	Protect / enhance arable land quality Safeguard rural livelihoods Increase economic productivity of sector
REDD / Afforestation	Protect forestry-dependent economy and energy supply security	Protect biodiversity, and dependent sectors Ensure security of wood fuel supply

The analysis suggests that many of the above measures are cost-effective, and can save money for the economy rather than add significant financial burden, whilst being consistent with development objectives. However, fully understanding the co-benefits in the context of other policy objectives will be key to justifying such investments in a low emitting country. Further work is required to develop other options and provide a more comprehensive picture of the different opportunities, building on this emerging picture of a lower carbon future.

Challenges to low carbon growth in Kenya

As with Mexico, this analysis suggest that many cost-effective opportunities exist that could help deliver low carbon growth. However, it is important to highlight a number of issues that could increase the challenge of realising low carbon growth:

- The rapid rise of transport demand will inevitably lead to significant growth in emissions, even with efficiency gains. The challenge will be to provide affordable public transport systems in urban areas, again made difficult by the high rate of urbanisation projected.

- Implementing lower carbon agriculture measures is challenging, particularly due to the fragmented land holdings, and consequently high number of stakeholders. Whilst the technology cost of such measures is generally seen as low, implementation and monitoring costs can significantly increase average mitigation costs. Raising carbon finance from such measures is also a challenge, again due to issues of permanence and monitoring and high transaction costs.

- Increased demand for modern energy services through switching away from biomass is also likely to drive up emissions. However, this growth is likely to be offset to some extent by the availability of low carbon electricity.

- Based on the study projections, Kenya will become increasingly reliant on hydro generation, primarily due to the envisaged imports of hydro generated electricity from Ethiopia. There is an issue of climate resilience here; as water resources become scarcer due to increased demand and less reliable due to climate variability, hydro generation potential could reduce and lead to switching to higher emitting rental power or other fossil based generation. However, further regionalising supply could reduce the risk of over reliance on a single import source – see Box below.

Increasing regional co-operation on electricity transmission and supply in East Africa

The regionalisation of the electricity network may also hold prospects for countries being able to benefit from the sale or use of low carbon electricity in reducing per capita emissions. Regional markets are projected to become increasingly important for Kenya if forecast demands are to be met. Imports could meet 35% of total demand in 2017, rising to over 50% by 2021. This then drops to 43% by 2025 and 32% by 2029 as the contribution from domestic geothermal generation increases. A major source of the imports will be Ethiopia, the proposed interconnector for which is at the feasibility assessment stage.

Some imports to Kenya already come from Uganda (between 30-50 MW); however, much greater regional integration is being considered by the East African Community (EAC). A study has been undertaken by Kenya, Uganda and Tanzania, assessing the viability of interconnected grids. Based on this study, a pooling arrangement is being pursued under the EAC and the proposed East African Community Power Pool (EACPP). In the wider Eastern African region, increased regional power grid integration through the Eastern African Power Pool (EAPP) is also being considered. There has been assessment of linking in with the Southern African Power Pool (SAPP); an interconnector project with Tanzania is near inception using Dutch funding. Both this interconnector and the Ethiopia project are projected (in context of the Least Cost Power Development Plan (LCPDP)) to be completed between 2012 and 2014.

Another important regional initiative called the Nile Basin Initiative (NBI) has been assessing the feasibility of greater integration of electricity distribution systems across NELSAP countries.[55] Pertinent to Kenya under this initiative is the second interconnector with Uganda, which will enhance power exchange between the two countries particularly after Uganda increases its capacity through planned hydropower projects.

In addition, there are a number of key concerns for low income countries in general. Firstly, access to upfront investment capital to capture even negative cost options can be highly constrained against other competing budgetary priorities. Secondly, in order to offset the financing barriers, carbon mechanisms such as the CDM, should have provided risk capital, but in practice low income countries have failed to take advantage of these mechanisms, with the bulk of finance (both by number of projects and total value) flowing to industrialising countries such as China and India. Thirdly, this reflects a lack of capacity, both in government and the private sector, to structure projects in order to attract private sector finance or carbon market credits. Sponsor issues and perceived corruption compound the limited mitigation flows.

Distributional impacts of any low carbon strategy are key with development goals focused on equitable growth, and alleviating poverty across all parts of the community. The RECCS work in East Africa has undertaken an assessment of the distributional consequences of mitigation policy and finds that the degree of sector focus could have very different benefits for different groups, and consequently for inequalities. It broadly found that electricity projects would be likely to benefit already wealthier/urban groups, whilst forestry and agriculture projects had more potential to benefit poorer/rural populations. However, significant stove improvement programmes would benefit the rural poor, through saving on fuel costs and reducing indoor air pollution. In other countries / regions, it is clear that distributional effects will arise but that these will be different based on mitigation action implemented, and that policy makers need to be proactive in reducing regressive effects.

Finally, the vulnerability to climate impacts require that low carbon patterns of growth are integrated with investment planning for adaptation, so that synergies and linkages between the two are fully exploited, conflicts avoided and costs reduced. A good example is planning for future

[55] Nile Equatorial Lakes countries (NELSAP) covering Uganda, Rwanda, Burundi, Tanzania, Democratic Republic of Congo (DRC) and Kenya

power generation, both in respect to supply and demand. On the supply side, the system cannot be too exposed to climate variability; a particular concern related to imported hydro and concerns about water resources was noted in the Kenya example. On the demand side, increased demand for cooling could increase demand, and change peak requirements that the system has to respond to. In conclusion, it is important that both are developed in an integrated way.

Appendix 5. Methods for Assessing the Economics of Climate Change and Adaptation Costs and Benefits

A wide range of approaches have been used for assessing climate change and adaptation, outlined in the box.

Climate Change Impact and Adaptation Assessment

There are a number of broad analytical approaches for climate change assessments. As outlined by the IPCC AR4 WGII, Chapter 2 (Carter et al, 2007) these include:

- Synthesis. This is a similar process to an IPCC review. It does not undertake new work, but collates and interprets existing information with expert consultation.
- Impact assessment. This links climate and socio-economic projections with sector specific assessments of impacts and sometimes economic values.
- Integrated Assessment. This involves integrated modelling, differentiated from impact assessment by its top-down nature and/or by the cross-sectoral linkages and feedbacks.
- Risk assessment. This uses probabilistic data to describe key variables. It may also use different metrics, defining 'impacts' in relation to acceptable or tolerable levels of risks.
- Vulnerability assessment. This first focuses on existing socio- and economic vulnerabilities, inequalities and adaptive capacity, and then considers the effects of future climate change.
- Stakeholder and participatory approaches. While stakeholder consultation is part of all the above approaches, it is also possible to base analysis on direct participatory approaches.

The IPCC also identifies a broad range of methods for adaptation assessments, which include:

- Scenario-based approaches, where climate risks are scoped qualitatively or quantitatively and adaptation options are identified.
- Technological assessments, which extend to include future adaptation options (that differ from those currently available) under alternative socio-economic scenarios.
- Normative policy assessments, which use the outputs of vulnerability and/or risk assessments to assess acceptable adaptation options or strategies.
- Risk management methods, which combine current risks to climate variability and extremes with projected future changes, using alternative decision support tools to assess adaptation.
- Anthropological and sociological methods, which identify learning in individuals and organisations and the processes needed to effectively adapt to climate change risks.
- Adaptive Capacity Assessments, which considers investment in adaptive capacity in a way similar to adaptation options.
- Cost-Benefit Analysis (CBA), where the benefits and costs of adaptation are expressed in monetary terms, and the net benefits or costs calculated.
- Non-formalised cost-benefit analysis, where costs and benefits are compared, using monetary and non-monetary terms as part of multi-attribute analysis.
- Cost-effectiveness Analysis (CEA), which is often used to assess alternative adaptation options or the least-cost path to reaching a given target (e.g. a predefined threshold level).
- Multi-criteria analysis (MCA), which allows consideration of quantitative and qualitative data together using multiple indicators.
- Portfolio Theory, which borrows principles from financial investment to maximise the expected rate of return for a portfolio as a whole rather than individually.
- Participatory techniques, which base analysis on direct participatory approaches.

A number of these can be used to consider the economics of climate change and adaptation. These are briefly described below.

Economic Integrated Assessment Models (IAMs)

Integrated assessment is a generic term used to describe the integration of different models, methods or sectors within a single analysis or analytical model. There are a large number of IAMs with around 30 or so global IAMs which have a focus on economics. However, only a handful of these include adaptation and most of the cited studies on global adaptation come from the PAGE model and the DICE/RICE/AD-RICE family of models.

These models combine the scientific and economic aspects of climate change within a single, iterative analytical framework, linking economy, emissions, climate, and economic costs together with feedbacks. To make analysis of economic costs manageable, they use simplified climate projections and simplified impact relationships which link changes in climate to economic damage at a very highly aggregated level. The models have mitigation modules that allow the analysis of the costs and benefit of climate policy and even optimal policy.

A number of them also have adaptation modules or functions. The PAGE model can assess the economic costs of climate change with and without adaptation. Adaptation is represented by parameterized functions, dis-aggregated by type of effect and region, which reduce the severity of economic costs up to a certain level of temperature change. It can also compare the benefits of adaptation against costs (as a net present value), though it cannot optimise adaptation and mitigation. Within the AD-RICE model, it is possible to disaggregate the damage function into the constituent elements of adaptation costs and residual damages. While adaptation and mitigation are not modelled as substitutes, the model can select a preferred combination of mitigation and adaptation in response to climate impacts.

Investment and Financial Flow Analysis

These studies provide an alternative approach to look at adaptation financing needs. They generally consider the current or future levels of investment or financial flows: in the context of developing countries, this focuses on Official Development Assistance (ODA) and concessional finance, Foreign Direct Investment (FDI) and Gross Domestic Investment (GDI).

This portfolio of investment is then considered in terms of the sensitivity to climate change – in the simplest studies, as a simple proportion of the total flow – in more detailed studies, on a sector by sector basis. The final step is to estimate the increase in investment to ‘climate-proof’ the investment, more accurately to enhance the resilience of the investment against future climate change. In the simplest studies, this is applied as a simple % increase or mark-up: in more detailed studies a more thorough analysis of the likely increase or analysis against adaptation costs for sectoral investment can be made.

More detailed IFF guidance has now been developed for implementation at national level, notably within the UNDP guidalines. This has a greater focus on looking at current and future plans and building in more detailed analysis of the likely increase in financing needs for mitigation and adaptation. In this case, once the scope of a sector is clearly defined, the relevant investment costs for that sector are projected for two future scenarios:
1) a baseline scenario, which reflects a continuation of current policies and plans, i.e., a future in which no new measures are taken to address climate change (a “business-as-usual” scenario), and

2) a climate change scenario, in which new mitigation or new adaptation measures are taken (an "adaptation scenario").

The investment costs of the baseline and mitigation (or the baseline and adaptation) scenarios are then compared to determine the changes in investments needed to adapt to the impacts to the sector. Note that changes in investments may include new funding and shifts in existing investments (reallocations). Investment flows (IF) are defined as the capital cost of a new physical asset with a life of more than one year. A financial flow (FF) is defined as an ongoing expenditure on programmatic measures.

The method is flexible. For example, for adaptation, models can be used to develop and define the climate change scenario. Otherwise, a sectoral plan, a projection of trends, or the current situation (assuming no change), or some combination, can be used. Prior work on climate change (e.g., National Communications, TNAs, NAPAs, GHG mitigation assessments, vulnerability assessments) can be use in this step.

Wider economic costs and computable general equilibrium models (CGE)

General equilibrium approaches (and computable general equilibrium models, CGEs) allow for linkages between all sectors of the economy. These economic modelling approaches quantitatively represent and trace through the consequences of inter-linkages between economic sectors and thus the effects from one sector on all others. They can therefore consider the entire economic system and consider how direct (first-order) effects of climate change have indirect (second-order) effects and how these in turn may exacerbate or reduce the size of first-order impacts. They can be used to look in detail at the national level as well as to assess the effects to countries or regions as part of a larger global system. They are primarily used to look at the economic impacts of climate change, though there are emerging examples where they have been applied to adaptation. This has been through two approaches.

The first has been to look at the changes in absolute and relative prices from climate change impacts and the wider economic implications as a form of autonomous adaptation, in relation to adaptation of a market-based economic system. Adjustments in the size of capital stock resulting from climate impacts are included in this aspect of autonomous adaptation – see Carraro and Sgobbi (2008), who modelled climate change impacts over a number of economic sectors in Italy. Second, the economic impacts of forms of planned adaptation can be modelled. This has mostly been applied in the context of sea-level rise, where hard coastal defences, such as sea-walls and dykes, are modelled. Hard defences are particularly well-suited to macro-economic modelling since costs are relatively easy to identify and adaptation responses are likely to be sizeable, quantifiable and expressed through changes in market output. In such models, these adaptation costs are modelled as investments in the economy; their effectiveness is determined by the degree to which they are assumed to crowd out other, productive, investment (see Bosello et. al. 2007).

The strengths of these models are that they assess wider economic effects that cannot be assessed by other approaches. However, such models lack a detailed sectoral representation and they are heavily dependent on the assumptions and calibration made, requiring knowledge of the detailed structure of the economy, a substantial data inventory and a high degree of sophistication. They do not capture non-market effects (at least easily). A key challenge is in their use for future time periods, due to the need to consider the economic linkages and factors, and they are not really applicable for longer-term assessments because of these uncertainties. Further, the adaptation that can be included is limited by whether it can be expressed in market terms. Both climate change and adaptation is represented through aggregate functional forms and such models provide aggregate outputs which are not applicable for detailed or local scales.

Impact assessment for climate change and adaptation

One of the more commonly used 'bottom-up' approaches in national studies is the impact assessment method. These generally start from climate change projections and socio-economic scenario data for a number of time-periods and then quantify physical impacts using impact relationships (sometimes with sectoral models), finally assigning economic values to the physical impacts quantified. Traditionally, this approach has had a strong sectoral focus. The level of physical impact and economic assessment varies by sector, but is usually strongest in the areas of sea level rise and river flooding, agriculture, health, energy and water resources.

Such studies can link through to an impact assessment based adaptation analysis. These follow scenario based approaches where adaptation options are identified to address the economic costs and then some form of economic analysis undertaken, either with explicitly quantification and valuation of benefits (and the potential for cost-benefit analysis) or through some assessment of the costs of reducing impact levels in relation to tolerable or acceptable levels (e.g. risk assessment and cost-effectiveness analysis).

Adaptation Assessment

adaptation assessments adopt a different approach to the national scenario-based climate change impact assessment approaches often considered above (which consider risks, adaptation options that currently exist, and then treat adaptation as an output). In contrast, adaptation assessments consider risks over a range of policy and planning horizons for specific activities and regions. They often focus on risk management by examining adaptive capacity and the adaptation measures required to improve the resilience or robustness of a system exposed to climate change.

Methods for economic assessment of climate change and adaptation

Approach	Description	Examples	Advantages	Issues
Economic Integrated Assessment Models (IAM)	Aggregated economic models. Values in future periods, expressed £ and %GDP and values over time (PVs)	Global studies (e.g. Hope et al, 20009). Regional/National studies (e.g. ADB SE Asia RECCS; SEI for East Africa RECCS)	Provide headline values for raising awareness. Very flexible – wide range of potential outputs (future years, PV, CBA).	Aggregated and low representation of impacts, generally exclude extreme events and do not capture adaptation in any realistic form. Not suitable for detailed national planning.
Investment and Financial Flows (I&FF)	Financial analysis. Costs of adaptation (increase against future baseline)	Global studies (e.g. UNFCCC, 2007) National Studies (e.g. UNDP I&FF) – will emerge later this year.	Costs of adaptation in short-term policy time-scale. More rigorous than NAPAs. Easier to apply even without detailed analysis of climate change.	No specific linkage with climate change or adaptation (though can be included). No analysis of adaptation benefits or residual impacts.
Computable General Equilibrium models (GCE)	Multi-sectoral economic analysis / trade considerations for sector (agriculture). £ values and GDP in future year.	National level - Brazil RECCS (2009) Sector e.g. Namibia natural resources (IIED, 2007), Tanzania agriculture (IIED, 2009), Malawi agriculture (2009), Zambia agriculture (2009)	Capture cross-sectoral linkages in economy wide models (not in other approaches). Can represent global and trade effects.	Aggregated representation of impacts and can only capture adaptation in market form. Omits non-market effects. Not suitable for detailed national planning.
Impact	Impacts of climate	Sectoral assessments	More sector specific	Not able to represent

assessment (functions and scenario based assessment)	in physical effects and economic values with sectoral models in units and £ in future year, and costs and benefits of adaptation	in East Africa RECCS (SEI, 2009)	analysis. Provides physical impacts as well as economic values – therefore can capture gaps and non-market sectors.	cross-sectoral, economy-wide effects.
Impact assessment - shocks	Use of damage loss relationships from historic events (statistics and econometrics) applied to future projections of shocks	Aggregate level, e.g. EACC (2009) Sector level, e.g. EAC study (2009)	Allow consideration of future climate variability (in addition to future trends)	Issues of applying historical relationships to the future. Issues with high uncertainty in predicting future extremes.
Impact assessment - econometric based	Relationships between economic production and climate parameters are derived with econometric analysis and then applied to future scenarios.	National level, e.g. GTZ, 2009 Household level or sector (agriculture).	Can provide information on overall economic growth and allow analysis of longer-term effects. Provide greater sophistication with level of detail.	Very simplistic relationships to represent complex parameters. No information on casual attributes that affect growth. Issues on whether relationships can be applied to future time periods with confidence.
Vulnerability assessment	Focuses on existing socio- and economic vulnerabilities, inequalities and adaptive capacity, then considers climate change	Numerous studies – though not focus here	Centres analysis within existing socio-economic conditions and decision-making structures, consideration distributional and equity issues and adaptive capacity.	Lack of common metrics makes prioritization challenging. Very difficult to frame in economic terms. Very low coverage against economic valuation aspects.
Risk management	Current and future risks to climate variability. Probabilistic approach.	Climate Proofing: A Risk-based Approach to Adaptation (ADB) Pacific developing member countries.	Well suited for current and future risks and uncertainty, Often used with Cost-effectiveness	Extra dimension of complexity associated with probabilistic approach. Limited applicability: focused on thresholds (e.g. risk of flooding).
Adaptation assessments	Risks over a range of policy / planning horizons. Often linked risk management and adaptive capacity.	No real economic examples. Emerging number of adaptation assessments.	Stronger focus on immediate adaptation policy needs and decision making under uncertainty and greater consideration of diversity of adaptation options (including soft options) and adaptive capacity.	Less explored in relation to economic assessment

Appendix 6. Towards future low carbon, climate resilient growth studies

It is a very positive step that a range of different studies on mitigation opportunities in the developing world have emerged, particularly recognising that developing world countries are part of a global solution to reducing GHG emissions. Having undertaken a broad review, there is an important opportunity to take stock of how issues have been approached and make some recommendations about what future studies should consider. Highlighting limitations of the evidence base (in respect of the objectives set out for this stocktake) and recommending research to plug gaps is the focus of this section.

Accounting for the full costs of mitigation measures

There is a concern that the representation of costs often suggests that a low carbon pathway is both achievable and very affordable, with many apparent low cost opportunities. Whilst this is an important insight, and consistently presented across many studies, we believe that there are a number of other factors which could significantly increase costs.

As discussed in section 4 of this report, most cost curves do not include the costs of implementation, and therefore do not fully reflect often high costs policy and transaction costs. Often such costs are highest for those measures which appear most cost-effective. Barriers are discussed although their non-representation in the financial analysis is problematic, often resulting in a more optimistic outlook than might reasonably be expected.

Costs of implementation can be significant; these include the costs of administering a policy but also the transaction costs associated with different options. Two studies from the UK, Enviros (2006) and Ecofys (2009) highlight this issue. Ecofys (2009) suggests that hidden costs not usually captured in financial analysis can significantly increase the payback period for selected household energy efficiency measures. Enviros (2006) analysis suggests that the inclusion in the analysis of additional hidden and missing costs can reduce cost-effective opportunities by between 10-30% in the buildings sector.

Another important barrier cited in Enviros (2006) was also expected payback period, with householders for example wanting payback on investment within two years. Based on this criteria, cost-effective (negative cost) potential was reduced by over 90%. To reflect these issues, hidden and missing costs can be added into the cost curve analysis, or higher hurdle rates (high technology-specific discount rates to account for market risks and consumer preferences) can be introduced to reflect difficulty in promoting take-up.

Effective policy measures are difficult to design and implement, and often require financial incentives which add to costs. The fact that significant energy efficiency opportunities still exist in many developed countries many years after strategies introduced to address GHG emissions reinforces this point. Finally, getting household and private sector buy-in to take up energy efficiency options is difficult; Enviros (2006) suggests that one of the most significant reasons is due to perceived risk of delivery; either they do not believe such savings can be realised or expect larger and quicker savings (returns on investment). Social factors are also important; individuals or companies may distrust new technologies, may not buy into the green agenda or simply do not want the hassle.

More work needs to be undertaken to incorporate these barriers into cost-effectiveness analysis, to provide more realistic assessments of the actual costs of realising potential across different sectors. Some analyses are starting to pick up on some of these issues; CMM (2008) considered the issue of capital intensity as a barrier to uptake of different measures including lower cost energy efficiency measures.

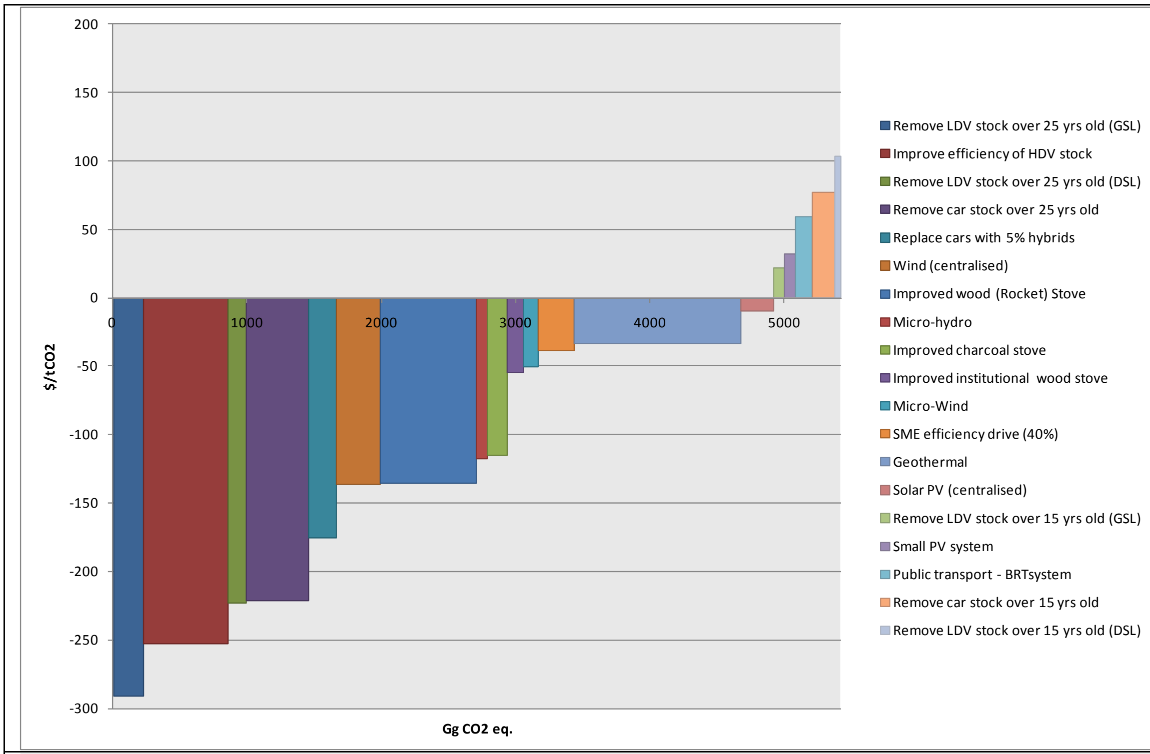
Exploring commercial perspectives concerning investment risks

The lower discount rate (commonly used in McKinsey work) represents a ‘societal view’ of costs and benefits, highlighting the measures that will be in the public interest to implement. A private sector perspective can be quite different, with investment decisions factoring in much higher rates. Higher rates make options with high upfront costs and future streams of benefits (e.g. many energy efficiency investments) appear less attractive. This moves the MACC upwards, and changes the order of options on the basis of cost-effectiveness. Conversely, a low rate will make such options more attractive. This is reflected in Figure A6.1.

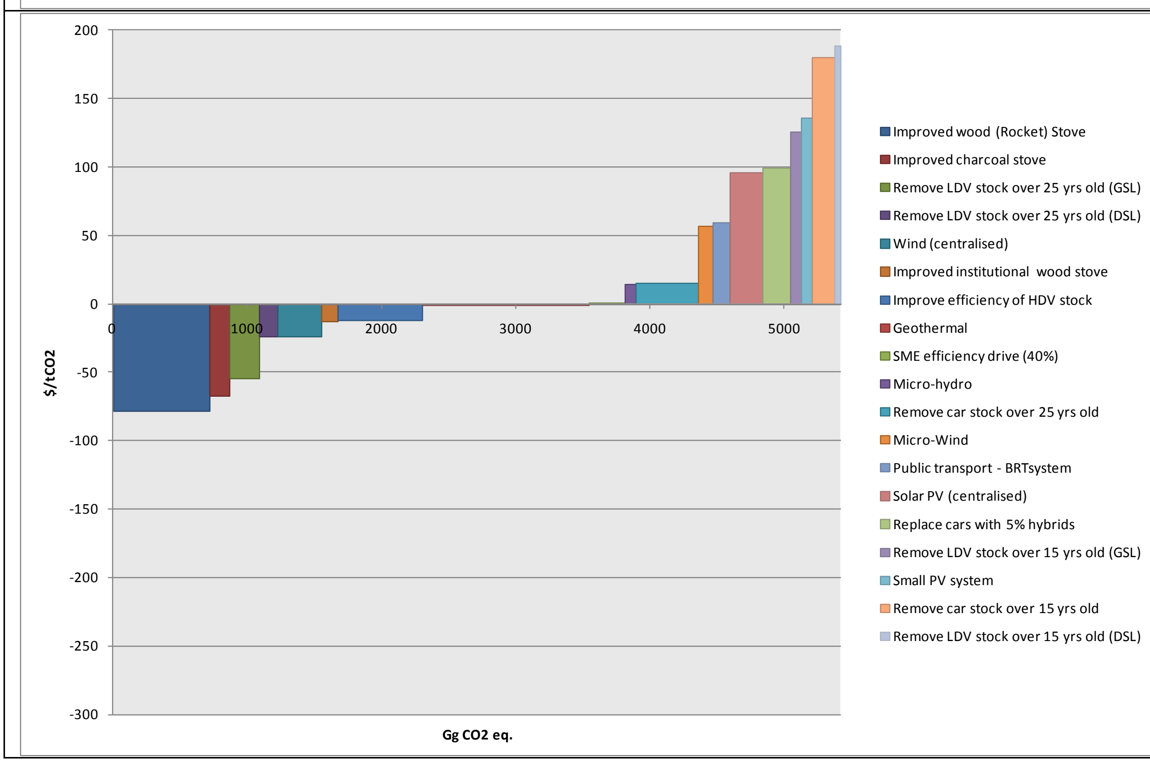
From the East Africa low carbon growth analysis (SEI 2009), a sensitivity was undertaken to highlight the importance of the discount rate chosen in MACC analysis, using a low value of 4% and high value of 30% (10% was adopted for the central analysis). The impact of a higher commercial discount rate and lower societal based rate are shown below for illustrative purposes below. At a very low discount rate, average cost are negative, in the order of -\$100/tCO_2. At 30%, they are \$5/tCO_2. Note that this is not a comprehensive cost curve but was developed to illustrate the most promising measures; hence even at a high discount rate, average costs are relatively low.

The difference in cost-effectiveness based on the high and low discount rate is significant. It illustrates that the societal view of what measures to include or prioritise in a low carbon strategy could differ significantly from the private sector. This is particularly important when thinking about who will be making investments in different sectors and expected rates of return and investment risk accepted.

It is recommended that sensitivity analysis is undertaken to explore different investment perspectives, to better understand mitigation costs, particularly in relation to mobilising investment in the private sector.



4% discount rate



30% discount rate

Figure A6.1. Indicative MAC curves of selected abatement measures for Kenya in 2020 using alternative discount rate assumptions

Widening the range of methodological approaches

In the evidence base, bottom-up approaches dominate e.g. World Bank LCG studies / McKinsey analysis with less use of top-down or hybrid modelling approaches. In particular there is a real prevalence of MACC analysis (see box below). Whilst this is not a problem in itself, the strengths of other analytical approaches need to be recognised and adopted where appropriate.

A short critique of MACCs

There is no doubt that MACCs have provided an important role in helping explore mitigation options, identifying those opportunities that are most cost-effective and present such information clearly and in an understandable way. However, there is both a danger of misinterpretation of and over-reliance on this approach. Misinterpretation comes because of the absence of information on underlying assumptions. Large amounts of cost-effective potential can be observed and provide an impression that this is easily attainable, without noting the many caveats and simplifications that have been made. Additional analysis may often be needed to compliment the MACC approach. Indeed it is often the case that MACC are derived from more complex models, as a simplified representation.

The following notes of caution need to be made for when using and interpreting MACCs:[56]

- Static snapshots of mitigation potential in a given year. Therefore, it is of limited benefit in helping understand when investments should occur, for example, or whether additional options will be available in subsequent years. If a MACC time series is available, care is then needed to ensure that the baseline in subsequent years is adjusted to account for any additional take-up of measures.
- Limited feedback between sectors. Integrated system modellers often cite the lack of interaction between sectors as a significant problem with MACCs. In an energy system, what happens in one sector might impact on electricity demand which in turn affects the upstream sectors. None, or at least very little of this is captured in MACC analysis. Some MACC analyses do account for changes in electricity sector intensity.
- An associated issue is the interaction between measures. Introducing one measure first could have an impact on the cost-effectiveness of the second measure and so on. This may be particularly true of building measures. (Note that such interactions are captured in model-derived MACCs).
- No feedback to the wider economy. The impacts (positive / negative) of introducing measures on the wider economy cannot be analysed dynamically.

The CCAP / Tsinghua Phase 1 report supplements the MAC curve analysis to look at some of the wider general equilibrium effects on the economy as a whole. The report provides a separate general equilibrium analysis based on a GTAP model extended to allow treatment of fuel switching and other factor substitutions affecting emissions of CO_2 in the economy. The model was run to look at the effects of increasing electricity prices and meeting certain emission reduction goals. The report does not provide very detailed discussion of the results, but some interesting conclusions can be deduced.

The results indicate that an electricity cost rise of 2.5% would lead to a drop in GDP of 0.01%, equivalent to a cost of $110m. In a static analysis where broader equilibrium effects were ignored, an increase of 2.5% in electricity costs would cost between $125-200m (the range is rather imprecise as the report does not give accurate figures for the total cost of electricity generation). In any case, it seems clear that taking into account equilibrium effects in the economy would reduce the overall economic impact of a rise in electricity prices due to adjustments in demand and structural shifts. These are dynamic effects that are very difficult to account for in MAC curve analysis, suggesting that such studies of technical potential may overestimate the costs.

- Few MACCs integrated the full cost of the measure in the analysis. Hidden and missing costs (e.g. implementation, transaction costs) are often omitted but can have a significant bearing on a given

[56] Note that we are referring to expert-based MACCs, not model derived MACCs, as this is approach primarily observed in the stocktake.

measure. In other words, full costing of measures could also lead to a better representation of the barriers to uptake. [57] As MACCs tend to represent technical measures, significant costs associated with implementation are usually overlooked.

- MACCs often take account of overlaps between the range of alternative options but not always. A MACC may list three power plant options; however, if one is introduced it may be the case that the other two are not needed. Therefore simply aggregating options in a MACC to get total potential is not always correct.
- MACCs tend to be an incomplete listing of the abatement opportunities. Key measures are not easily included although can be, such as behavioural change, modal shift, other structural change etc

There is a concern that much of the findings from MACC analysis are derived from a narrow evidence base, namely the McKinsey global MAC curve (2009d). This tool has been extremely important, particularly as often in the absence of national data, in providing a first cut of opportunities, and the costs. However, it broadly provides the same results for countries in which it has been used; this is not surprising as whilst some country-based adjustment are undertaken, similar cost-effectiveness assumptions are applied.

More robust data (plant level and local mitigation costs) is required for the development of actual policy and implementation. CCAP experience on developing sectoral level targets and strategies indicates that the proxies and assumptions are used for higher level MAC modelling which are not robust enough when developing sectoral targets and their recent report (CCAP 2009) demonstrates the challenges of modelling realistic abatement costs and setting sectoral targets at the plant level. Data collection strategies are required. Many of the McKinsey policy options are generic technology focused rather than locality focussed.

However, it should also be said that in the Mexico case study, it does appear that both the MEDEC (WB 2009) and CMM (2008) analyses use different data but come up with similar insights. In addition, other independent national analysis (e.g. Winkler et al. 2007) also come up with broadly similar outlooks.

Going beyond MACC cost-effectiveness analysis includes further developing cost-benefit analysis approaches and undertaking more macroeconomic analysis. In the context where co-benefits are deemed critical to investment decision, the analysis framework should be extended to more fully account for wider costs and benefits.[58] Whether this is done through CBA quantitatively or multi-criteria analysis (semi-quantitatively), it should be more widely considered. This would further an approach focused on sustainability rather than climate mitigation alone.

This should also mean increasing assessment of the impacts on growth through macro-economic or hybrid modelling approaches, and incorporation of the dynamic feedback from investment. Greater use of top-down macroeconomic approaches would be very useful for examining what additional costs mean for growth. In addition, approaches that were able to incorporate dynamic feedback from investment back into growth estimates (perhaps through input-output modelling) would add significantly to the evidence base.

[57] Some economic analysis (although not found in the review) also use higher cost of capital (or CRF) known as a hurdle rates to reflect the barriers to uptake of perceived higher costs, consumer choice or the quick payback period that consumers expect.
[58] The World Bank study for Mexico has gone further in quantifying wider benefits (e.g. time savings) and including them in the financial analysis.

Developing robust baselines

Across most country / region comparisons, studies did not have consistent baselines. This is for a variety of reasons, due to sectoral coverage, different projection drivers or inclusion of current / planned measures. This is important because this significantly impacts on what can be assumed for mitigation potential and with respect to measure inclusion, what is additional. In future negotiations it is going to be critical for country's to have robust baselines from which caps can be agreed. There is a danger that very different baselines emerging from the literature could lead to misleading conclusions. Note that politically it may be in a Government's self interest to have a higher baseline if indeed it means more head room for emitting under a cap or raising carbon finances.

Particularly in Low Income Countries, there is a real need for investment in developing emission inventories and energy projections. Based on the East Africa RECCS, it was evident how much work was needed in this area to provide a robust starting point for assessment of low carbon potential.

Exploring new and emerging mitigation options

Most MACC studies (particularly World Bank and CCAP studies) only considered fully commercial technology options. It may be that emerging technologies that are commercially available in 2020 / 2030 offer better longer term investment choices. In addition, not considering emerging technologies could risk lock-in in the longer term timescales e.g. 2050; however, many of the studies focus on 2020 / 2030. In addition, it would be interesting to see more demand side measures analyses, and their potential contribution to future mitigation; as discussed earlier, significant potential exists in behavioural change measures and in transport, through modal shift.

Additionally, few analyses consider measures associated with structural changes (e.g. spatial planning, urban transport systems, economic restructuring) or behavioural change (demand-side focus). These issues may be critical, particularly in the context of development, where the structure of the economy may be significantly evolving.

Developing analysis of uncertainties

Across most studies there is a limited uncertainty and sensitivity analysis. Most of the studies present a central case, and do not present (transparently at least) the range of baselines, costs, etc. from key assumptions in relation to growth, oil and energy prices, population growth, discount rate etc.[59] This lack of uncertainty analysis is highlighted as a major issue, and a priority for future studies. The main exception to this was the LTMS study. This analysis demonstrates the importance of sensitivity analysis on core assumptions, and highlights inherent uncertainties.

In UK mitigation analysis, there has been a tendency to move away from a single centralised baseline but rather have a number of baselines based on different assumptions (fuel prices, economic growth, discount rate). This provides ranges rather than single estimates, and highlights the uncertainties that may be hidden in core assumptions. In addition to sensitivity analysis, no mitigation assessments undertook any uncertainty analysis around technology learning or availability of an emerging / new technology. Current UK modelling analysis is increasingly taking account of the cost of uncertainties associated for example with technology failure e.g. CCS or missed targets, using stochastic techniques.

[59] For example, the McKinsey MACC analysis tends to present cost curves using a lower (societal) discount rate. This will make capital intensive projects appear at much lower cost than a higher rate representing private investment risk.

Lengthening the analysis timeframe

Most of the studies have a short timeframe, mainly to 2030. A 2030 timeframe can be problematic because post-2030 emissions may still be rising and further mitigation options (which will be higher costs e.g. further up the cost curve) may be required to sustain stabilisation pathways.

Failure to consider the potential linkage between the medium term (2030) and the longer term (2050), may result in lock-in to technologies that are not low carbon or from an optimisation point of view, investment in technologies too early e.g. before the benefits of technology learning are realised. In addition, technologies such as CCS may well be commercially available around 2030 but not taken up because of a short analysis timeframe. The shorter timescale also means a much greater focus on energy efficiency measures.

The UK recently went through the process of thinking about shorter term (2020) versus longer term targets (2050) and the potential to lock-in investment due to short sightedness as it proposed carbon budgets.[60] It suggested that costs could be significantly higher if the wrong investments were made without consideration of longer term targets, particularly for high capital measures with a long lifetime e.g. power stations.

This is particularly important in relation to the very high level of decarbonisation that is needed globally to achieve the global emission reductions targets. In developed countries such as the UK, there is an extremely high challenge in moving from emission reductions cuts of 25-40% in 2030 (note 32% for the UK) to an 80 % or greater emission reduction in 2050. Similarly, there will be very large challenges for developing countries in potentially moving from the ambitious levels of early self interest (2030) to the likely future reductions needed to ensure global reductions of 50% by 2050.

In summary, there are two key issues with the use of analysis timeframes that are too short – 1) it underestimates the longer term challenge, both in terms of required reductions and costs and 2) risks of non-optimal investment and technology lock-in increase.

Improved integrated assessment of adaptation and mitigation options

One of the research gaps identified by the DECC/DFID scoping study preceeding this review was that approaches need to better integrate climate impacts and adaptation with mitigation. The RECCS have done this to some extent; however it is important that this issue is given greater focus, particularly as countries start to plan and integrate adaptation and low carbon growth strategies into development plans. Optimal spending of resources cannot happen unless mitigation and adaptation options are considered in an integrated way.

More focus on Low Income Countries

It is not surprising that the focus of mitigation studies has been on the higher emitting countries. As a result, there are very few studies on Low Income Countries (LICs). Particularly emerging from the East Africa RECCS is a sense that low carbon issues are very different for LICs.

These countries are at lower levels of development and tend to have low emission levels. Therefore, there is a sense that low carbon opportunities can be justified as co-benefits of other policies e.g. health improvement and forestry preservation through use of improved stoves, or

[60] CCC (2008), Building a low-carbon economy – The UK's contribution to tackling climate change, The First Report of the Committee on Climate Change, December 2008, London: TSO

decentralised small-scale renewable technologies as a mean of rural electricity provision. The self-interest case will also be strengthened by access to carbon finances.

Going beyond self-interest is less likely unless a country is already moving towards low carbon patterns of growth, and therefore may want to position itself as a regional leader in moving to a low carbon economy, again to leverage finances / generate investment opportunities. It is important that research captures the experience and situation in a wide range of LICs, and the prospect for low carbon growth. This is particularly important as the relative emission contribution is likely to be significantly higher in 10-20 years. There is also an emerging issue of the potential inequalities involved for these countries with different options and mitigation, i.e. that some policies may have different distributional consequences

More focus on such countries could also facilitate increased investment in a country's capacity for undertaking low carbon growth analysis. This will be beneficial, as countries will increasingly need to do these types of analysis to assess priorities for investment and associated finance requirements. In-country capacity and capability could be more beneficial in the near to medium term than simply contracting consultants to undertake necessary analysis.

Regionalising the analysis

Prospects for regional co-operation should be assessed to a greater extent, to look for opportunities for regional energy systems integration (for energy security issues) and sharing of mitigation burden (to optimise investments). This type of analysis is being done increasingly using regional or global energy models, such as the Pan European TIMES and PRIMES models for European analysis.

Developing low carbon growth studies in the future

Based on the above issues, there are a number of elements that should be incorporated into the design of studies addressing the extent to which developing countries can move towards a low carbon growth pathway:

- Combination of top-down econometric and bottom-up engineering approaches that provide both the wider economic implication of a given strategy plus the sector-specific costs and potential of different options.
- Fuller consideration of costs, particularly with respect to implementation, and types of available options
- Strong focus on developing robust baselines prior to assessing mitigation potential
- Formulation of a range of scenarios that provide pathways at different levels of ambition.
- Integration of climate impacts and adaptation issues into choices concerning mitigation options
- More rigorous assessment and quantification/valuation of co-benefits to ensure the self interest arguments can be made. Where quantification is not possible, approaches such as Multi-Critieria Analysis (MCA) should be considered.
- Longer time horizon for modelling (or linkages between early 2030 and later 2050 time scales) to ensure that all mitigation options can be considered in view of emission growth rates over the longer term, so that optimal investment strategies can be assessed, and issues of lock-in and irreversibility, overall decarbonisation rates, etc can be considered.
- Greater consideration of uncertainty and sensitivity analysis.
- Possible use of consistent and common marker scenarios and assumptions, e.g. to allow direct comparison between studies (similar to the EMF process), alongside specific scenarios and inputs for the study.

Research needs on climate resilience

A number of key future research areas have been identified.

1) Future systematic review with emerging evidence

This study has reviewed the existing studies on economic costs and adaptation. However, a very much larger number of studies will emerge over the next 6 months or so. This includes:

- The World Bank (EACC) seven country case studies Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam, which will be available in early 2010.
- The National Economic, Environment and Development Study (NEEDS) for Climate Change Project of the UNFCCC, which is providing technical assistance for financial needs assessments of climate change mitigation and adaptation measures. Ten countries have joined the project (Egypt, Indonesia, Ghana, Mali, the Philippines, Costa Rica, Lebanon, Maldives, Nigeria and Pakistan).
- The UNDP Methodology Guidebook for the Assessment of Investment and Financial Flows to Address Climate Change, which is being tested in around 20 or so countries for mitigation and/or adaptation, in specific sectors in Namibia, Bangladesh, Niger, Turkmenistan , Gambia, Nepal, Algeria, Paraguay, Togo, Costa Rica, Liberia, Dominican Republic, Honduras, Colombia, St Lucia, Nicaragua, Peru, Ecuador and Uruguay.
- A large number of other studies, e.g. work on the economics of climate change and adaptation in India, Foresight studies on river basins in China, etc.

A key recommendation is that this review should be repeated once this wider evidence base is available. This will allow a better analysis of the potential international financing needs for adaptation for developing countries, by looking to compare the country studies against current global estimates. It will also provide new information to compare different methods. Finally, it will provide a wider evidence base to consider and progress climate resilient growth.

2) Building the evidence base

There is a generally low level of evidence on the economics of climate change and adaptation and more studies are needed different scales and different locations. There are complex methodological issues that need to be addressed, including:

- Baseline issues, socio-economic change
- Autonomous adaptation.
- Capturing adaptive capacity within economic assessments.
- Exploring decision making under uncertainty, and flexibility, reversibility, option values, etc
- Attribution issues, particularly between development and climate change.
- The levels of residual damages.
- Distributional effects.
- Public vs. private adaptation.
- Ancillary effects.
- Adaptation – mitigation linkages.
- Decision frameworks and support tools.

There is a need for more methodological work, but also more case studies of practical assessment of adaptation to explore these issues and enhancing resilience. There is also a need for more studies that try and capture the effects of both slow onset and climate variability (acting individually and together).

3) Addressing climate resilient growth

The current studies are mostly focused on long-term changes in specific time periods or smaller short-term shocks. There has been less work to date on the economic effects on long-term growth from the cumulative changes arising from long-term trends and shocks. Furthermore, there has been almost no explicit consideration (that we have been able to find) of analysis of climate resilient growth, i.e. on what patterns of economic growth reduce vulnerability. The potential studies that might address these issues are set out in the box below.

What might a future climate resilient patterns of growth study look like?

The current generation of national studies has a rather static assessment of future climate change, looking at future periods from the outputs of climate projections. They have not included a dynamic approach assessing changes over time in each year, considering the cumulative effects and feedbacks, because of the modeling and analytical complexity of doing so. Such an analysis would become even more complex when considering the probabilistic (and highly uncertain) patterns of climate variability.

An analysis of sectoral and even cross-sectoral dynamic assessments over time should be possible for long-term changes, by incorporating some form of model feedbacks in the system. However, it would be extremely resource intensive (e.g. for impact assessment modeling) because it needs to estimate the impacts in each year and use the outputs for the starting analysis for the next year, i.e. it would require the building of new models. There is also an issue because the climate data is usually presented as 20 or 30 year data sets, to reflect the variability in the climate models. There is an issue on how best to reflect this large variability into a single model year, that then analytically feeds through to the subsequent year. Such an analysis would need to start adjusting for autonomous adaptation, potentially also on an annual basis.

A more complex version of this type of analysis could be undertaken within a CGE model, to look at economy wide effects. This could be run dynamically over time (some models already exist that do this), e.g. within a domestic CGE model. By introducing different sectoral shifts (and examining the sensitivity of each to climate change over time), it would be possible to explore possible future effects of macro-economic policy shifts. A key problem is whether the inter-sectoral relationships also change over time and whether it is possible to consider this in a manageable framework, or with any real insight to allow informed analysis. Undertaking this type of dynamic assessment at a global level (e.g. to include world trade effects as for agriculture) would be extremely challenging.

Similarly, modeling the macro-economic effects of individual events (shocks) is already demonstrated. This can be undertaken using CGEM models or through econometric analysis, but these reveal very little about the drivers of losses and therefore how to avoid them. Moving to a situation where cumulative patterns of effects from future climate variability are assessed over time from climate change would be very challenging but is a key area of investigation. However, the complex uncertainty and probabilistic nature of these events would make any assessment highly illustrative. Nonetheless, it would be possible to explore individual cases, but difficult to see how this could be accurately represented at national scale.

Faced with these challenges, and the high resources needed for developing such work, an initial set of studies might explore the issues with climate resilient patterns of growth. Studies could look at the current sensitivity of current economies, and then consider the potential changes under future development paths across sectors (overview studies).