Scenarios in the context of assessment of mitigation and adaptation

Summary:

- Without additional policies, greenhouse gas emissions are likely to grow by 40-80% in the 2000-2030 period. The IEA WEO06 reference takes a central position within this range.
- With additional policies, greenhouse gas concentration can be stabilized at various levels – with values in published scenarios ranging from 400 ppm CO_2-eq. to more than 1000 ppm CO_2-eq.
- The increase in global mean temperature is a function of this stabilization levels – although considerable uncertainty exists. 650 ppm CO_2-eq is likely to lead to an equilibrium temperature around 3.5^oC, 550 ppm to 3^oC and 450 ppm to $2\text{-}2.4^oC$. Impacts, however, are determined by the transient temperature change. For 2025, hardly any difference exists between stabilization and baseline scenarios ($1\text{-}1.5^oC$). In 2050, the transient temperature for 650, 550 and 450 ppm CO_2 are respectively $1.6\text{-}2.5^oC$, $1.5\text{-}2.2^oC$ and $1.4\text{-}2^oC$. In 2100, these numbers are $2.2\text{-}3.5^oC$, $1.8\text{-}3^oC$ and $1.6\text{-}2.5^oC$. Uncontrolled, 2100 temperature would be around $2.2\text{-}4.8^oC$.
- Mitigation costs increase as a function of the stabilization level. Income losses in 2030 are estimates to be around 0.2% for 650 ppm, 0.6% for 550 ppm and less than 3% for 450 ppm. Permit prices are in the order of 20, 50 and 100 US\$/tCO_2.
- The IEA WEO06 AP scenario corresponds more-or-less to a 650 ppm case. The BAPS scenario takes a position in between 550 and 450 ppm CO_2-eq.
- Different methods exist for comparing mitigation costs and benefits of climate policy, among which risk based approaches and cost-benefit analysis. The latter shows the uncertainty ranges of monetary estimates of costs and benefits to be overlapping.
- Further progress is made in use of scenarios in adaptation and impact studies, among other by downscaling techniques – but assessment remains complex. One contributing factor is that impacts of climate change can be strongly modified by non-climate factors.

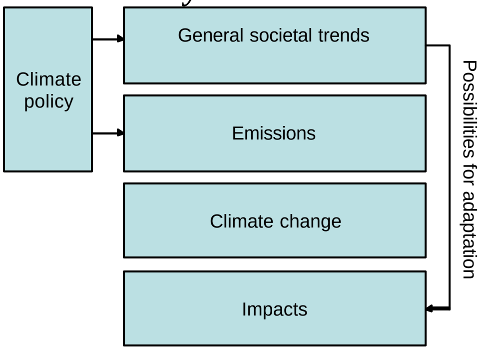
1. Introduction

Scenario-analysis provides an effective tool for exploring future trends in view of the large uncertainties involved. The term *scenarios* refers to a plausible description of how the future might develop, based on a coherent and internally consistent set of assumptions ("scenario logic") about the key relationships and driving forces (e.g. rate of technology change or prices) (Nakicenovic and Swart, 2000). The rationale of the scenario approach is that instead of estimating the likeliest future, the situation moves into an assessment of possible pathways of events ("what if"?).

Despite the large uncertainties, exploration of long-term societal trends is required to human abilities to mitigate or to adapt to climate change. This is because:

- *Climate change is a slow process*. Current emissions will continue to influence the world's climate system over the next century.
- Important parts of the *energy infrastructure* (the main cause of climate change) have *very long lifetimes*
- The *infrastructure that is affected also often has long lifetimes*.
- *Lock-in effects* (in infrastructure, technology and product design) further slow down the rate of change in the societal system.

Figure 1: Overview of cause-effect chain of climate change underlying most scenario analysis



Scenarios are normally developed along the cause-effect chain of climate change, thus going from general societal trends ("drivers"), to emissions, climate change and climate impacts. Climate policy possibly affects the societal trends and emissions, while the societal trends also determine the possibilities for adaptation. Feed-backs from climate change impacts onto the drivers are usually not considered.

IPCC's 4th Assessment Report recently reviews the current long-term scenario literature – both in the context of the mitigation (Chapter 3; Working Group 3 (Fisher et al., 2007)) and adaptation assessment (Chapter 2; Working Group 2 (Carter et al., 2007)). This document provides an overview of the information contained in these chapters. The paper is organized as follows:

1. Type of scenarios used in literature
2. Insights in long-term societal trends (population, income, energy consumption);
3. Development of greenhouse gas emissions in the absence of climate change
4. Development of emissions with climate policy
5. Possible use of scenarios for adaptation analysis
6. Integrated assessment on mitigation, climate damage and adaptation.

7. Conclusions

2. Type of scenarios used in literature

Scenarios exist in very different forms (Van Vuuren, 2007). An important difference in types of scenarios occurs between primarily *descriptive / explorative scenarios*, i.e. scenarios that are constructed to explore the future under a set of “what-if” assumptions and *normative scenarios*, i.e. scenarios that lead to a future that is pre-defined on the basis of a set of goals. Within the first group, studies may look at a set of contrasting scenarios, but also “*business-as-usual*” or “*best-guess*” scenarios are part of this group.

Probabilistic scenarios represent a different approach to uncertainties than the normal descriptive scenarios. Probabilistic scenarios are based on estimates of the probability density function (pdf) for crucial input parameters. In these cases, outcomes are associated with an explicit estimate of likelihood, albeit one with a substantial subjective component.

The most important characterization of scenarios here is formed by *baseline* and *mitigation* scenarios[1] (these two categories are simply a special form of descriptive and normative scenarios). *Baseline scenarios* explore possible development without climate policies – while *mitigation scenarios*, in general, aim at a pre-specified GHG reduction pathway. Most *mitigation scenarios* belong to the subgroup of *stabilization scenarios*, aiming to stabilize GHG concentrations in the atmosphere. Some scenarios in the literature are difficult to classify as either mitigation or baseline scenarios, such as those developed to assess sustainable development paths. Moreover, with the current development of climate policies, the distinction between baseline and mitigation scenarios becomes more difficult to make.

3. Changes in underlying societal trends

Important factors that determine the future greenhouse gas emissions include 1) population, 2) income growth, 3) changes in the energy system, 4) changes in land use. Changes in these factors will be briefly discussed here.

Figure 2: Overview of scenario literature for main driving forces in comparison to the WEO-2006, IS92a and A1 and B1 IPCC SRES (based on (IEA, 2006; Nakicenovic et al., 2006; Fisher et al., 2007))

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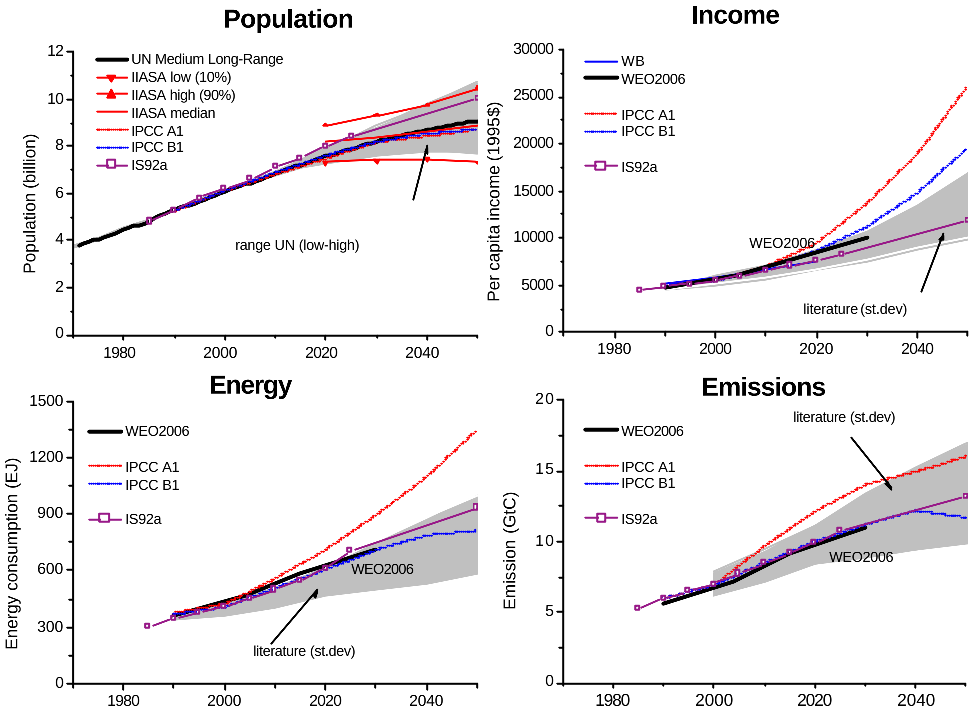
[1] Alternative terms for baseline scenarios used in literature are reference scenarios and non-intervention scenarios. Mitigation scenarios are sometimes referred to as intervention scenarios.



Population

Current projections expect a further growth of the world population in the first half of the century (from 6.1 billion in 2000 to around 9 billion in 2050). In the second half of the century, world population is expected to stabilise and finally decline – but the rate at which this transition occurs is highly uncertain. Scenarios from most commonly referenced demographic institutions (UN and IIASA) range from 6 to 15 billion for global population in 2100 – with a more likely range of outcomes around 8-10 billion (Lutz et al., 2004; UN, 2005). The increase of global population is fully determined by the increase in developing countries. It should be noted that current population projections show a lower increase than was expected a few years ago. The most important reason is new data indicating that birth rates in many parts of the world have fallen sharply, but to some degree also a much more pessimistic view on the extent and duration of the HIV/AIDS crisis in sub-Saharan Africa contributes to this. The decline in population projects is driven primarily by changes in outlook for the Asia and the Africa-Latin America-Middle East (ALM) region. In contrast, in the OECD region updated projections are somewhat higher than previous estimates

Income

Many of the long-term economic projections in the literature have been specifically developed for climate related scenario work. A comparison of the global GDP projections in scenario literature with the SRES scenarios and WEO-2006 is shown in Figure 2. The SRES scenarios project a very wide range of global economic per person growth rates from 1.0 % (A2) to 3.1 % (A1) to 2030, both based on MER. This range is somewhat wider than the range covered by the more recent literature. The central projections of DOE, IEA and the World Bank all contain growth rates of around 1.5 to 1.9%, thus occurring in the middle of the range of the SRES scenarios

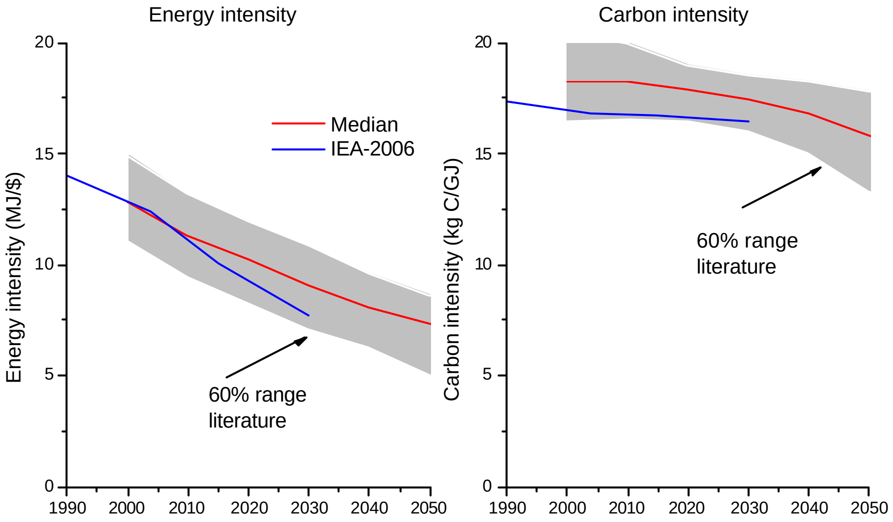
(US.DoE, 2004; WorldBank, 2004; IEA, 2006). Other medium term energy scenarios are also reported to have growth rates in this range (IEA, 2006).

Energy use

Driven by an increasing population, further income growth and changes in life-style virtually all scenarios expect a further growth of primary energy use. The IEA WEO2006 projection of a further increase of 50% in the 2000-2030 period compares well to other central estimate scenarios. The total uncertainty range of 65% interval in 2030 primary energy represents a 40-70% increase compared to 2000. As there have been no major changes in primary energy use projections over the last few years in literature – the IPCC SRES scenarios also compare reasonably well to current literature (they intentionally cover the full range of uncertainty and thus go beyond the central range indicated in Figure 2).

Trends in energy use can be represented by changes in energy intensity, expressed as gigajoule (GJ)/GDP, and change in the carbon intensity of the energy system (CO_2/GJ) as shown in Figure 3. In all scenarios that have been published over the last few years, energy intensity improves significantly across the century - with a mean annual intensity improvement of 1.0 %. The 90 % range of the annual average intensity improvement is between 0.5 and 1.9 % (which is fairly consistent with historic variation in this factor). The carbon intensity is more constant in scenarios without climate policy, showing an improvement rate of 0.4 %, but the uncertainty range is relatively large (-0.2 to 1.5%). On the high end of this range scenarios are found that assume that carbon free energy technologies become competitive without climate policy (increasing fossil fuel prices and rapid technology progress). Scenarios with a low carbon intensity improvement coincide with scenarios with a large fossil fuel base, less resistance to coal consumption or lower technology development rates.

Figure 3: Development of carbon intensity of energy and primary energy intensity (based on (IEA, 2006; Nakicenovic et al., 2006)). Differences in carbon intensity values in 2000 are due different categories of emissions included in the analysis.

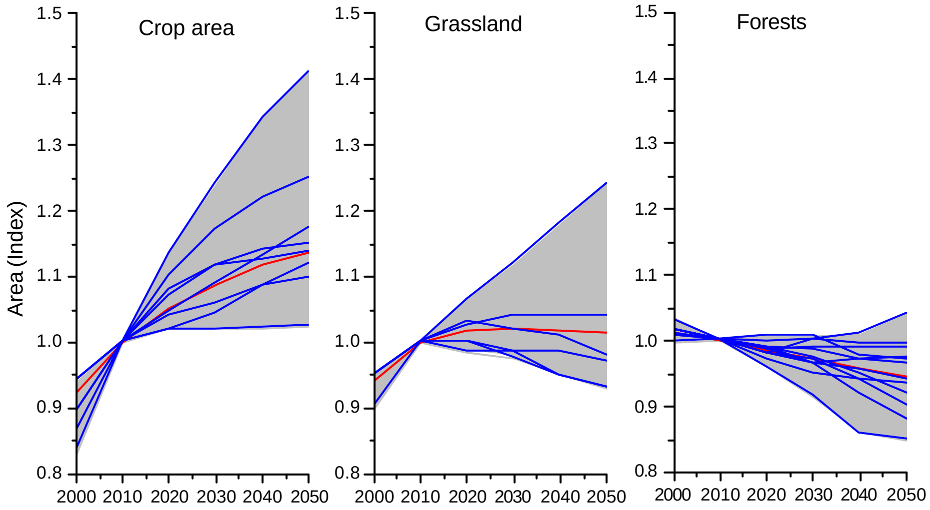


Land use

Land use and land cover change represents another important factor development of climate change. Even if land activities are not considered as subject to mitigation policy, the impact of land use change on emissions, sequestration, and albedo plays an important role in radiative forcing and the carbon cycle. At the moment, only a subgroup of the scenarios takes land use and land cover change into account. The results of comparing these scenarios (in the absence of climate policy) is shown in Figure 4.

The figure shows that most scenarios expected a further increase in crop land world wide in the next 50 years, with a central estimate of around 20%. After 2020, this increase seems to level off. Forest area follows the opposite trend (as a consequence of crop land changes) with a further decline of 10-20% in the next 50 years. It should be noted that this global trend is the result of a net reforestation in temperature zones and a more rapid deforestation in tropical areas. For grasslands, some scenarios expect them to remain constant – while others expect a noticeable increase.

Figure 4: Global cropland, forest land and grassland projections (2010 = 1; shaded areas indicate full range; red line indicates average value, based on (Fisher et al., 2007))



Scale of available information

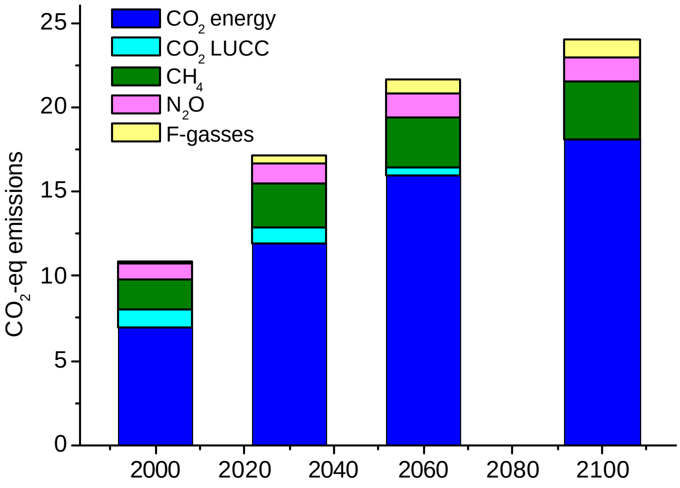
So-far, in formation on scenario drivers has been mostly developed at the level of large regions (e.g. 10-20 regions) – with is often sufficient for climate modeling and mitigation analysis. For analysis of impact, adaptation and vulnerability, however, a finer scale is needed. Recently, a range of downscaling methods and regional scenario development have been applied to produce information at finer scales – including for climate parameters, socio-economic conditions, land use and land cover, atmospheric composition and sea-level rise.

4. Development of emissions in the absence of climate policy

Nearly all mitigation scenarios in literature show greenhouse gas emission to grow further over the next decades[2]. In the 2000-2030 period, a mid range estimate indicates an emission increase of around 40-80%. The mean value of 60% is virtually equal to the increase in the IEA scenario. Figure 5 shows the contribution of the different sources and gases to total emissions (mean across a representative set of scenarios). It shows the CO_2 emissions from fossil fuel use are expected to remain the largest contributes to overall emissions – and in fact, it share is expected to increase from nearly 65% in 2000 to 70% in 2030 and 75% in 2100. Also CH_4 and N_2O emissions are expected to grow further – but at a slightly slower rate (these gases originate mostly from agricultural activities which are expected to grow less fast than energy consumption). CO_2 emissions from land use change are expected to decline over time as a result of declining net deforestation rates.

The comparison made in Figure 1 between the energy-related CO_2 emissions in current literature (scenarios published since IPCC-TAR), the IPCC SRES scenarios (markers) and the reference scenario of the World Energy Outlook shows that the IPCC SRES scenarios are in the short-term somewhat on the high end of the range. Although in the short-term the WEO-reference scenario follows the B1 emission pathway, based on its 'storyline' one should expect in the long-run the WEO-ref scenario to follow a path near the A1 and B2 emission scenarios.

Figure 5: Greenhouse gas emission development (mean across a set of representative scenarios) (based on (Fisher et al., 2007))



Position of the IEA-WEO6 scenario against current literature on baseline emission scenarios used in IPCC AR4.

Overall, it can be concluded that the IEA scenario tends to take a central position within the range of current literature. For some drivers, the trajectory depicted in the IEA scenario is somewhat higher than the mean literature value – but for emissions, the trajectory is very near to the mean of the scenarios published in the 2001-2006 period. Compared to the IPCC SRES scenarios, emissions are close to the B1 trajectory – but given the storylines, in the longer-term one could expect the IPCC-

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[2] The total number of scenarios published is a few hundred of which about 100 were published in the last few years.

WEO scenario to be more comparable to the A1 and B2 scenarios. It should be noted that the IEA scenario does not include several important emission categories such as non-CO_2 emissions, emissions from land-use and land cover change and the f-gasses.

5. Mitigation scenarios

A large number of mitigation scenarios have been published since 2001. Most of these scenarios are so-called stabilization scenarios, i.e. aim for stabilization of greenhouse gases. Some scenarios, however, have explored alternative targets such as temperature and peak profiles for greenhouse gas concentration. Emerging literature shows that the latter a for very stringent temperature targets (such as for instance the 2^{o}C target proposed by the EU) to reach these targets at limited costs.

Among the stabilization scenarios, an increasing body of literature is considering so-called multi-gas scenarios – not only looking into emission reductions for energy-related CO_2 but all relevant greenhouse gases. These scenarios tend to find that multi-gas strategies can reach similar climate targets as "CO_2-only" scenarios at considerable lower costs. The presence of both multi-gas and "CO_2-only" analysis in literature forms some complication in an overall assessment. In order to compare scenarios, IPCC WG-III has introduced a scenario classification scheme based on different classes of ambition with respect to the stabilization target.

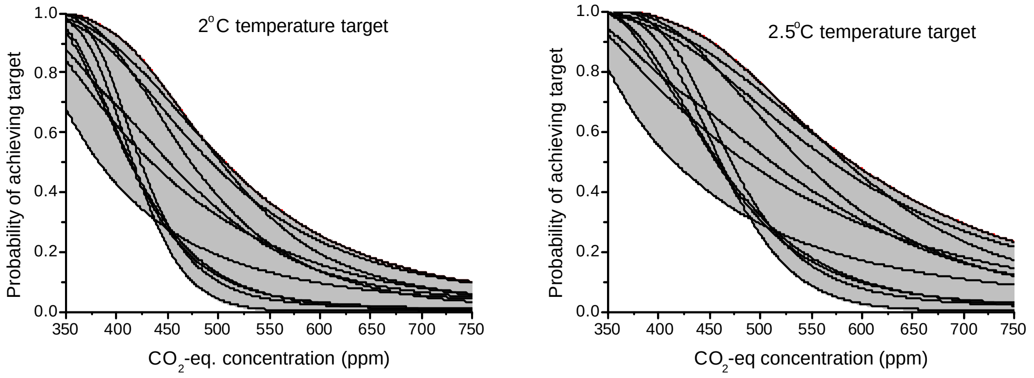
Table 1: Classification of recent (Post-TAR) stabilization scenarios according to different stabilization targets and alternative stabilization metrics. Groups of stabilization targets were defined using the relationship in Figure 3.17 ((Fisher et al., 2007))

Category	Stabilization target			Global mean temperature change*	2050 emission (% of 2000 emissions)	No. of scenarios
	Additional radiative forcing	CO2 concentration	CO2 - eq. Concentration			
	W/m2	ppm	ppm		%	
Ia	2.5 – 3.0	350 – 400	445 – 490	2.0 – 2.4	-90 to -50	6
Ib	3.0 – 3.5	400 – 440	490 – 535	2.4 – 2.8	-60 to -30	18
II	3.5 – 4.0	440 – 480	535 – 590	2.8 – 3.2	-30 to +5	21
III	4.0 – 5.0	480 – 570	590 – 710	3.2 – 4.0	+10 to +60	118
IV	5.0 – 6.0	570 – 660	710 – 855	4.0 – 4.9	+25 to +85	9
V	6.0 – 7.5	660 – 790	855 – 1130	4.9 – 6.1	+90 to +140	5

*global mean temperature estimate is based on the 'best-guess' climate sensitivity of 3.0^{o}C.

In the last years, there has been a shift to express the temperature consequences of stabilization scenarios more in term of probabilistic expressions than single values and/or ranges. In Figure the probability for equilibrium temperature for 2^{o}C and 2.5^{o}C are shown as a function of the CO_2-eq concentration. The figure shows that 50% probability for 2^{o}C more-or-less corresponds to 450 ppm CO_2-eq or category Ia. For 2.5^{o}C the corresponding concentration is around 525 ppm CO_2-eq or category Ib. For 3^{o}C, a 50% probability is achieved at around 550 ppm CO_2-eq or category II. Finally, category III corresponds more-or-less to a 50% probability at 3.8^{o}C.

Figure 6: Probability of equilibrium temperature change staying within the 2^{o}C or 2.5^{o}C limit for compared to pre-industrial for different CO_2-eq. concentration levels compared to pre-industrial (following calculations of (Meinshausen, 2006).

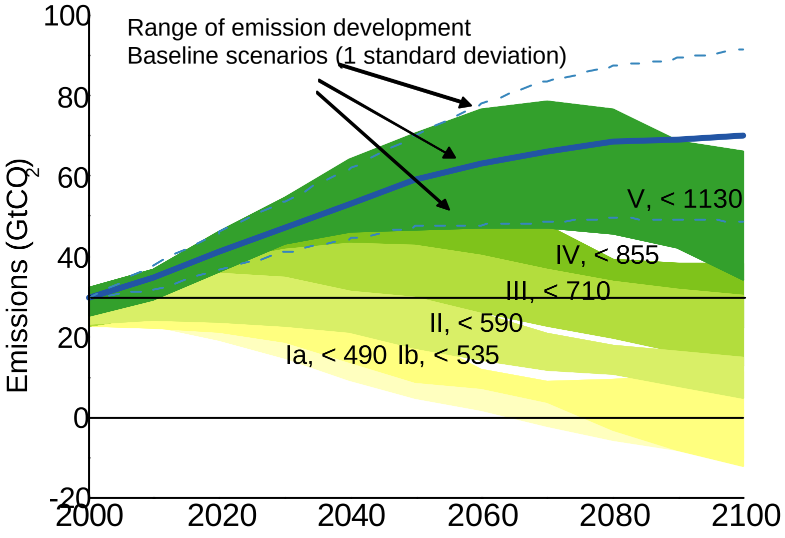


Note: The lines indicate the probability function as indicated in the individual studies quoted by (Meinshausen, 2006); the grey area indicates the total range between the highest and lowest study.

Required emission reductions

In Figure 7, the emission trajectories corresponding to the IPCC categories are shown. A study by Van Vuuren et al. (2007)) developing scenarios for similar targets using one set of models finds a similar emission ranges – based on uncertainty in the land-use emissions, other baseline emissions and timing in reduction rates (the latter implies that being low in the range early in the scenario period, allows being high in the range later on and visa-versa).

Figure 7: Emission profiles for different categories of scenarios ((Fisher et al., 2007))



The required emission reductions can also be shown in terms of the comparison between 2030 emissions and 2000 emissions. This is done in Table II. As shown, the emission reduction increase from an allowed 70% increase (no mitigation compared to baseline) to a 7% increase in category II, a 3% reduction in category Ib and 20% in category Ia. It should be noted that in cases, the reduction are based on actual emission scenarios reported in literature (in other words, there are feasible pathways for the energy system to reach these reduction according the model used).

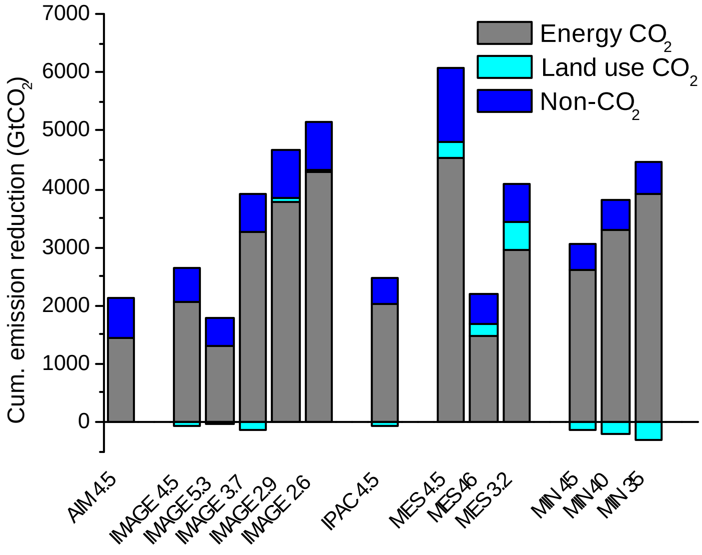
Table II: Emission in 2030 compared to 2000 (Fisher et al., 2007; van Vuuren et al., 2007)

	Mean	15%	85%	Van Vuuren et al., 2007 (IMAGE)
Ia	-23%	-44%	-1%	-15%
Ib	-3%	-21%	15%	-10%
II	7%	-16%	29%	+12%
III	36%	15%	57%	+30%
IV	45%	25%	64%	
V	70%	59%	81%	

Reduction measures

A comparison of selected model runs has been made to obtain some idea of the reduction measures underlying these stabilization scenarios. Emission reductions can also be achieved from other gasses and sources. Figure 8 illustrates the relative contribution of measures for achieving climate stabilization from three main sources: 1) CO_2 from energy and industry; 2) CO_2 from land-use change; and 3) the full basket of non-CO_2 emissions from all relevant sources. An important conclusion across all stabilization levels and baseline scenarios is the central role of emissions reductions in the energy and industry sectors. The non-CO_2 gases and land-use related CO_2 emissions (including forests) are seen to contribute together up to 35 % of total emissions reductions. While this may suggest a limited role, the majority of recent studies indicate the relative importance of the latter two sectors for the cost-effectiveness of integrated multigas GHG abatement strategies.

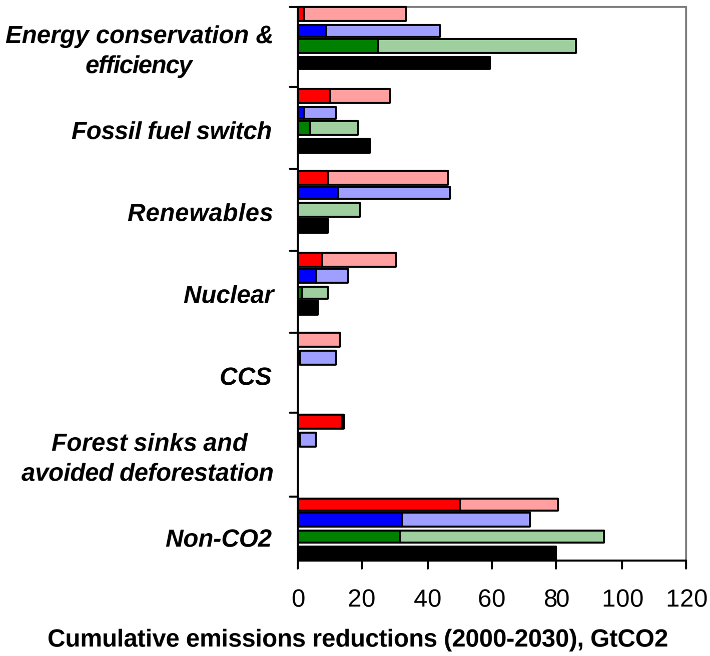
Figure 8: Contribution of various options in reducing emission – period 2000-2100, various targets (Fisher et al., 2007)



Reduction measures in the energy sector

Zooming in on the energy sector, the options can be grouped into two principal measures for achieving CO_2 reductions: 1) improving the efficiency of energy use (or measures geared toward energy conservation); and 2) reducing the emissions per unit of energy consumption. The latter comprises the aggregated effect of structural changes in the energy systems and the application of CCS. In analyzing the results of a large number of studies, it is found that the mitigation response to reduce CO_2 emissions would shift over time from initially focusing on energy efficiency reductions in the beginning of the 21st century to more carbon intensity reduction in the latter half of the century. An illustrative example for the further breakdown of mitigation options is shown in Figure 9. The figure shows stabilization scenarios for a range of targets (about 3 to 4.5 W/m^2) based on four illustrative models (IMAGE, MESSAGE, AIM and IPAC) for which sufficient data were available. The scenarios share similar stabilization targets, but differ with respect to salient assumptions for technological change, long-term abatement potentials, as well as model methodology and structure. Among the category types that have a large potential over the long term (2000-2100) in at least one model are energy conservation, carbon capture and storage, renewables, nuclear and non-CO_2 gases. These options could thus constitute an important part of the mitigation portfolio. However, the difference between the model also emphasizes the impact of different assumptions and the associated uncertainty (e.g. for renewables, results can vary strongly depending on whether they are already used in the baseline, and how this category competes against other zero or low emission options in the power sector such as nuclear and CCS). The figure also illustrates that limitations of the mitigation portfolio with respect to CCS or forest sinks (AIM and IPAC) would lead to relatively higher contributions of other options, in particular nuclear (IPAC) and renewables (AIM).

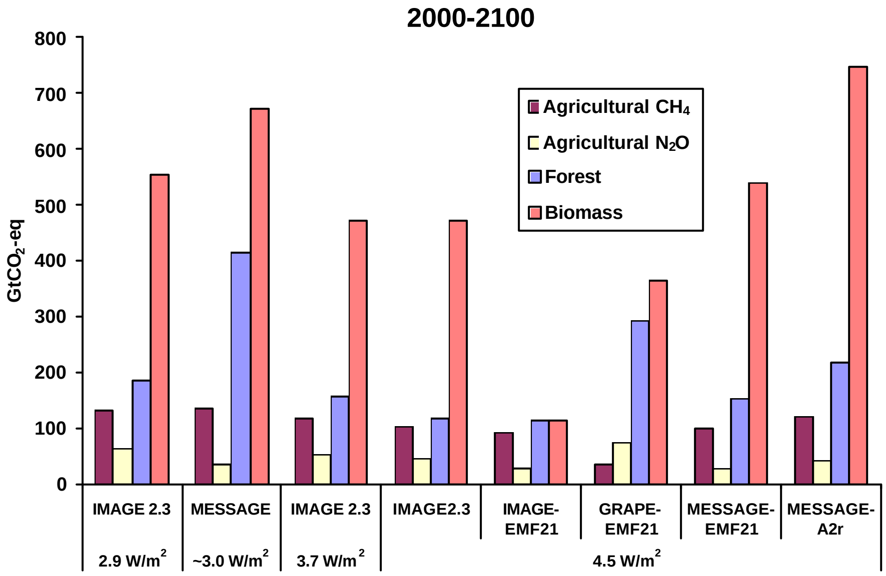
Figure 9: Contribution of different types of measures in emission reductions (2000-2030 and 2000-2100) (all categories). (Fisher et al., 2007)



Reduction measures in land use

Various measures related to agriculture and land use also contribute to the emission reductions. Figure 10 provides an overview. The models used in this comparison seem to agree that among the options in this category biomass provides the largest potential for emission reduction. The second largest category is formed by afforestation of reduced deforestation – although considerable differences exists among the models).

Figure 10: Cumulative cost-effective agricultural, forestry, and biomass abatement 2000-2100 (Fisher et al., 2007).



Source: Rose *et al.* (2007)

Costs

Models use different metrics to report the costs of emission reductions. Top-down general equilibrium models tend to report GDP losses, while system-engineering partial equilibrium models usually report the increase of energy system costs or the net present value (NPV) of the abatement costs. A common cost indicator is also the marginal cost/price of emissions reduction (\$/tC or \$/tCO$_2$). For 2030, Figure 11 shows results from selected studies for all three cost indicators. Table 3 provides an overview of GDP losses in 2030 and 2050.

GDP losses in 2030 in the vast majority of the studies (more than 90 % of the scenarios) are generally below 1 % for the target categories IV and V (see Figure 10). Also in the majority of the category II and III scenarios (70 % of the scenarios) GDP losses are below 1 %. For category III the interval lying between the 10th and 90th percentile varies from about 0.6 % gain to about 1.2 % loss. For category II, this range is shifted upwards (0.2 to 2.5 % loss). This is also indicated by the median GDP losses by 2030, which increases from below 0.2 % for categories IV and V to about 0.2 % for the category III scenarios and to about 0.6 % for category II scenarios. For category I, too little scenarios are available to provide meaningful statistics. However, the highest reported loss in this category is 3% - while other studies report considerable lower numbers. This number is therefore interpreted as a reasonable estimate for the maximum 2030 GDP losses in this category.

As shown in Table 3, GDP losses increase further in the 2030-2050 period in most studies – at more-or-less the same rate as the preceding period.

Table 3: GDP losses for different categories of scenarios (Fisher et al., 2007)

Category	**Stabilization level**	**Median GDP reduction**	**Range**	**Reduction of aagr of GDP**
2030				
III	590-710	0.2	-0.6% – 1.2%	<0.06
II	535-590	0.6	0.2% – 2.5%	<0.1
I	445-535	n.a.	<3%	<0.12
2050				
III	590-710	0.5	-1% – 2%	<0.05
II	535-590	1.3	0%-4%	<0.1
I	445-535	n.a	<5.5%	<0.12

Aagr= average annual growth rate

The results for the net present value of cumulative abatement costs show a similar picture (Figure 10). Given the fact this indicator captures only direct costs, its results are more certain.[3] The interval from the 10th to the 90th percentile in 2100 is from nearly zero to about 11 trillion US$. The highest level corresponds to around 2-3% of the NPV of global GDP over the same period. Again, on the basis of comparison across models it can be seen that costs depend both on the stabilization level and baseline emissions. In general, the spread of costs for each stabilization category seems to be of similar order as the differences across stabilization scenarios from different baselines. In 2030, the interval covering 80 % of the NPV estimates is from around 0-0.3 trillion for category III scenarios. The majority of the more stringent (category II) scenarios range between 0.2 to about 1.6 trillion.

Finally, a similar trend is found for carbon price estimates. In 2030, typical carbon pricess across the range of models and baselines for a 4.5 W/m^2 stabilisation target (category III) range from around 1 – 24US$/t$CO_2$ (80 % of estimates), with the median of about 11US$/t$CO_2$. For category II, the corresponding prices are somewhat higher and range from 18 – 79US$/t$CO_2$ (with the median of the scenarios around 45 US$/t$CO_2$). Most individual studies for the most stringent category (I) cluster around prices of about 100 US$/t$CO_2$.[4]

Figure 10: Costs in 2030 :GDP losses, abatement costs (NPV using a 5% discount rate) and carbon price (Fisher et al., 2007)

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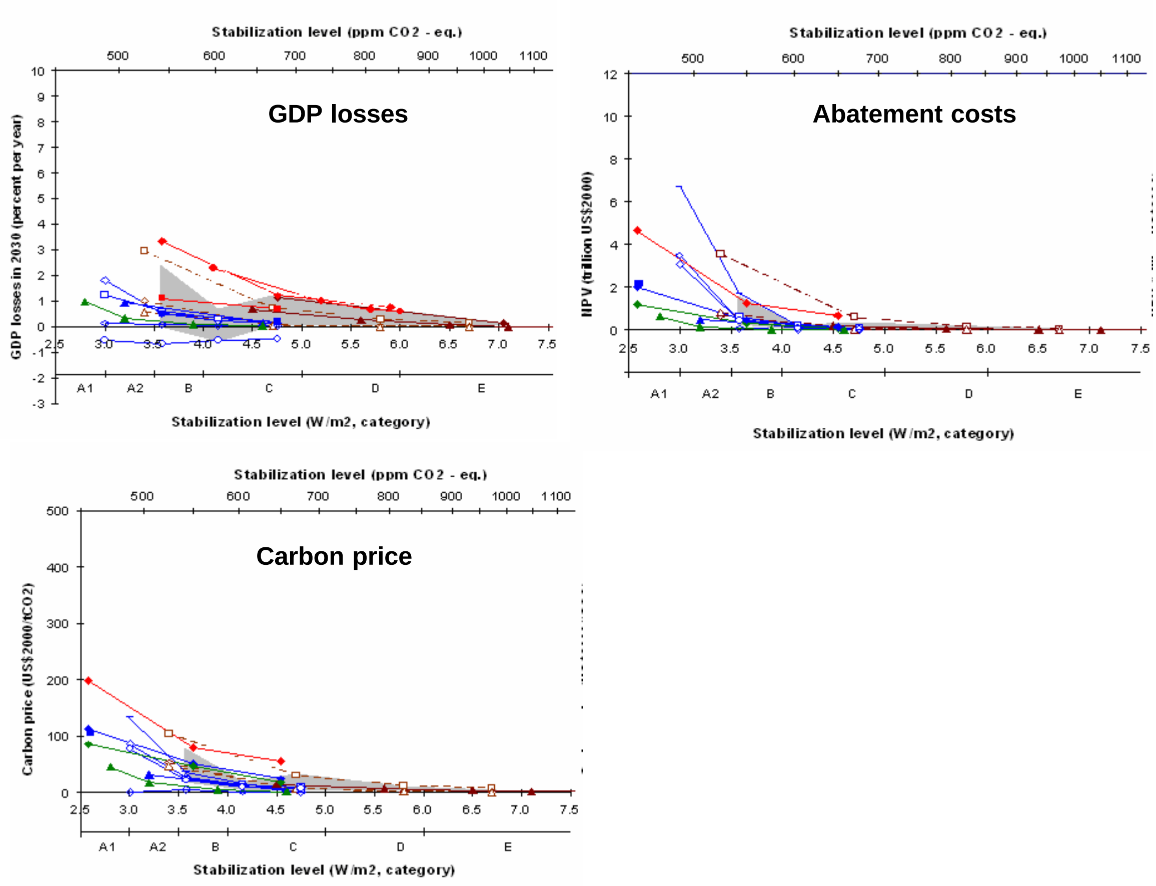
[3] NPV calculations are based on carbon tax projections of the scenarios, using a discount rate of 5%, and assuming that the average cost of abatement would be half the marginal price of carbon. Some studies report abatement costs themselves, but for consistency this data were not used. The assumption of using half the marginal price of carbon results in a slight overestimation.

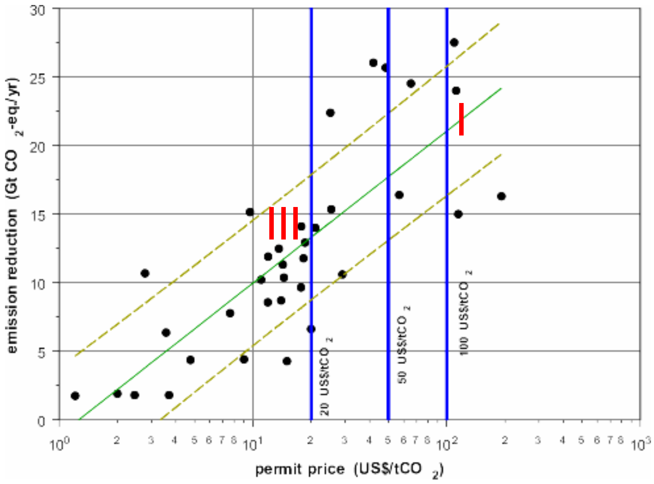
[4] Note that the scenarios of the lowest stabilization categories (A1 and A2) are mainly based on intermediate and low baseline scenarios.



Estimate of reduction potential at various prices

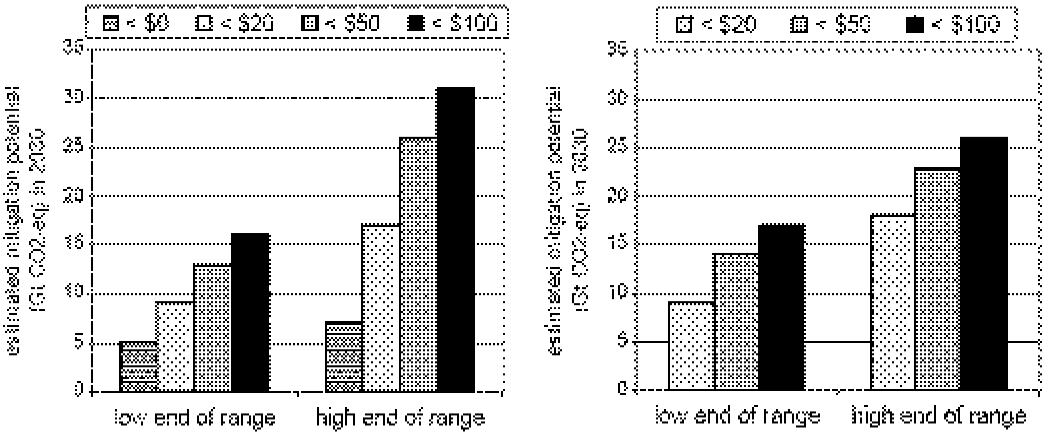
The information included in literature also allows to estimate the reduction potential at various carbon prices by plotting the permit price reported in each study against the obtained reduction. This is shown in Figure 11.

Figure 11: Reduction potential as a function of the permit price (dots indicate individual studies, lines indicate best-guess and uncertainty range) (Fisher et al., 2007)



Across the range of studies it is found that the reduction increases as a function of the permit price (Figure 11). The relation found can be used to derive the 68 percentile interval of the reduction potential for the 20. 50 and 100US$/$tCO_2$-eq price levels, which are 13.3 ± 4.6 Gt CO_2-eq/yr, 17 5 ± 4.7 Gt CO_2-eq/yr and 21.5 ± 4.7 Gt CO_2-eq/yr, respectively. Interestingly, the numbers compare very well to the reduction potentials found in bottom-up engineering studies as indicated in Figure 12. If compared to the reduction requirements for stabilization summarized earlier results show that at around 20 US$/t$CO_2$ it is possible to obtain the reduction required for category III, at 50 US$/t$CO_2$ it is possible to obtain the reduction requirements of category II and finally, the reductions required for category I correspond to permit prices in the order of 100 US$/t$CO_2$.

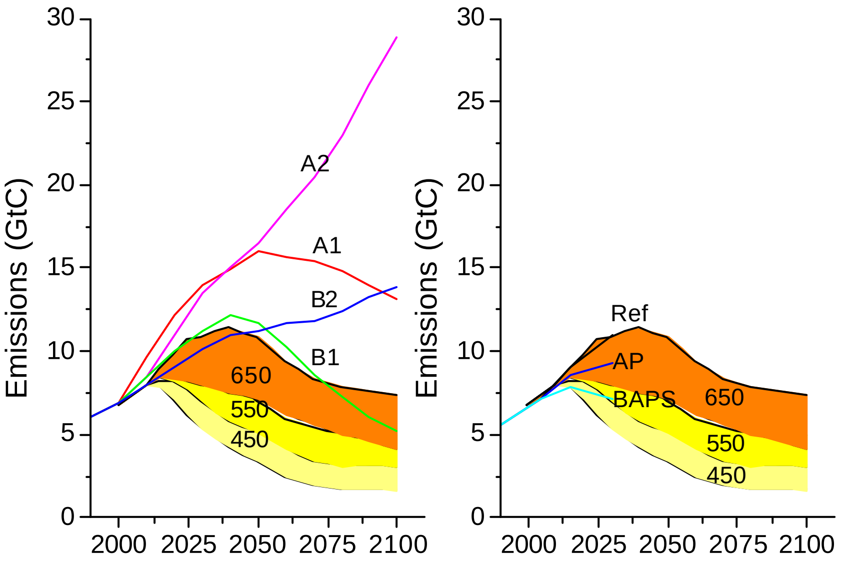
Figure 12: Reduction potential in 2030 for various permit prices (US$/t$CO_2$). Bottom-up and top-down studies (IPCC-WG3, SPM).



Position of the IPCC-SRES and WEO-2006 scenarios

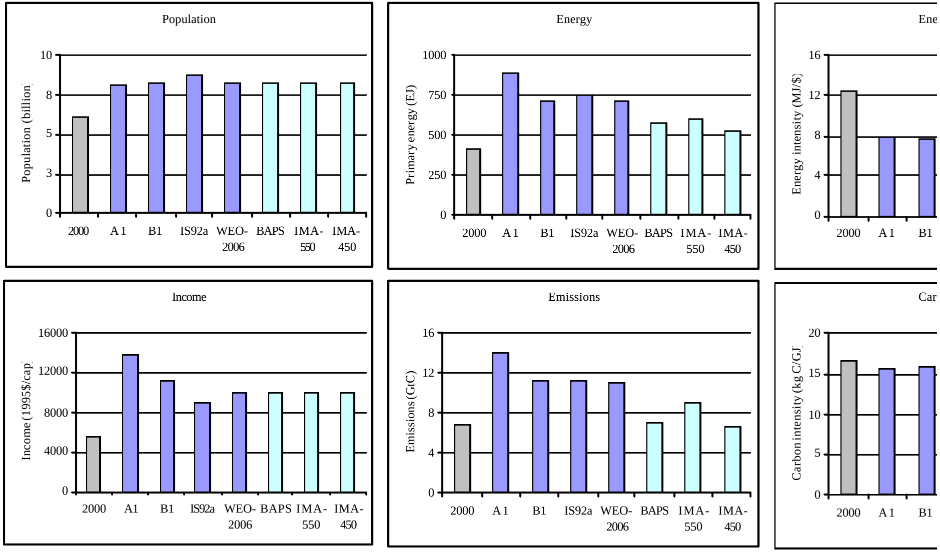
Figure 13 shows that the B1 scenarios more-or-less corresponds to a 650-700 ppm CO_2-eq stabilization scenario (mitigation scenarios based on (van Vuuren et al., 2007)). The B1 scenario is the lowest scenario that has been compared in climate model calculations in the recent IPCC-WG1 report (AR4) (have not scanned the report for individual model studies yet). The WEO-2006 AP scenario can be considered as a category III (650 ppm CO_2-eq scenario), while the BAPS scenario possibly corresponds to a case I/II (500 ppm CO_2-eq) scenario.

Figure 13: Comparison of emission pathways leading to 650, 550 and 450 ppm CO_2-eq. (van Vuuren et al., 2007) and the IPCC-SRES scenarios (left)(Nakicenovic and Swart, 2000) and the WEO-2006 scenarios (IEA, 2006)



The scenarios can also be compared in terms of some key-characteristics (Figure 14). As shown, the mitigation scenarios differ in terms emissions and energy use from the set of baseline scenarios reducing emissions by about 20% to 50%.

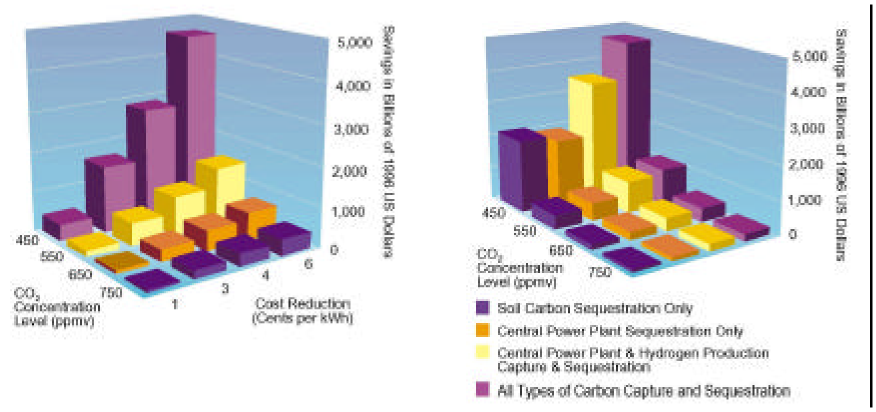
Figure 14: Comparison of baseline and mitigation scenarios for 2030 data (IPCC-SRES, IS92a, IEA-ref and BAPS, and IMAGE 550 and 450 ppm CO$_2$-eq).



The role of technology change

The numbers presented so-far are based in most cases on around 50-100 individual scenarios. Each of these scenario studies makes bold assumptions with respect to technology change. Some studies have explored the impact of different rates of technology change – emphasizing the need for research and development in order to make the more optimistic assumptions more likely to come true. One of these studies is summarized in Figure 15, that plots the investment need as a function of the costs of PV solar cells – starting at a base value of 9 US cents/kWh, and lowering this by 1, 3, 4, and 6 cents/kWh respectively. For instance the value of reducing PV costs from 9 to 3 cents per kWh could amount to up to 1.5 trillion dollars in an illustrative 550 ppmv stabilization scenario compared to the reference scenario in which costs remain at 9 cents/kWh). The right panel shows a similar experiment in which the potential of different types of options is left out in the calculations. For instance, adding soil carbon sequestration to the portfolio of carbon capture and sequestration technology options (forest-sector measures were not included in the study) reduces costs by 1.1 trillion dollars in an illustrative 450 ppmv stabilization scenario. Removing all carbon capture sequestration technologies would triple the costs of stabilization for all concentration levels analysed.

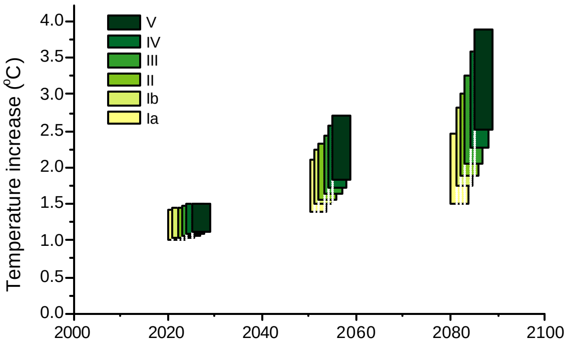
Figure 15: The value of improved technology. Modelling studies enable to calculate the economic value of technology improvements that increase particularly drastically with increasing stringency of stabilization targets (750, 650, 500, and 450 ppmv respectively) imposed on a reference scenario (modelling after the IS92a scenario in this particular modelling study). Source: (Fisher et al., 2007)



5. Changes in global mean temperature

In assessment studies, global mean temperature change (GMT) is often used as a proxy indicator for climate change damages. According to IPCC, in most cases the impacts of climate change correlate to GMT change. GMT can be expressed of the equilibrium temperature or the transient temperature profile. The latter is more relevant for climate impacts. Changes in global mean temperature as a function of the stabilization level are shown in Figure 17. Figure 16, instead, shows the changes in transient temperature for the different categories. As shown, there is a strong overlap between the different categories for the first half of the century. In the second half of the century the different categories, however, unfold – with category 1a leading to about 2°C increase and category V to about 2.5-4°C.

Figure 16: Transient temperature increase as function of the stabilization level (based on (Carter et al., 2007)).



6. Assessment of climate change impacts, adaptation and vulnerability

The number of scenario studies published assessing climate change impacts, adaptation and vulnerability (CCIAV) is still far-less than the number of scenario studies focusing on baseline and mitigation issues. One reason is that the diversity of impacts and the influence of local circumstances complicate more generalized approaches. Still, the need for improved decision-analysis has led to a growth of different approaches for assessing impacts. Such methods include the so-called top-down (global scenarios downscaled to the local scale) and bottom-up methods (local scale studies), assessment of possible future adaptations, adaptive capacity, social vulnerability and assessment of more integrated (sustainable development) approaches.

The application of the 'standard' analysis of climate impacts has significantly expanded – describing possible impacts as a function of climate change (mostly global mean temperature). Important examples include the work of Parry et al (Parry et al., 2001) (overall assessment), Thomas et al. (Thomas et al., 2004) (biodiversity), Hitz and Smith (Hitz and Smith, 2004) (multi-sectors), Fischer et al. (Fisher, 2002) (agriculture), sea-level rise (Nicholls and Tol, 2006). Also the work of WG-2 (many chapters) provide important examples of impacts as a function of estimated global mean temperature change (see also next section). Some work has also been done on adaptation analysis, but a considerable part of the work here still concentrates on methodological issues.

From the literature, it can be derived that risk management provides a useful framework for analysis given the fact that it provides a mean to handle the large uncertainties between different scenario assumptions and CCIAV issues. As such, the use of probabilistic approaches and risk management is expanding rapidly. Risk-based approaches are also useful in integrated analysis of climate policy (see next section).

Overall, an important trend is that scenario information is increasingly being developed at finer geographical resolution. This is true for several areas, including climate modeling. The construction of higher resolution outputs, by regionalization methods, (e.g. 50 x 50 km) has encouraged new type of impact studies (e.g. combined impacts from heat stress and air pollution). More detailed data is also developed for socio-economic conditions (see earlier), land-use and land cover and sea-level rise.

An important factor in impact analysis is formed by extreme events. Attempts have been made summarize information in current climate runs. Moreover, statistical methods have been developed to relate extreme events better to more aggregated indicators. However, these methods are still mostly untested.

7. Integrated assessment of mitigation, impacts and adaptation.

Responses to climate change include a portfolio of measures:

a) mitigation - actions that reduce net carbon emissions and limit long-term climate change;
b) adaptation - actions that help human and natural systems to adjust to climate change;
c) research on new technologies, on institutional designs and on climate and impacts science, which should reduce uncertainties and facilitate future decisions.

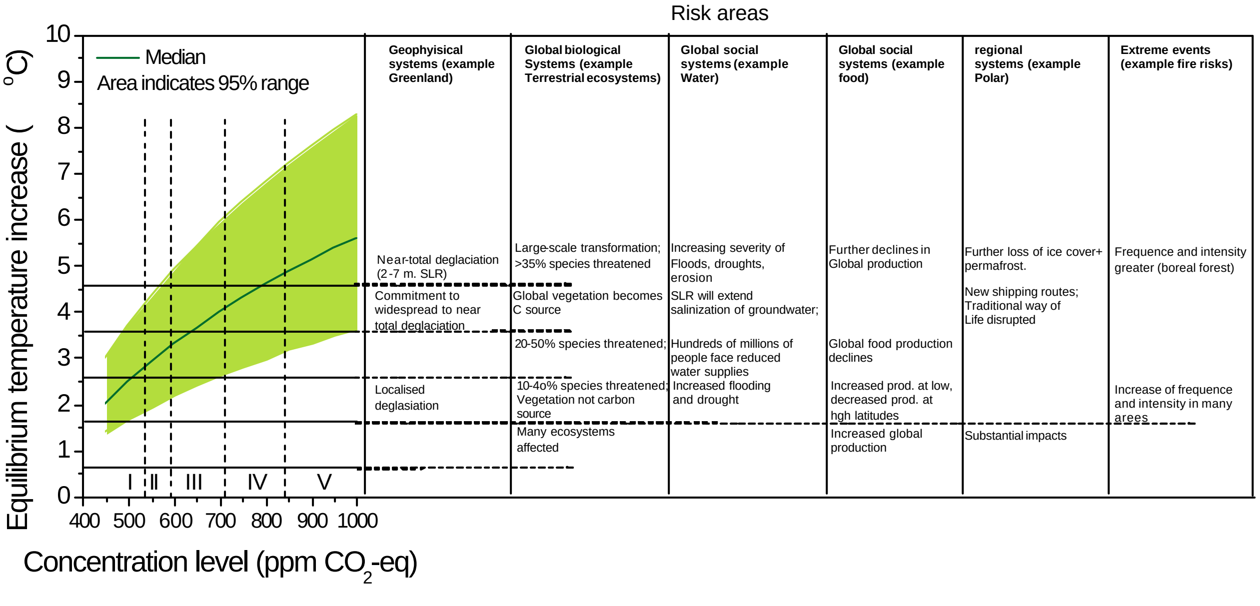
A key question for policy is what combination of near- and long-term actions will minimize total costs of climate change (in whatever form these costs are expressed) including mitigation costs, adaptation costs and climate damages. Policy decisions will have to be made with incomplete understanding of the magnitude and timing of climate change, of its likely consequences, and of the cost and effectiveness of response measures. Different approaches exists with respect to determining an useful combination of policy actions, the most important being 1) risk-oriented approaches that compare mitigations costs and reduction of climate change risks, and 2) costs-benefit analysis. Since the Third Assessment Report, attention has shifted towards the interaction between mitigation and adaptation in reducing damages in a risk management framework. This has accompanied a growing realization that some climate change in the coming decades is inevitable.

Handling uncertainty in all available approaches remain an important challenge. This not only involve factors as uncertainty in temperature outcome, but also low-probability large consequences events and the fact that impacts of climate change can be strongly modified by non-climate factors. The latter implies that it is best not to rely on a single characterization of future conditions.

Risk oriented approaches

In a risk management framework, connections are made between the risks of climate change (mostly global mean temperature increase) as a function various stabilisation levels for concentrations of greenhouse gases in the atmosphere and risks of serious climate impacts (so-called key vulnerabilities) as a function of climate change. One complication here is that the temperature increase for the mitigation scenarios is often assessed in terms of equilibrium temperature change – while for climate impacts transient temperature increase is more relevant. Using equilibrium temperature as a guide, impacts or KV could be less than expected, for example if impacts do not occur until the 22nd century because there is more time for adaptation. Or they might be greater than expected as temperatures in the 21st century may transiently overshoot the equilibrium, or stocks at risk such as human populations might be larger. Some studies explore the link between transient and equilibrium temperature change for alternative emission pathways (Schneider and Mastrandrea, 2005; Meinshausen et al., 2006).

Figure 17: Equilibrium temperature change as a function of the stabilization level and associated impacts (based on (Fisher et al., 2007)).



Costs benefit analysis

For costs benefit analysis, the damages of climate change are normally expressed in monetary terms. One way to express the damages in terms of the so-called social costs of carbon (SCC). Progress has been made since the TAR in assessing the impacts of climate change. Nonetheless, as noted in (Watkiss et al., 2005), estimates of the social cost of carbon (SCC) in the recent literature still reflect an incomplete sub-set of relevant impacts; many significant impacts have not yet been monetized (see also WGII ; on SCC see WGII, Section 20.6) and others are calibrated in numeraires that may defy monetization for some time to come. Reviews exist of available estimates of SCC show that they span several orders of magnitude – ranges that reflect uncertainties in climate sensitivity, response lags, discount rates, the treatment of equity, the valuation of economic and non-economic impacts, and the treatment of possible catastrophic losses (WGII Ch. 20). The majority of available estimates in the literature also capture only impacts driven by lower levels of climate change (e.g. 3 ^{o}C above 1990 levels).

Key empirical parameters that increase the social value of damages include: 1) climate sensitivity and response lag, 2) coverage of abrupt or catastrophic changes, 3) inclusion and social value of non-market impacts, 4) valuation methods for market impacts such as value of life, 5) adaptative capacity, 6) predictive capacity, 7) geographic downscaling and 8) the propagation of local economic and social shocks .

Working Group II highlights available estimates of SCC that run from -3 to 95$/tCO$_2$ from one survey but also note another survey has included a few estimates as high as 400$/t CO$_2$ (Carter et al., 2007). A more recent estimate by Stern (Stern, 2006) is at the high end of these estimates at $85/tCO$_2$ because an extremely low discount rate is used in calculating damages that include additional costs attributed to abrupt change and increases in global mean temperature for some scenarios in excess of 7^{o}C. According to economic theory, the social costs of carbon establish a target price of carbon (or an economically efficient 'carbon tax') for which the associated marginal costs of mitigation would equal the marginal benefit of emission reduction. Allowing a range of carbon prices for 2005 running from $4-95/tCO$_2$ (based on estimates by Tol (see (Fisher et al., 2007))), to increase annually by 2.4 % produces a range of estimates for 2030 between $7-172/tCO$_2$. The mitigation studies in Chapter 3 WG3 suggest carbon prices in 2030 of $1 to $24/t CO$_2$eq for category III scenarios, $18-79/t CO$_2$eq for category I scenarios and $31-121/t CO$_2$eq for category I scenarios. This implies that the costs and benefits are in fact of a similar order of magnitude. With some degree of confidence, one could hypothesize that the cost of mitigation is comparable to or lower than the cost of climate change impacts, even for the most stringent of mitigation scenarios.

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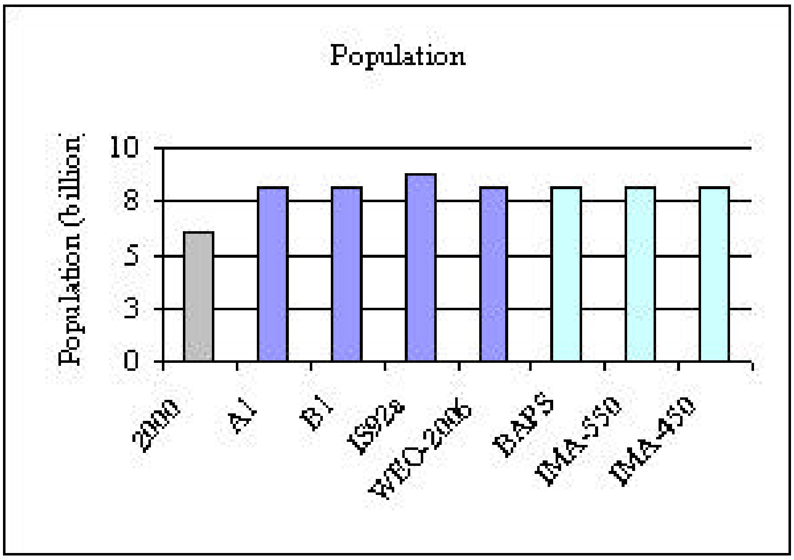
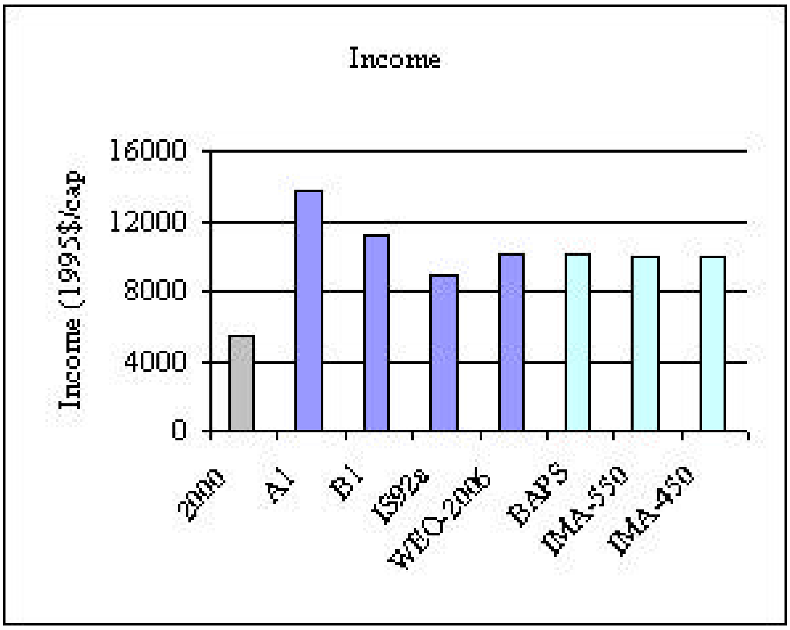
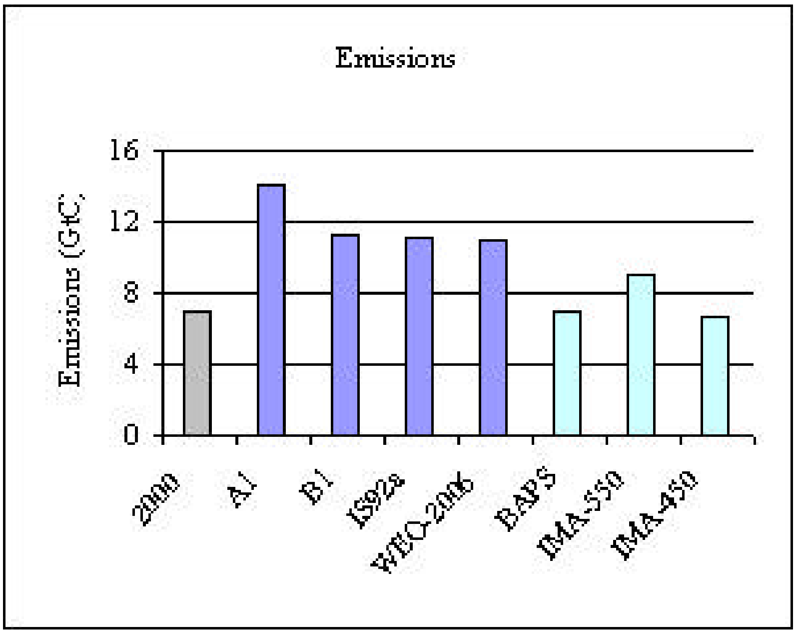
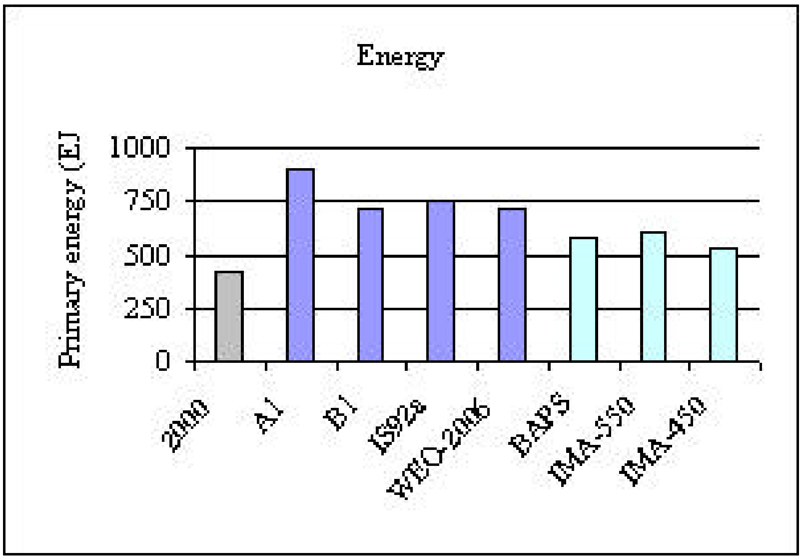
Work Spreadsheet








Energy
Primary energy (EJ
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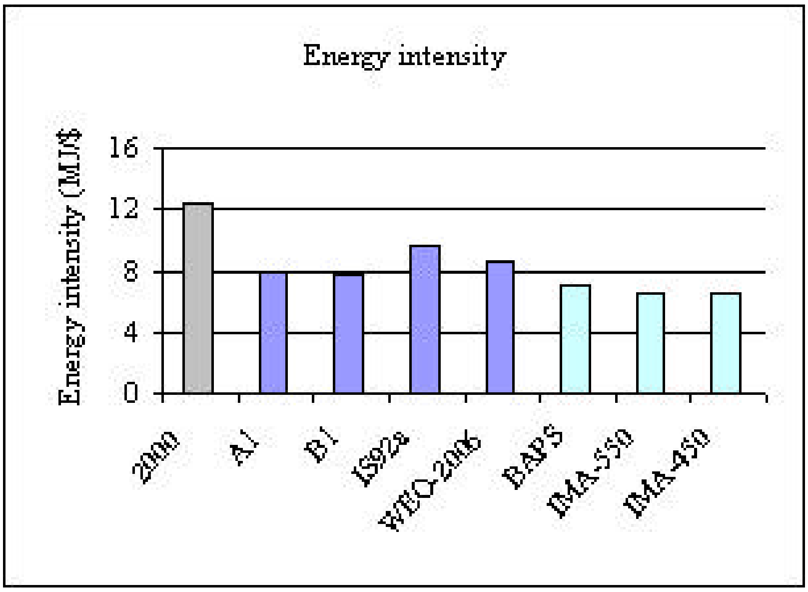
750
500
250
0
2000
A1
B1
IS92a
WEO-2006
BAPS
IMA-550
IMA-450


Energy intensity
Energy intensity (MJ/$
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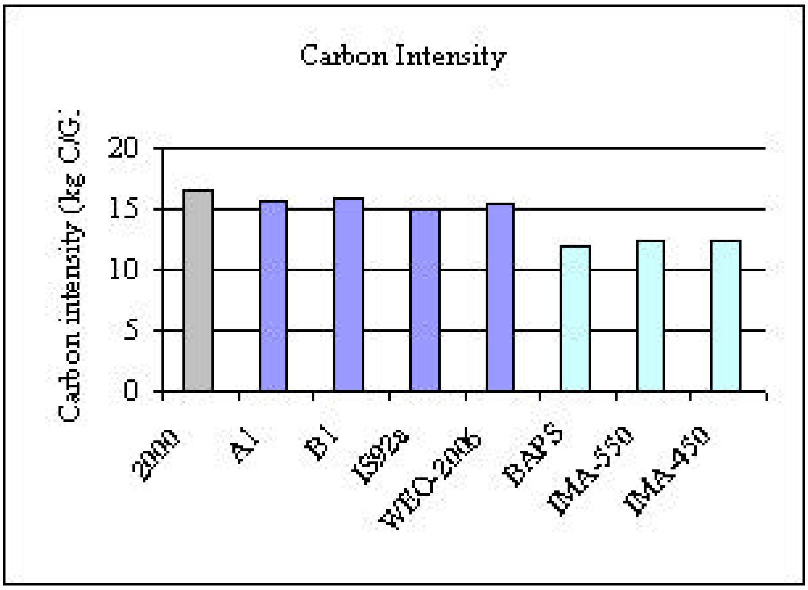
12
8
4
0
2000
A1
B1
IS92a
WEO-2006
BAPS
IMA-550
IMA-450


Carbon Intensity
Carbon intensity (kg C/G
20
15
10
5
0
2000
A1
B1
IS92a
WEO-2006
BAPS
IMA-550
IMA-450