# Long Term Mitigation Scenarios

## Technical Summary

**Prepared for:**
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**South Africa**

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The suite of reports that make up the Long Term Mitigation Scenario study include the following:

A Long Term Mitigation Scenarios for South Africa

B Technical Summary

C Technical Report

C.1 Technical Appendix

D Process Report

The study was supported by the following inputs:

LTMS Input Report 1: Energy emissions

LTMS Input Report 2: Non-energy emissions: Agriculture, Forestry and Waste

LTMS Input Report 3: Non-energy emissions: Industrial Processes

LTMS Input Report 4: Economy-wide modeling

LTMS Input Report 5: Impacts, vulnerability and adaptation in key South African sectors

# 1. Introduction

The Long-Term Mitigation Scenarios (LTMS) process is mandated by Cabinet, led by the Department of Environmental Affairs & Tourism and project managed by the Energy Research Centre. The purpose is to outline different scenarios of mitigation action by South Africa, to inform long-term national policy and to provide a solid basis for our position in multi-lateral climate negotiations on a post-2012 climate regime.

LTMS has been conducted as a process involving key stakeholders, informed by the best available information. Four research teams produced information that was discussed by a Scenario Building Team (SBT) comprised of strategic thinkers from a range of government departments, key industry players and civil society. The Technical Summary provides a concise version of the technical work reviewed and accepted by the SBT.

The scenarios produced by the LTMS process are data-based scenarios. This Technical Summary therefore provides the basis, in abridged form, for the scenarios – stories of possible futures. The Scenarios together with the underlying technical work are forwarded by the SBT to high-level discussions in the first half of 2008.

# 2. Climate change: reasons for concern and action

Climate change and its projected impacts provide a powerful reminder of why we are engaging in the Long-Term Mitigation Scenario process in the first place. The IPCC recently concluded that significant, predominantly negative impacts on human society and its supporting agro- and natural ecosystems are projected with medium to high confidence over the course of this century, especially in Africa. The impacts study[1] conducted as part of this process reiterates the multiple impacts that South Africa will very likely face, if we and the rest of the world do not take action. It is important to point out that the approach in this study *may significantly underestimate the risks of larger impacts* due to the uncertainty inherent in the climate sensitivity. The climate modelling studies project a range of possible scenarios and impacts in South Africa, given the uncertainties in global greenhouse gas emissions scenarios and in the response of the climate system. Some of these projected impacts are alarming and of immediate societal relevance – for example, a projected change in available water supply and its predictability in South Africa would have major implications in most sectors of the economy, but especially for urban and agricultural demands.

In addition, the immediate health impacts of extreme climatic events on rural livelihoods, in particular, are well established and documented. Production and income activities are likely to be significantly affected by climate change and increased climate variability by ~ 2050 at least, particularly in rural areas. Similarly in urban environments, a higher risk of frequent flooding in some cases and drought induced water shortages in other areas will be the result of increased climate variability. A range of risks for natural ecosystems and associated economic sectors such as nature-based tourism and rural livelihoods is identified. These include the risk of endemic species extinctions in biodiversity hotspots, increased frequency of natural fires, and disruption to ecosystems via species geographic range shifts and the enhanced threat of alien invasive organisms.

Two main types of adaptation have been suggested, namely "resilience-type" adaptation, which addresses the potentially damaging effects of changing climate extremes on sectors, and "acclimation-type" responses, which address strategies to cope with the gradual changes in background climate such as slow rates of warming that may ultimately require new behaviours and practices in human society. This distinction might allow adaptation strategies, implementing agencies and financing sources to be more effectively allocated to where needs are most urgent.

The overarching message is that the costs of inaction are very real, even if – given our current state of knowledge - they have not been comprehensively quantified in monetary terms. If we do nothing, others are likely to follow suit – and ultimately the costs of not acting exceeds those of inaction. With these messages in mind, the LTMS report focuses on mitigation, starting with the Scenario Framework.

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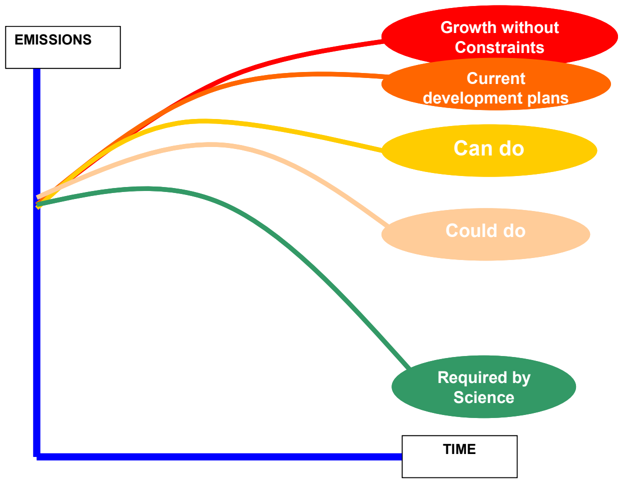
[1] Summarised in section 1.4 of the full Technical Report. The full study is downloadable from the closed web-site www.ltms.uct.ac.za

# 3. Scenario framework

The SBT defined a scenario framework. The limits of the framework are defined by Growth without Constraints (GWC) and Required by Science (RBS). They define the space within which mitigation action occurs. Current Development Plans (CDP) shows what implementing existing policy would achieve, if extended into the future. In the space between GWC and RBS, several action-oriented strategies are defined. They indicate what South Africa 'Can Do' or 'Could Do'. Variations on the action-oriented strategies were discussed by the SBT[2]. First, however, the report outlines some important results from the modeling of the envelope scenarios.




# 4. GWC: without constraints, emissions grow

In GWC, greenhouse gas emissions are projected to rise dramatically. Without constraints, growth leads to an almost four-fold increase in greenhouse gas (GHG) emissions – from 446 million tons of $CO_2$–equivalent (Mt $CO_2$-eq)[3] in 2003 to 1 640 Mt $CO_2$–eq by 2050.

Most of the emissions, and the largest part of the increase, comes from the energy sector. Energy-related emissions ($CO_2$, $CH_4$ and $N_20$) almost quadruple by 2050. Energy emissions grow on the back of rising energy demand, particularly in the industry and transport sectors. Without constraints, energy-related emissions grow at an average 2.9% annually and reach 1 330 Mt $CO_2$eq in 2050, an increasing by almost 1 000 Mt. Industrial process emission add 277 Mt and non-energy 31 Mt $CO_2$-eq.

Electricity generation accounts for 45% of energy-related GHG emissions in 2003 declining to 34% in 2050. The declining share is due to emissions growth in liquid fuels, with five new coal-to-liquid plants, an a faster rise in transport emissions, other industrial process emissions, and direct coal use in industry. Electricity continues to be generated overwhelmingly from coal and to a lesser extent nuclear power, with renewables remaining a small share of capacity and entering the mix only late. All new PF coal plants are super-critical, and a large number of Integrated Gasification Combined Cycle (IGCC) coal plants are built in GWC, in the absence of new sub-critical coal plants. Industrial process emissions (non-energy) increase more than four times in GWC. The largest share in this category is from synfuels. Emissions in the other non-energy sectors – notably waste, agriculture and forestry, increase much less rapidly than for energy.

Liquid fuel supply is dominated by oil and synfuel (coal-to-liquids, CTL) refineries, and five new crude oil refineries. The costs of bringing forward water supply options are a potential constraint, with the costs of securing a reliable supply potentially prohibitive under current economic conditions, especially when taken together with increased demand from other users. If CTL plants

[2] Terminology for the strategies changed considerably during the SBD process. Three strategies were finally settled on – 'Start Now', 'Scale Up' and 'Use the Market', in order of emissions reduction (least to most).

[3] 'Megatons' are millions of tons, abbreviated Mt. Emission reductions from the major GHGs are converted to $CO_2$-equivalents by Global Warming Potentials, 21 per ton of methane, 310 per ton of nitrous oxide. Units of million tons are preferred; inventories tend to report in Gg. 1 Mt = 1000 Gg.

are built without carbon capture and storage (CCS), they massively increase emissions. Currently, emissions from CTL are the largest from a single facility, although taken together coal-fired power plants emit more GHGs. In the GWC scenario, CTL – combining both emissions from utilities and process emissions – emit on average 10% of total GWC emissions.

Current Development Plans (CDP) make some difference relative to GWC in the initial years. However, over the longer time horizon up to 2050, the difference becomes small, compared to the gap between GWC and RBS. In other words, while implementing existing government policy makes a difference, its not enough to solve the climate problem.

In plain language, if our economy grows without constraints over the next few decades, GHG emissions will continue to escalate, multiplying more than four-fold by mid-century. If the other countries (and more specifically the larger developing ones and the US) did the same, the implications are that global emissions would increase dramatically – and dangerous, if not catastrophic, climate change will very likely be upon us. The predicted impacts of climate change would be at the higher end of the projections, rather than the more cautious estimates. This would have a very serious impact on South Africa, in turn.[4]

# 5. Required by science

One scenario is different from all others, in that it is driven by a climate target. 'Required by Science' (RBS) asks what would happen if South Africa reduced emissions by the same percentage that is needed globally, i.e. -30% to -40% from 2003 levels by 2050.

They are defined by two key points – the end point (with the percentage reductions stated) and the peak (both its level and timing). The RBS reductions in 2050 are roughly half the reduction in 2100 (i.e. in half the time), based on earlier IPCC projections that stabilizing atmospheric concentrations of GHG in the atmosphere would require emission reductions of -60% to -80% from 1990 levels by 2100. Later assessments have indicated even greater reductions, but ultimately the reductions required depend on the level of stabilization of atmospheric GHG concentrations desired. In this scenario, only the emissions trajectories are sketched.

Initial analysis showed that RBS cannot be achieved with in a least-cost minimisation framework and the 'ambitious but realistic' limits on resources, technologies, and policies implied in that modelling context. Attempts to model a constraint on carbon emissions in the Markal framework proved infeasible, and no costs analysis is available for this scenario. The RBS climate target cannot be met using only known technologies, policies and measures with well-understood parameters, including cost. Put another way, in a carbon-constrained world, it will not be feasible to continue with growth as usual.

To indicate the level of emission reductions that would be required by science, we assume that emissions continue to increase only for a short while, peaking by 2020 at 473 Mt $CO_2$-eq (already slightly lower than GWC), before declining to 65% of base year levels, i.e. -35% means that emissions in 2050 are 290 Mt $CO_2$-eq. The highest (lowest) part of the RBS band peaks at 483 (463) Mt in 2026 (2016), before declining to -30% (-40%) or 314 (268) Mt in 2050. In other words, the later the peak, the higher the emissions level at which it peaks and the higher the emissions at the end.

The lower end of the RBS cloud can be thought of as a global or collective bottom line. The band suggests some differentiation, acknowledging that countries have different capability and national circumstances. The band of emission in the RBS scenario is narrow, compared to the gap between GWC and the whole RBS cloud.

The emissions projections for GWC and RBS are shown in Figure 1, showing the space within which solutions to climate mitigation need to be found.

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[4] A summary of the study on climate impacts, vulnerability and adaptation is included in the Technical Report; the full report is available on the LTMS web-site, www.ltms.uct.ac.za .

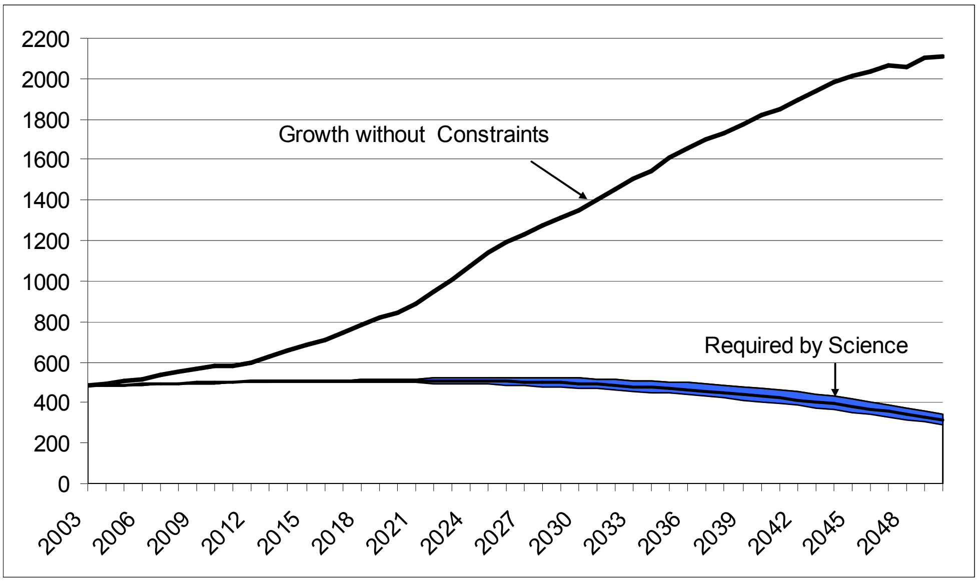


**Figure 1: Emissions trajectories for GWC and RBS**

# 6. Results for mitigation actions: the costs of wedges

Figure 1 shows a large gap between where emissions might go in a scenario of Growth without Constraints (GWC) and where the scientific information suggest they need to go. To get from GWC to RBS, action on mitigation is needed. The SBT adopted the language of 'wedges' to describe mitigation actions.

Wedges in the LTMS context mean emission reductions over time. If the emission reductions increase over time, the graphs have the shape of a wedge.

## 6.1 Initial wedges (Start Now)

A wide variety of wedges have been analysed to provide information to the LTMS process. An initial set of wedges was modelled for SBT4, which then commissioned extended actions and separate analysis of economic instruments. The initial wedges provide the basis for the Start Now strategy described in the LTMS Scenario Document, the extended wedges underpin Scale Up and Use the Market is consistent with using economic instruments. Most of the wedges are in the energy supply and use sectors -- as might be expected, given that almost 80% of our GHG emission come from that sector. Important options are reported in industrial process emissions and other non-energy sectors, notably waste, agriculture and 'LULUCF' (land use, land use change and forestry).

The wide variety of mitigation actions is reflected in the range of emission reductions and costs reported and summarised for comparison in Table 1. The costs of single wedges range from large *savings* per ton of $CO_2$, for example for passenger modal shifts at close to -R 1 300, positive cost options, such as almost + R 2 000 per ton of $CO_2$-eq for hybrids.[5] Emission reductions in aggregate are obviously largest for combined cases, with the escalating $CO_2$ tax the largest reduction from a single wedge.

**Energy efficiency** is generally a negative cost option, i.e. the savings from reduced energy use outweigh the programme costs. Commercial (-R203 / t $CO_2$-eq) and residential (-R198 / t $CO_2$-eq) energy efficiency are more cost effective than industrial (-R34 / t $CO_2$-eq), but the latter provides greater absolute savings – by a factor of more than ten. Industrial energy efficiency shows savings of 4 572 Mt $CO_2$-eq over the period, one of the largest single wedges. Residential energy efficiency

[5] Net negative cost options are those mitigation options, which, if implemented, would result in a lower total cost to society in the relevant sector than would have been the case in the 'Growth Without Constraints' scenario. Positive costs options are the opposite, i.e. the mitigation cost would result in an additional cost to society in the relevant sector. Thus, energy efficiency is most often a negative cost option, since the energy saved usually outweighs the cost of investing in more efficient technology. Similarly, renewable or nuclear energy is usually a positive cost option.

(including solar water heaters) is not only a good negative cost mitigation option, but also has important socio-economic benefits. While individual interventions are small, across a large number of households they add up avoided emissions of over 400 Mt $CO_2$-eq over time.

In **electricity generation,** cleaner coal is the smallest of the three wedges. Given that super-critical is the default new coal option and IGCC is built extensively in GWC, relatively modest emission reductions are possible here. Carbon capture and storage provides greater potential, if the challenge in scaling up storage can be achieved – a challenge also faced by synfuels and its dilute and concentrated streams of $CO_2$.

Other options would similarly need to scale up. This is reflected in the extension of both renewable and nuclear wedges from 27% of electricity generated to 50% of electricity generated. The wedge representing the results of a subsidy of 38 c / kWh for renewable electricity shows cumulative emission reductions that are greater than the other renewables cases (at 3 887 Mt $CO_2$-eq from 2003-2050), be they initial, with learning or extended. Only if one assumes technology learning *and* extends renewables to 50% do emissions go higher, to 3 990 Mt over the period. For renewables on its own, learning makes the difference between positive and negative cost. With technology learning, renewables become economically competitive by the end of the period with coal-fired technologies. The extended nuclear wedge is also a large wedge, with total emission reductions at 3 467 Mt $CO_2$-eq over the period.

**In the transport sector**, shifting from modes is a major infrastructure option – from private to public transport modes for passengers, and from road to rail for freight. Passenger modal shift appears, on this analysis, more attractive than freight – it is a negative cost mitigation option with reductions of 469 Mt $CO_2$-eq. Analysis of modal shifts includes infrastructure costs, but not a return on investment. Biofuels are reported as a separate wedge, the moderate scale of emission reductions reflecting the limits on the potential of biofuel in SA. Greater efficiency is possible in the transport sector. Promoting vehicle efficiency is a negative cost option, saving R 269 / t $CO_2$-eq. Even in a coal-dominated electricity grid, electric vehicles are a significant mitigation option, but only reach their full mitigation potential in a renewables- or nuclear-based grid - the results for electric vehicles show that the grid in which they operate matters.

**Non-energy sectors (waste, agriculture, forestry and other land use changes)** result in emissions reductions ranging from 47 to 455 Mt $CO_2$-eq for the period 2003-2050. While the reductions are smaller than some energy mitigation options, non-energy options provide some negative cost options (manure management, fire control and savannah thickening), but not the cheapest on offer (even ignoring transport). Also, some agricultural mitigation actions are have significant positive costs (enteric fermentation, reduced tillage, afforestation). For waste, note that the costs of flaring only are considered, at R 14 / t $CO_2$-eq.

The **waste sector** can provide substantial emission reductions at 432 Mt $CO_2$ -eq for the 48 year period, not including waste minimization. Reduction of fire frequency (rather than complete fire prevention) interacts with savannah thickening in that reduced fire is a major driver of thickening. Together, fire control and savannah thickening sequester carbon equivalent to 455 Mt $CO_2$, at a negative mitigation cost of R 15 / t $CO_2$-eq. Mitigation from reduced tillage is limited – firstly, the effect of putting land under reduced tillage wears off and less land is put on low-tillage over time. Hence emissions in the mitigation case converge with the baseline. Afforesting an additional 760 000 hectares of land sequester 202 Mt $CO_2$-eq at R 39 / t $CO_2$-eq.

The largest potential reduction of **industrial process emissions** results from **carbon dioxide capture and storage** (CCS) from new coal-to-liquid synfuel plants, using similar technology to the current plants at Secunda. Compared to CCS on electricity generation, CCS from the synfuel process is attractive, in that roughly half the $CO_2$ is in concentrated forms, avoiding most of the cost of capture. The key constraint is whether sufficient storage is available. Analysis so far has assumed 23 Mt $CO_2$-eq per year from synfuels could be stored at most, which on its own is more than 20 times larger than the largest existing CCS project and ten times planned. With the limit, the mitigation potential is still large at 851 Mt $CO_2$ –eq. over the period.

The large number of wedges analysed in the Technical Report is summarised in Table 1.

It shows all the wedges, in the energy sector, non-energy (agriculture, waste and forestry) as well as industrial process emissions. It reports the key parameters of mitigation cost (R / t $CO_2$-eq), the cumulative emission reductions from 2003 – 2050 and a comparative perspective on total mitigation costs. Total mitigation costs are shown in the last two columns in relation to the size of the economy (average share of GDP) and a percentage change in total energy system costs in GWC. Table 1 also provides ranking of the actions by these two key results parameters, firstly on R / t $CO_2$-eq, and secondly on GHG emission reduction from 2003 to 2050. In other words, it makes clear which are the most cost-effective options and which are the 'big hits'.

**Table 1: Summary table showing mitigation cost, total emission reductions and total mitigation costs in relation to GDP and the energy system**

| *Mitigation action* | *Mitigation cost (R / t CO2-eq)* | *GHG emission reduction, Mt CO2-eq, 2003-2050* | *Rank costs - lowest cost is no.1* | *Rank emission reductions - highest reduction is no.1* | *Mitigation costs as share of GDP* | Increase on GWC energy system costs |
|---|---|---|---|---|---|---|
| | *Average of incremental costs of mitigation action vs base case, at 10% discount rate* | *Positive numbers are reductions of emissions by sources or removals of emissions by sinks* | *Rank cost* | *Rank ER* | *%, negative numbers mean lower costs* | *%, negative numbers mean lower costs* |
| *Combined energy cases* | | | | | | |
| Start Now | -R 13 | 11,079 | | | -0.5% | -2.2% |
| Scale Up | R 39 | 13,761 | | | 0.8% | 3.6% |
| Use the Market | R 10 | 17,434 | | | 0.1% | 0.6% |
| Current Development Plans | -R 510 | 3,412 | | | -2.4% | -11.4% |
| *Individual Wedges* | | | | | | |
| Limit on less efficient vehicles | -4,404 | 18 | 1 | 36 | -0.2% | -0.7% |
| Passenger modal shift | -1,131 | 469 | 2 | 16 | -1.1% | -4.9% |
| Improved vehicle efficiency | -269 | 758 | 3 | 14 | -0.4% | -1.9% |
| SWH subsidy | -208 | 307 | 4 | 25 | -0.1% | -0.4% |
| Commercial efficiency | -203 | 381 | 5 | 22 | -0.1% | -0.6% |
| Residential efficiency | -198 | 430 | 6 | 21 | -0.1% | -0.5% |
| Renewables with learning | -143 | 2,757 | 7 | 10 | -0.4% | -2.1% |
| Industrial efficiency | -34 | 4,572 | 8 | 5 | -0.3% | -1.2% |
| Agriculture: manure management | -19 | 47 | 9 | 34 | n/a | n/a |
| Land use: fire control and savannah thickening | -15 | 455 | 10 | 17 | 0.0% | n/a |
| Cleaner coal | -4.8 | 167 | 11 | 28 | 0.0% | 0.0% |
| Aluminium | 0.2 | 29 | 12 | 35 | 0.0% | n/a |
| Renewables with learning, extended | 3 | 3,990 | 13 | 6 | 0.0% | 0.1% |
| Synfuels methane reduction | 8 | 146 | 14 | 30 | 0.0% | n/a |

| *Mitigation action* | *Mitigation cost (R / t CO2-eq)* | *GHG emission reduction, Mt CO2-eq, 2003-2050* | *Rank costs - lowest cost is no.1* | *Rank emission reductions - highest reduction is no.1* | *Mitigation costs as share of GDP* | Increase on GWC energy system costs |
|---|---|---|---|---|---|---|
| Waste management | 14 | 432 | 15 | 20 | n/a | n/a |
| Nuclear | 18 | 1,660 | 16 | 12 | 0.0% | 0.2% |
| Nuclear, extended | 20 | 3,467 | 17 | 8 | 0.1% | 0.7% |
| Agriculture: reduced tillage | 24 | 100 | 18 | 31 | 0.0% | n/a |
| Land use: afforestation | 39 | 202 | 19 | 27 | 0.0% | n/a |
| Escalating CO2 tax | 42 | 12,287 | 20 | 1 | 0.9% | 4.3% |
| Agriculture: enteric fermentation | 50 | 313 | 21 | 24 | 0.0% | n/a |
| Renewables | 52 | 2,010 | 22 | 11 | 0.1% | 0.6% |
| Nuclear and renewables, extended | 52 | 8,297 | 23 | 2 | 0.8% | 3.8% |
| Nuclear and renewables | 64 | 5,559 | 24 | 4 | 0.6% | 2.7% |
| CCS 2 Mt | 67 | 306 | 25 | 26 | 0.0% | 0.2% |
| CCS 20 Mt | 72 | 449 | 26 | 19 | 0.1% | 0.3% |
| Renewables, extended | 92 | 3,285 | 27 | 9 | 0.6% | 2.6% |
| Electric vehicles with nuclear, renewables | 102 | 6,255 | 28 | 3 | 1.1% | 5.1% |
| Synfuels CCS 23 Mt | 105 | 851 | 29 | 13 | 0.1% | n/a |
| Subsidy for renewables | 125 | 3,887 | 30 | 7 | 0.8% | 3.7% |
| Coal mine methane reduction (50%) | 346 | 61 | 31 | 33 | 0.1% | n/a |
| Synfuels CCS 2 Mt | 476 | 78 | 32 | 32 | 0.0% | n/a |
| Biofuels | 524 | 154 | 33 | 29 | 0.1% | 0.5% |
| Electric vehicles in GWC grid | 607 | 450 | 34 | 18 | 0.5% | 2.3% |
| Biofuel subsidy | 697 | 573 | 35 | 15 | 0.4% | 2.3% |
| Hybrids | 1,987 | 381 | 36 | 23 | 0.5% | 6.3% |

Three combined cases are shown – those combining initial wedges, a combination of extended wedges, and combined economic instruments, i.e. taxes and subsidies. They provide the analytical basis for three of the strategic options in the Scenario document.

A combination of initial wedges provides the basis for a strategic option (Start Now), defined in more detail in the LTMS Scenario document. It includes all the energy efficiency wedges – in industry, commerce, residential and transport sectors. These are all negative cost options, that is the initial cost required is more than outweighed by the savings on energy bills over time. Start Now also includes positive cost wedges, notably it requires that 27% of electricity is generated from each of nuclear and renewables.

## 6.2 Extended wedges (Scale Up)

Wedges were extended in various ways, as commissioned by SBT4. Some have been reported above as extensions of initial wedges. Another approach to extending is to combine wedges. The combined extended wedges provide the basis for the Scale Up strategy. In this strategic option, nuclear and renewables are each required to generate 50% of electricity by 2050.

Extended nuclear and renewables are shown as a combined wedge in Table 1, that is without efficiency measures. It is so large a wedge that they might be thought of as a strategy in its own right. In that case, the approach would be to move close to zero-carbon electricity by 2050. The analysis shows that with this combination, 8 297 Mt $CO_2$-eq can be avoided by 2050, 173 Mt on average each year. However, emission reductions are significantly greater in the combined extended wedges *with* efficiency (Scale Up), more than 5 000 Mt more. And of course the cost per ton reduced is lower when the negative cost options are included.

At the request of SBT members, the research team ran two variants of the extended renewable and nuclear wedges at 80% electricity generated. These cases, while reducing emissions relative to GWC, have smaller emissions reductions than combined cases, do not diversify energy supply and the energy modeling team expressed a lack of confidence in the results. Essentially this is because the energy system is stretched beyond limits normally considered in modelling.[6] However, the results for these cases are outlined the Technical Report.

## 6.3 Economic instruments (Use the Market)

**Economic instruments** are considered for the Use the Market strategic option. It includes an escalating $CO_2$ tax on the whole energy sector, together incenctives for renewable electricity, solar water heating and biofuels. Taxes generate revenues, and these can be used to provide incentives. In Use the Market, for example, much greater use of solar water heaters is incentivised. Instead of setting a target for renewables (as in the other two options), the cost gap is closed by 38 c / kWh[7] for renewable electricity.

The results for the $CO_2$ tax shown in Table 1 are for an escalating tax level, from R100 / t $CO_2$-eq to R 750 in 2050 (see the Technical Report for details). The tax as a single wedge induces emission reductions of 12 287 Mt over the period. Combined with incentives in Use the Market, an *additional* 5 000 Mt reductions can be achieved in Use the Market.

Considering the time profile of emission reductions, it is clear that the economic instruments have a dramatic effect in reducing the use of coal in the energy economy, at least initally. Earlier analysis modelled taxes at a range of levels. A $CO_2$ tax at R 1000 / t $CO_2$-eq, showed emission reductions of about 16 400 Mt $CO_2$-eq. However, it could not prevent emissions rising again towards the end of the period. After coal is reduced, the rising emissions – particularly from industry and transport, bend the emissions curve upward again. This is true for a wide range of tax levels analysed. This effect is more muted in Use the Markets, since the tax does not only affect energy supply, but there is also some response on the demand-side, with switching to gas and greater efficiency.

Overall, the combined cases show costs that move from net negative (initial wedges / Start Now at – R13 / t $CO_2$-eq) reducing over 11 000 Mt $CO_2$-eq cumulatively from 2003-2050. Extended wedges / Scale Up show a modest positive cost - Scale Up reduces almost 14 000 Mt at R39 / ton. Economic instruments / Use the Market achieve greater emission reductions (17 500 Mt) comparatively cost-effectively, at R 10 / t $CO_2$-eq. The treatment of tax revenues merits some discussion.

Next we examine how the combined cases and strategic options help to bridge the gap between the GWC and RBS scenarios.

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[6] For example, assumptions around the time-resolution of load factors, storage costs, cooling and availability of plants and fuel no longer hold. See the Technical Report for details.

[7] The subsidy level of 38c was arrived at by calculating the difference between the average bulk price of electricity in South Africa (12c), and the average bulk price required to make many renewable energy technologies financially viable (50c).

# 7. Overviews of results

## 7.1 Bridging the gap between GWC and RBS

Figure 2 shows combinations – initial wedges, X-wedges and economic instruments combined. It illustrates how far they close the gap between GWC and RBS. As can be clearly seen, a gap remains in all cases by 2050.

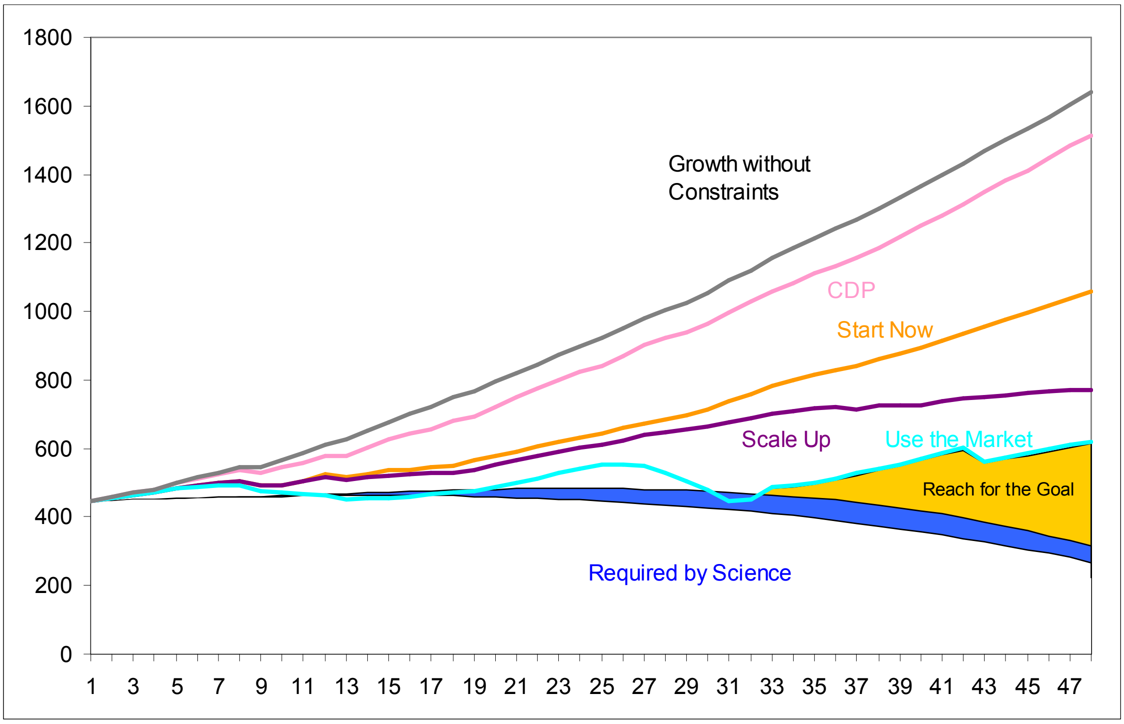



**Figure 2: GWC, RBS and combined mitigation actions** [8]

The initial combined case, demonstrates that making use of all the net negative cost mitigation options allows space to include some with net positive costs. The main qualifier is that the emissions are reduced relative to the high baseline in GWC, but increase in absolute levels right up to 2050. Expressed in terms of the gap between GWC and RBS, the combined initial scenario has closed just under than half (43%) of this gap in the year 2050.

Extending the combined case with further positive cost wedges increases emission reductions, but only stabilises them from 2040 to 2050. A key difference to the initial combined case is that emission stabilise, albeit only right at the end of the period. The combined extended scenario closes the gap about tow-thirds (64%).

The combination of economic instruments is the largest wedge analysed and the only case where emissions decline below RBS.. The emission *reductions* are larger than 2003 annual emissions. Compared to GWC, emissions decline up to 2025, but grow again in the second half of the period. Considering the end year, 2050, the gap is closed by 76% or three-quarters.

In all cases, however, the gap between GWC and RBS is not fully closed. Combined initial or even extended wedges stay well above RBS. Fundamental reasons are that rigorous quantitative analysis relies on known technologies (and cannot model the unknown or future), and does not capture behavioural changes which may be important to emission reductions in future. Economic instruments get close to RBS, but emissions rise in the end. A 'golden triangle' of remaining emission reductions needs to be addressed in other ways.

[8] The lines in Figure 2 include the emission reductions not only in the energy sector, but also in other sectors (see section 5.1 of the Technical Report).

One way is to consider future technologies and people-oriented policies. These cannot be quantified with the same rigour as the wedges presented in Table 1, at this stage. These were discussed in a meeting as part of the LTMS process and the outcomes are shown in the Process Report.

A transition to a lower-carbon economy would be another way. Instead of investing in energy-intensive sectors, which were at the heart of our economy over the twentieth century, South Africa would move towards a low-carbon economy. The possibilities of moving economic and industrial policy to favour those sectors that use less energy per unit of economic output was discussed at a meeting of eminent economists, and is discussed in the Technical Report.

## 7.2 Mitigation cost curve

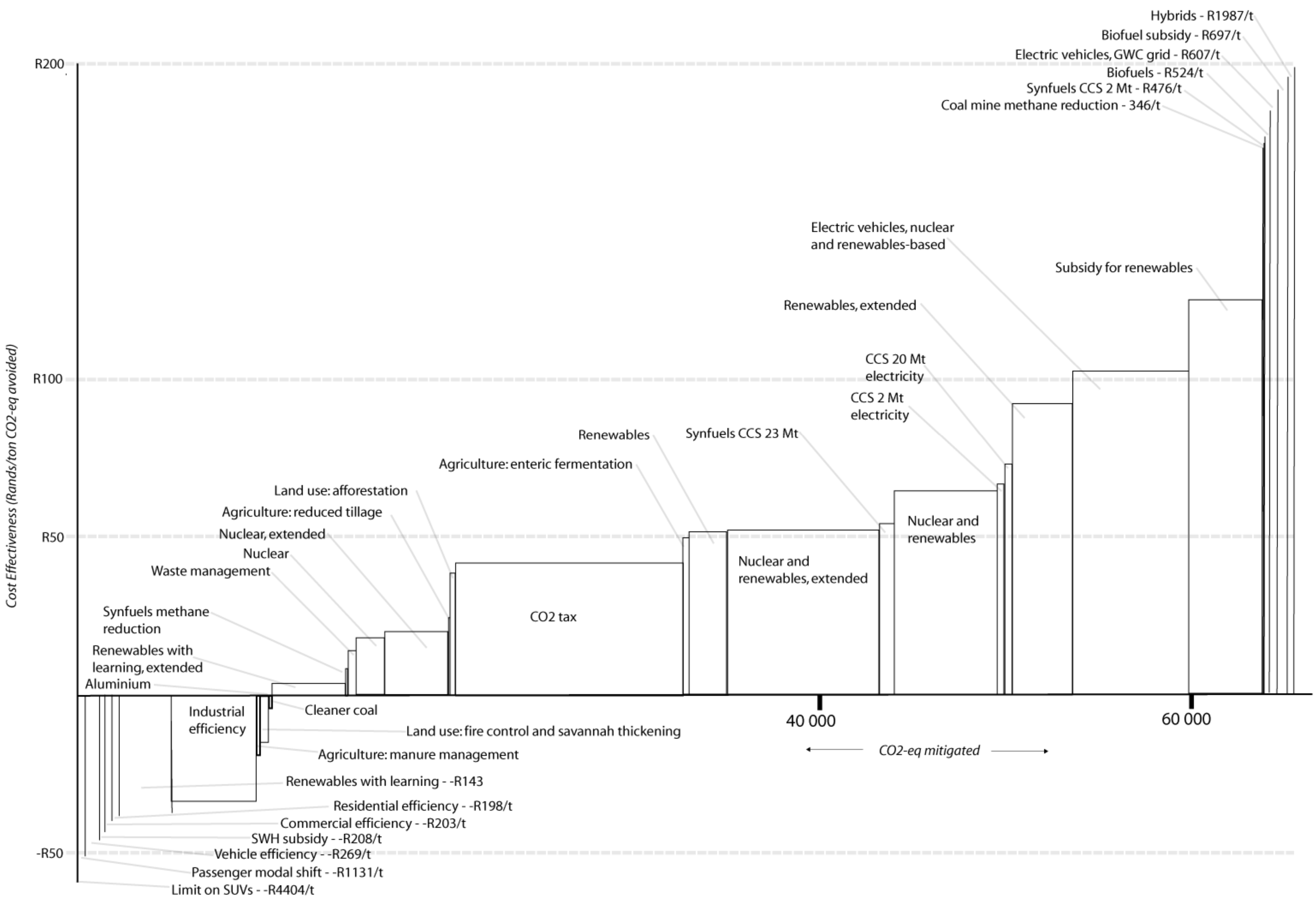
The costs and emission reductions of most wedges are summarised in a single figure, the mitigation cost curve. Figure 3 shows such a cost curve for South Africa.

The units on the y-axis are R / t $CO_2$-eq, and on the x-axis Mt $CO_2$-eq. In other words, the height of a bar shows the cost-effectiveness of mitigation, while the width of the bar indicates how much emissions are reduced. Since there are both negative and positive cost options, the x-axis extends above and below the zero line.

Since the range of mitigation costs is wide, some of the wedges have been cut off at the top. In these cases, at the extreme right and left-hand sides of the graph, the mitigation costs has been included next to the label. 'R / t' is short for R / t $CO_2$-eq.

Figure 3 shows different 'break-points' as mitigation actions are arranged from lowest to highest cost. Read in this way, the mitigation cost curve suggests that wedges are grouped in four groups. A first group - from the lowest-cost wedge to reduced tillage – includes all the net negative cost wedges and some with very modest positive costs (below R 25 / t $CO_2$-eq). This could be called the 'efficiency plus low-cost' group. The next group starts with afforestation (costs increase to R 39 / t) up to and including CCS on electricity generation at around R 75 / t $CO_2$-eq. R 50 per ton at current exchange rates is less than € 5 / t $CO_2$-eq, i.e. at the lower end of the range of prices in the carbon markets today already. The group might be given the name 'technology improvement', but it also includes the escalating $CO_2$ tax. The third group extended renewables, the subsidy for renewables, and electric vehicles, i.e. wedges grouped around R 100 / t $CO_2$-eq. The fourth group are the highest-cost options, start from coal-mine methane at R 346 / ton, rising to almost R 2000 per ton.

**Figure 3: Mitigation cost curve for South Africa**



## 7.3 Mitigation cost as cumulative shares of GDP

Total mitigation costs over a 48-year period add up to substantial numbers. These numbers can be seen in relation to the size of the economy (GDP) or the energy system. These comparative figures have been reported for individual wedges in Table 1, as a 'share of GDP' and 'increase on GWC energy system costs'. This gives some sense of the scale of effort required, based on the methodology outlined in section 2.2.5 of the Technical Report.

For net negative cost wedges[9], there are overall savings and hence a negative share of GDP or benefit. Compared to the total costs of the energy system (both supply and demand side), the ratio is larger – because the overall system one is comparing to is smaller. The costing boundary is narrower. Small wedges would cost a small percentage of GDP, which is unsurprising since GDP is a large absolute amount of money. As wedges get combined into larger combined cases, and when positive cost measures are added, the share increases.

Assuming the Stern threshold of 1% of GDP level were acceptable overall costs to the South African economy, it is of interest to see where this level is crossed. We proceeded as follows:

- A set of wedges is run, starting with the most negative cost option (among the energy wedges)
- Another negative cost option is added
- Wedges continue to be added, seeking to avoid double-counting, e.g. including an initial wedge and its extended version

The results are shown in Figure 4 and the sequence of runs in the table below it. The first run (Run00) includes SUV's, the wedge with the highest negative cost in Table 1. Run1 then adds modal shift in passenger transport, Run 2 vehicle efficiency and so on. For each successive run, the previous wedges are also included.

The results are plotted shown the 'share of GDP' on the y-axis and cumulative emission reductions on the x-axis. The horizontal distance between two points shows how much mitigation the combined runs have produced. As the line moves up the y-axis, it can be seen when total mitigation costs are equivalent to 1% of GDP.

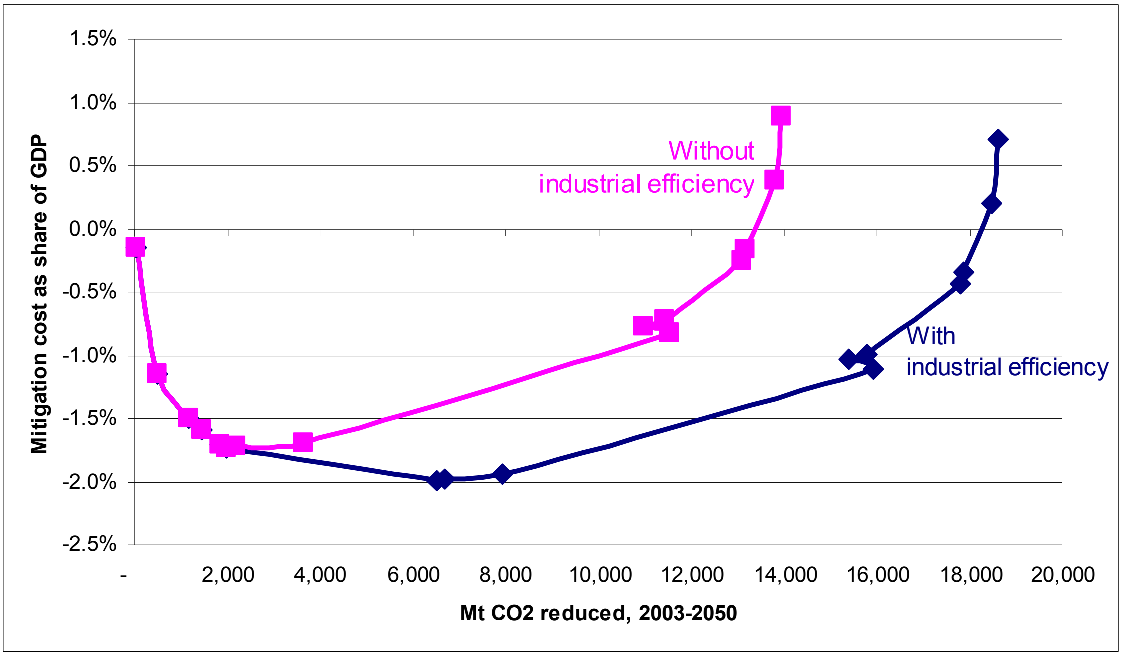
As is seen in the results, combining a set of negative cost options – mostly energy efficiency in various sectors - would make the share of GDP more negative, so that the curve initial slopes downward.

Figure 4 shows that a range of positive cost wedges, such as those in electricity generation or CCS, can be added and still remain below 0% of GDP. *On their own*, positive cost wedges would have total mitigation costs that are a positive percentage, when compared to economic output. But when *added up cumulatively*, then the total cost of the package represented by the runs is still net negative. They become positive *overall* when electric vehicles and hybrids (both positive cost with large reduction potential) are added in the last two runs. The sensitivity analysis shows that electric vehicles are more competitive at higher oil prices.

The results depend on the wedges chosen. This becomes clear when the industrial energy efficiency is included, or excluded – as represented in Figure 4 by the two lines. Initially, the two lines are the same as the runs are identical. From the sixth run, they diverge. Industrial energy efficiency not only drives the overall costs further into negative territory, but it also adds a large amount of emission reductions. With the big efficiency wedge, even when all the positive-cost wedges are added, the total still does not exceed expenditure equivalent to 1% of GDP.

[9] For an explanation of negative and positive cost options, see Footnote 5.

**Figure 4: Mitigation costs as share of GDP, for cumulatively combined wedges**




| | ***With industrial efficiency*** | | ***Without industrial efficiency*** | |
|---|---|---|---|---|
| ***Wedge added in this run*** | ***Mt CO2, 2003-2050*** | ***% GDP*** | ***Mt CO2, 2003-2050*** | ***% GDP*** |
| Limit on less efficient vehicles | 18 | -0.15% | 18 | -0.15% |
| Passenger modal shift | 480 | -1.15% | 480 | -1.15% |
| Improved vehicle efficiency | 1,157 | -1.50% | 1,157 | -1.50% |
| SWH subsidy | 1,462 | -1.59% | 1,462 | -1.59% |
| Commercial efficiency | 1,838 | -1.70% | 1,838 | -1.70% |
| Residential efficiency | 1,992 | -1.74% | 1,992 | -1.74% |
| Industrial efficiency | 6,505 | -1.99% | n/a | n/a |
| Cleaner coal | 6,683 | -1.98% | 2,194 | -1.73% |
| Nuclear | 7,926 | -1.94% | 3,659 | -1.70% |
| Escalating CO2 tax | 15,922 | -1.11% | 11,556 | -0.83% |
| Renewables | 15,408 | -1.04% | 10,981 | -0.77% |
| CCS 20 Mt | 15,775 | -0.99% | 11,434 | -0.72% |
| Subsidy for renewables | 17,803 | -0.43% | 13,107 | -0.25% |
| Biofuels | 17,872 | -0.34% | 13,175 | -0.16% |
| Electric vehicles in GWC grid | 18,493 | 0.20% | 13,800 | 0.38% |
| Hybrids | 18,629 | 0.71% | 13,936 | 0.89% |

# 8. Economy-wide implications

The economy-wide study focuses on the long run economic effects of energy efficiency in productive sectors, and changes in the energy supply fuel mix. The implications for overall economic output, jobs and income distribution are reported, given insight into the broader economic impact of efficiency wedges and those change the structure of electricity or liquid fuel supply.

Industrial energy efficiency is assessed both in terms of saving electricity or heat. Electrical efficiency can increase the wages of skilled workers rise by 0.5 and 0.7 per cent, while employment among abundant low-skilled workers rise by 0.5 per cent. For thermal savings, skilled wages increase by 0.5 and 1.1 per cent, and low-skilled employment increases by 0.3 and 0.8 per cent in the two periods.

While the small change in employment means that there are no major income distribution effects, some positive welfare effects are reported. Aggregate household expenditure levels increase across all representative household groups in the model. GDP increases only marginally by 0.4 and 0.5 per cent in 2020 when electricity is saved, up to 0.9 per cent when other fuels are saved.

The commercial sectors uses predominantly electricity and hence the focus is on electrical efficiency. Because energy makes up less of the input costs (commerce is less energy-intensive), changes in skilled wages, low-skilled employment and household expenditure levels (welfare) are all smaller than in industry, but nonetheless positive (around 0.1 and 0.2 per cent).

Overall, energy efficiency gains have 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.

The economy-wide analysis also considered structural changes in the energy output mix. For electricity supply, the fuel mixes of the renewables and nuclear 'ordinary wedges' are examined in the economic model. For liquid fuels, biofuels are considered.

A shift to nuclear power causes an increase in high skilled employment at the expense of a relatively large number of low-skilled jobs. The overall employment level in the economy declines marginally as a result. Even small job losses are of concern. The renewables intensive process, which is characterised by a higher labour intensity than any of the other electricity generation processes[10], results in employment gains relative to the reference case. Further details on the effects of individual wedges are described in the full report (in particular, see section 13.4.2.3 of the Appendices to the Technical Report).

The overall changes in employment are small in relative terms, ranging between -0.2% and +0.2% change from the economic reference case. Where there are job losses, they would need to be off-set. Household income changes are also small and almost negligible. Given the importance of fighting unemployment, however, any changes in absolute job numbers deserve attention.

In the biofuels alternative a slightly greater reliance on biofuels is modelled, but given the small overall contribution of biofuels, even a large increase in biofuels output does little to alter trends in production and employment. A visible effect under the biofuels scenario is a slightly higher increase in agricultural output relative to the reference case. This comes at the expense of coal mining output. A biofuels scenario, as modelled here, is unlikely to have any significant economy-wide welfare implications.

The aforegoing has focused on the impacts on the economy of individual wedges. The economy-wide implications of combined wedges (and the strategic options) were also considered. These impacts are described more fully in the Technical Report (section 7.2). In this Technical Summary, Table 2 provides an overview of the economy-wide results for the strategic options.

[10] For a more detailed discussion of this point, including references, see the full report on economy-wide impacts in the Appendices to the Technical Report.

**Table 2: Condensed summary of results of economy-wide modeling**

| | ***Structural Shift*** | ***Efficiency*** | ***Investment*** | ***Impact on GDP*** | ***Employment / job impact*** | ***Poverty / welfare*** |
|---|---|---|---|---|---|---|
| | Description of inputs to economic model | | | Results | | |
| Start Now / combined initial wedges | Moderate shift towards renewables, e.g., electricity supply from coal declines to 46 %, with nuclear and renewables each contributing around 27 % in 2050 (9% renewables and 5% nuclear by 2015)<br>Also: changes in transport to more efficient vehicles and shifting to public transport | Net-negative cost wedges, esp energy efficiency, implemented esp in industry | Relatively little additional investment required, few positive cost mitigation options added. | Small / negligible (+0.2% GDP in 2015) | Small and ambivalent - positive for unskilled (1%), skilled (1.2%) and highly-skilled (1.7%) in 2015, but negative for semi-skilled (-2% in 2015, -2.5% in 2010) – which is of concern. Only short-term costs of mitigation are considered and not the longer-term productivity gains. | Household welfare increases relative to reference case for all household groups.<br>High income HH benefit as high skilled labour gains and low skilled labour loses. Savings reduce investment requirements also avoid negative consumption effects of higher savings |
| Scale Up /combined extended wedges | Transition to zero-carbon electricity by mid-century. Significant shift towards renewables and nuclear, e.g., output share of coal-fired electricity plants declining to 2 %. Add carbon capture and storage, extend biofuels as far as possible, introduce electric vehicles | Mitigation extended, adding more efficiency and further positive cost wedges | Significant investment required, between 5 and 10% above the reference case | Initially higher (+1% in 2015) | Increase: +1% in 2015<br>Semi-skilled jobs peak at 3% in 2015 | Generally negative with positive impacts for low skill labour if biofuels is pushed hard<br>High income HH lose (opposite of above) |
| Use the Market / $CO_2$ tax | Uses economic instruments. Key driver is a CO2 tax, starting at current carbon prices and escalating. Tax quickly reduces coal in electricity and synfuel sectors and shifts in fuel and towards efficiency.<br>[Incentives included in energy modeling for SWH, biofuels and renewable electricity not assessed in CGE modeling] | Driven by tax, but efficiency allows (limited) response on energy demand side. Plus fuel switching to gas | High investment required initially, 20% above reference case | Negative (-2% in 2015) as taxes result in energy price increases unless countered by fiscal policies. Recycling revenue can off-set economic impact at lower tax levels. | Jobs *increase* for lower-skilled (+3% semi-skilled, 0% for unskilled in 2015)<br>*Decrease* for higher-skilled workers (-2% for skilled and -4% for highly skilled) | Negative for all households, except poorer households who gain initially from food subsidy; impact depends on fiscal options, low income households can be targeted directly |

# 9. Sensitivity analysis

All model results are sensitive to variation in key input parameters. Sensitivity analysis was conducted on GDP, the discount rate and energy prices (oil, gas, coal and uranium).

The assumed GDP *growth rate* has significant implications for emissions. Other things being equal, greater economic growth will increase emissions. The composition of GDP – how much of it comes from primary, secondary and tertiary sectors – has major implications as well since some sectors are less emissions-intensive than others. The GDP growth *rate* is kept in the ASGISA range between 3% and 6% per year; but we do assume that the structure of the economy changes over time, in GWC, in line with current trends (see section 2.4.1.2 of the Technical Report).

The discount rate matters for costs results. As noted in the section on Drivers, the IPCC recommends that for long-term mitigation studies, a lower rate based ethical considerations, around 3%' (IPCC 2001: 467). This study integrated sensitivity analysis on the discount rate, including the 3% value, by reporting all cost results for 15%, 10%, and 3%. As expected, a high discount rate favours mitigation actions where many of the costs are in the future, and present costs are relatively low. Conversely, a low discount rate shows lower mitigation costs for wedges with high initial costs and low ongoing costs. This would apply in cases where little money has to be spent on capital upfront, but running costs are high over time. The future operating costs are discounted. A low discount rate is favourable for wedges that have high capital costs, but low running costs, e.g. renewables.

For the sensitivity on energy prices, a key finding was that the costs associated even with large wedges can be relatively small compared to additional costs incurred because of increases in crude oil prices. A higher oil price would, for example, be comparable to the impacts of a carbon tax. Furthermore, in a world with higher coal and oil prices, mitigation costs would in fact drop as the total costs of the energy system rise. In cases where synfuel use is minimised (carbon tax), a high crude oil price *increases* the use of synfuels, thus raising emissions. But the most significant response is to the coal price, which reduces coal used in synfuels plants, but less so for electricity.

Additional sensitivities were run for specific wedges: the Cleaner Coal, Industrial Efficiency, Subsidy for Renewables, and Extended Nuclear and Renewables wedges were run with a higher coal price and the Improved Vehicle Efficiency, Electric Vehicles in GWC Grid, Hybrids and Passenger Modal Shift wedges were run with the higher of the two oil prices ($150 / bbl by 2030).[11] No variation on the uranium price was conducted here, since the above sensitivities showed little response. The results are contained in Table 3 and Table 4. The results with existing assumptions for energy prices are included in brackets in each cell for comparison.

**Table 3: Sensitivity of selected wedges to high coal prices**

| *Numbers in brackets are with existing energy price assumptions, see text* | ***Mitigation cost (R / t CO2-eq)*** | ***GHG emission reduction, Mt CO2-eq, 2003-2050*** | ***% increase on GWC costs*** | ***Mitigation costs as share of GDP*** |
|---|---|---|---|---|
| Cleaner coal | -11<br>(-5) | 195<br>(167) | -0.02%<br>(-0.01%) | -0.01%<br>(0.00%) |
| Industrial efficiency | -46<br>(-34) | 4675<br>(4572) | -1.70%<br>(-1.24%) | -0.39%<br>(-0.26%) |
| Subsidy for renewables | 105<br>(125) | 4590<br>(3887) | 3.23%<br>(3.65%) | 0.73%<br>(0.77%) |
| Nuclear, extended | 7<br>(20) | 3186<br>(3467) | 0.17%<br>(0.68%) | 0.04%<br>(0.15%) |
| Renewables, extended | 72<br>(92) | 3698<br>(3285) | 2.10%<br>(2.64%) | 0.48%<br>(0.56%) |

[11] The oil prices for the sensitivity analysis rise to $100 / bbl and $150 / bbl respectively in 2030 and are extrapolated beyond. Gas prices vary with oil prices. The coal price is increased at the same rate, in relation to the coal price in the GWC reference case. For details, see the Technical Report, section 8.2.

**Table 4: Sensitivity of selected wedges to high oil and gas prices**

| *Numbers in brackets are with existing energy price assumptions, see text* | ***Mitigation cost (R / t CO2-eq)*** | ***GHG emission reduction, Mt CO2-eq, 2003-2050*** | ***% increase on GWC costs*** | ***Mitigation costs as share of GDP (%)*** |
|---|---|---|---|---|
| Improved vehicle efficiency | -720<br>(-269) | 758<br>(758) | -3.86%<br>(-1.90%) | -1.19%<br>(-0.41%) |
| Electric vehicles in GWC grid | -997<br>(607) | 471<br>(450) | -3.30%<br>(2.27%) | -1.02%<br>(0.48%) |
| Hybrids | 1244<br>(1987) | 371<br>(381) | 2.56%<br>(6.27%) | 0.74%<br>(0.52%) |
| Passenger modal shift | -1907<br>(-1131) | 456<br>(469) | -5.86%<br>(-4.89%) | -1.79%<br>(-1.05%) |

As with the sensitivity analysis above, the general trend is for mitigation costs to drop, due to the increased fuel costs in the higher-priced GWC. The most startling result is for electric vehicles, which switch from quite a high positive cost to a large negative cost with a high crude oil price, due to avoided consumption of crude oil products. The impact on mitigation is more equivocal, with small fluctuations in both directions.

More details on the sensitivity analysis are reported in section 8 of the Technical Report.