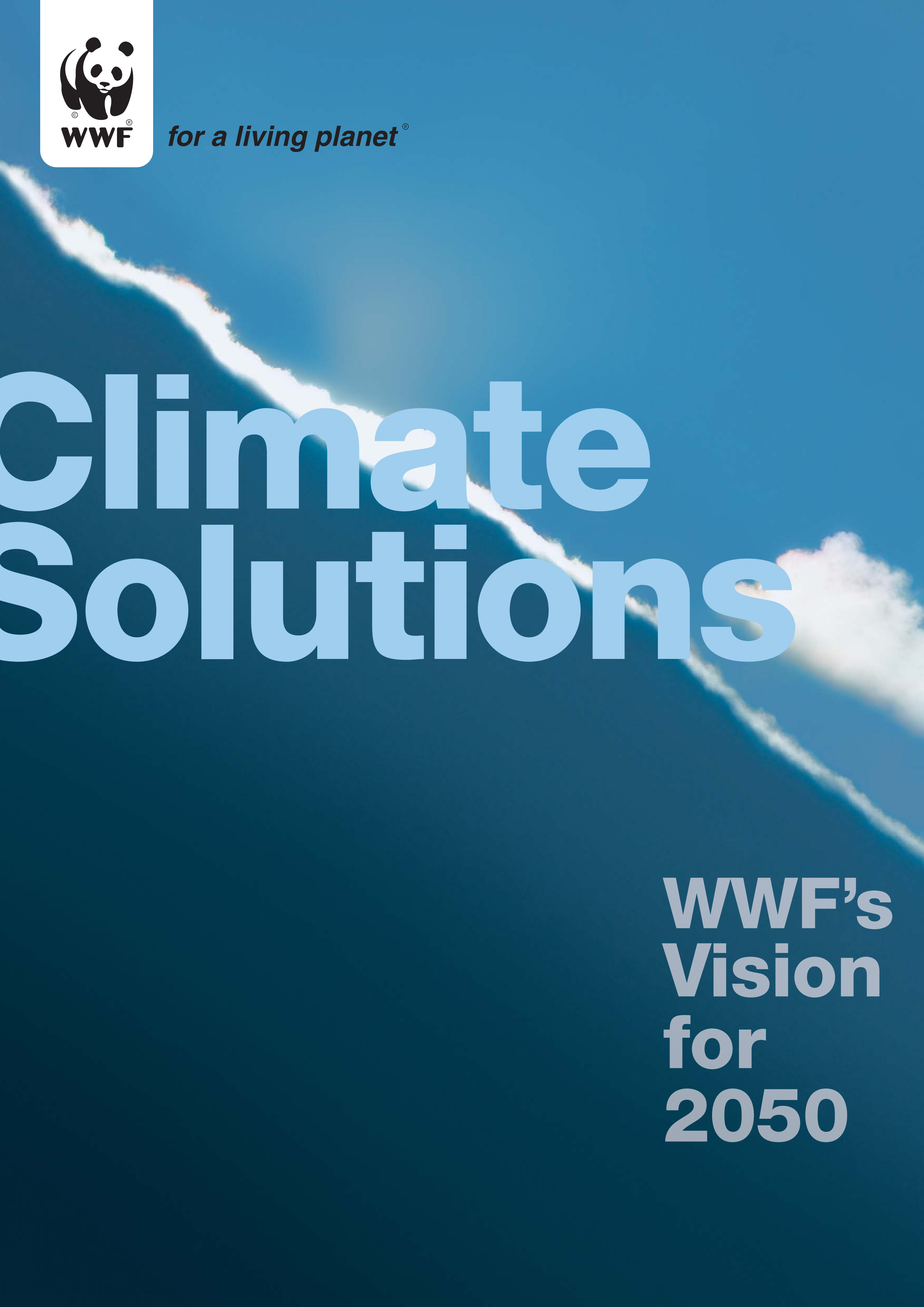

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Climate Solutions

WWF's Vision for 2050

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Paper repared for
WWF's Global Energy
Task Force by:

Karl Mallon
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Climate Solutions: The WWF Vision for 2050

Paper prepared for WWF's Global Energy Task Force by Karl Mallon[1], Greg Bourne[2] and Richard Mott[3]

EXECUTIVE SUMMARY

This WWF report seeks to answer the question: "Is it technically possible to meet the growing global demand for energy by using clean and sustainable energy sources and technologies that will protect the global climate?" In other words, can a concerted shift to the sustainable energy resources and technologies that are available today meet the more than doubling of global energy demand projected by 2050, while avoiding dangerous climatic change of more than two degrees Celsius above pre-industrial levels?

The report's conclusion is that the technologies and sustainable energy resources known or available today *are* sufficient to meet this challenge, and there is still sufficient time to build up and deploy them, but only if the necessary decisions are made in the next five years. Yet it is clear that the economic policies and governmental interventions needed to propel this transition are not now in place, or even in prospect in most cases. This is a matter to which the world needs to give urgent attention.

WWF is acutely aware that many of the steps considered in this report – an end to the dominance of fossil energy, a phase-out of nuclear power, a rapid expansion of biomass energy – carry with them social, environmental, and economic consequences that must be carefully weighed and closely managed. To take a single example, even the limited shift to energy crops today threatens accelerated conversion of wild habitats and further deprivation of the world's poor by driving up food prices. A global energy transition must be managed to reflect the differing priorities and interests of the world community at large.

Halting climate change is a long-term undertaking, but the first steps must be taken by governments currently in power. The future depends on them making critical decisions soon which could lead to a low-emission global energy economy in a timescale consistent with saving the climate, and planning for the social and economic dimensions of that transition to minimize the negative impacts of such urgent change.

The WWF Global Energy Task Force

In 2006, WWF convened a Global Energy Task Force to develop an integrated vision on energy for 2050. The Task Force explored the potential for successful achievement of the following goal for energy policy: to **meet the projected global growth in demand for energy <u>services</u>**

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while **avoiding the most dangerous impacts of climate change,** but **using energy sources that are socially and environmentally benign**[4]**.**

The time-sensitive approach taken here differs from other studies in a number of ways. It draws on authoritative sources for projections of energy demand and climate change trends, uses WWF expertise to estimate the sustainable limits of technologies and resources, and assesses a wide range of published data on the potential rate of development and deployment of these technologies and systems. Finally, it exposes this information to analysis in a model which assesses the feasibility of successful delivery of the goal described above. A scenario showing high success potential is illustrated in this paper.

The task force began by reviewing 25 different low-carbon energy technologies, broadly construed: these included renewable energy sources, such as solar and wind power; demand-side options such as efficient buildings and vehicles and reduced travel; and other low-carbon technologies such as "carbon capture and storage" and nuclear power. The sole constraint was that technologies be "proven", by virtue of being commercially available already.

Each of the energy sources was then sorted and ranked based on its environmental impacts, social acceptability, and economic costs. This ranking exercise yielded three groupings of technologies: those with clear positive benefits beyond the ability to reduce carbon intensity (efficiency technologies dominate this group); those with some negative impacts but which remain on balance positive; and those whose negative impacts clearly outweigh the positive.

The WWF Climate Solutions Model

The technology groups whose benefits were found to outweigh their negative impacts were then run through a newly designed WWF Climate Solutions Model. This model was designed to determine the *industrial feasibility* of developing and deploying these resources and technologies in a timeframe that can avert dangerous climate change over the period to 2050, and at levels that can accommodate the projected increase in global demand for energy.

It bears emphasis that the WWF Climate Solutions Model is *not* an economic model: no price for carbon was set, nor were the costs of the technologies assigned or modelled. Economic scenarios have been explored by others, including Stern[5] and McKinsey[6], noting that costs of dangerous climate change are far in excess of the costs of avoiding it. Likewise, no assumptions have been incorporated about the policies or measures needed to drive a transition to the sustainable energy technologies in the model. Rather, the model seeks to answer only the narrow question whether, given what is known about physical resources, the capacity of the technologies themselves and the rate of industrial transitions, it is feasible to deploy the needed technologies in time to avert dangerous climatic change.

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[4] No energy source is free of impacts. The word 'benign' is used here to describe sources that WWF judges deliver a positive yield of advantages over disadvantages.

[5] *Stern Review Report on the Economics of Climate Change*: Cambridge University Press, 2007.

[6] Per-Anders Enkvist, Tomas Nauclér & Jerker Rosander: A Cost Curve for Greenhouse Gas Reduction: in *The McKinsey Quarterly* March 2007, http://www.mckinseyquarterly.com/article_abstract.aspx?ar=1911&L2=3&L3=0&srid=246

On this all-important point, the WWF Climate Solutions Model offers a qualified basis for hope: it indicates that with a high degree of probability (*i.e.* greater than 90%), the known sustainable energy sources and proven technologies could be harnessed between now and 2050 to meet a projected doubling of global demand for energy services, while achieving the significant (in the order of 60%-80%) reductions in climate-threatening emissions, enabling a long-term stabilization of concentrations at 400ppm (parts per million) – though concentrations in the short term will peak at a higher level before being absorbed by oceans and the biosphere. A solution, in other words, is at least possible.

However, from this threshold determination of technological feasibility, the outlook immediately becomes more complex and ominous. The economic policies and measures, as well as the intergovernmental actions, needed to drive this transition are not yet in place, and may well be years away based on current progress. And with real-world constraints on the speed of industrial transition, analysed in our model, it is clear that time is now of the essence. In five years it may be too late to initiate a sustainable transition which could avert a breach of the two-degree threshold for avoiding dangerous climate change. In that event, dangerously unsustainable options may be forced upon us or we will face more severe interventions which will have significant impacts on the global economy.

Solutions

The WWF report identifies the following six solutions and three imperatives as key to achieving the goal of meeting global energy demand without damaging the global climate:

1 **Breaking the Link between Energy Services and Primary Energy Production** — Energy efficiency (getting more energy services per unit of energy used) is a priority, especially in developed countries which have a very inefficient capital stock. The model shows that by 2020-2025, energy efficiencies will make it possible to meet increasing demand for energy services within a stable net demand for primary energy production, reducing projected demand by 39% annually, and avoiding emissions of 9.4Gt carbon per year, by 2050.

2 **Stopping Forest Loss** — Stopping and reversing loss and degradation of forests, particularly in the tropics, is a crucial element of any positive climate-energy scenario. The probability of success of the climate solutions proposed here drops progressively from greater than 90% down to 35% in the absence of effective action to curb land-use emissions.

3 **Concurrent growth of Low-Emissions Technologies** — The rapid and parallel pursuit of the full range of technologies, such as wind, hydro, solar PV & thermal, and bio-energy is crucial, but within a set of environmental and social constraints to ensure their sustainability. By 2050, these technologies could meet 70% of the remaining demand after efficiencies have been applied, avoiding a further 10.2Gt carbon emissions annually.

4 **Developing Flexible Fuels, Energy Storage and New Infrastructure** — Deep cuts in fossil-fuel use cannot be achieved without large volumes of energy from intermittent sources, like wind and solar, being stored and transformed into transportable fuels and into fuels to meet the thermal needs of industry. New fuels, such as hydrogen, that meet these requirements will require major new infrastructure for their production and distribution.

5 **Displacing High-Carbon Coal with Low-Carbon Gas** — Natural gas as a “bridging fuel” offers an important opportunity to avoid the long-term lock-in of new coal power stations, providing significant carbon savings in the near term, while other energy sources and technologies are grown from a smaller industrial base.

6 **Carbon Capture and Storage (CCS) —** The model shows that, in order to stay within the carbon emissions budget, it is essential that fossil-fuel plants are equipped with carbon capture and storage technology as soon as possible – all by 2050. This has major and immediate implications for the planning and location of new plants, since transport of carbon dioxide to distant storage sites would be very costly. Overall, fossil fuels with CCS could account for 26% of supply in 2050, avoiding emissions of 3.8Gt C/yr.

Additional Imperatives

1 **Urgency —** Delays will make the transition to a low-carbon economy increasingly expensive and difficult, with much greater risks of failure. The case for early, decisive action is overwhelming.

2 **A global effort —** Every country has a role to play in response to the scale and the type of challenges arising in its territory[7].

3 **Leadership —** Action is needed by governments of the world to agree **targets**, to collaborate on **effective strategies**, and to influence and coordinate the **investment** of the many trillions of dollars which, in any event, will be spent on energy developments in the coming decades, so that future needs are met safely and sustainably.

Following an introduction, the balance of this report is comprised of sections that provide greater detail on the range of sustainable energy technologies reviewed by the WWF Task Force, the WWF Climate Solutions Model, and the findings and conclusions that emerge from its analysis.

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[7] See Topic Paper Annex.

Contents

1 INTRODUCTION

Averting the unfolding calamity of global climate change, while at the same time ensuring stable and secure supplies of energy services to meet the needs of a growing global population and level of development, especially in the relief of poverty, is the most important challenge our generation is likely to face. Doing so without wreaking new havoc on the environment (*e.g.*, by excessive hydro-development or by massive conversion of tropical forests to biofuels production) is an additional but so far little-considered dimension.

With this in mind, WWF's Global Energy Task Force undertook the analysis and modelling project described in this report. Its aim was to determine whether it is technically feasible, at this late date, to meet projected global energy services needs while avoiding a level of climate change which would threaten catastrophic environmental and social consequences.

The starting point for WWF's analysis was the strong scientific consensus that any human-induced warming greater than two degrees Celsius above pre-industrial levels would have a dangerous and highly damaging impact on both human societies and their economies and the global environment as a whole. The Task Force then looked at the projected growth in energy services needs, taking into account population trends and development goals, through to the year 2050. It then sought to determine how these needs for energy services might be met while remaining below the two-degrees Celsius ceiling for the average increase in global temperature above pre-industrial levels, and without resort to unacceptably damaging technologies or resources.

The result, described in more precise and technical detail in the sections that follow, represents what we believe to be among the very first technically and industrially pragmatic, time-sensitive energy scenarios, containing the threat of climate change while meeting legitimate future development goals.

The good news is that it appears to be still possible to avert the worst consequences of climate change while expanding our energy supplies to meet the needs of both the developed and developing world in the 21st century. The bad news is that the outcome is extremely sensitive to decisions made in the next five years. In these five years, the trajectory must be set for the required technology, systems, infrastructure, and resource exploitation, sufficient to ensure that *global greenhouse gas emissions (GHG) peak and start to decline within ten years.*

What the study did not examine is the social and economic dislocation that would probably attend the kind of swift energy transition needed to avert dangerous climate change. In this respect, there is no single, easily recommended course for all societies, but it is important that such impacts are anticipated. Global warming of greater than two degrees Celsius will bring with it significant adverse impacts, particularly in the poorest countries. An abrupt global shift of the energy systems which underpin current national economies threatens disruptions of its own.

Nonetheless, the world is fortunate that the technology and resources are available to avert a dangerous disruption of the global climate. With determination, it appears technically and industrially possible to convert this technical potential into reality. However, the world is currently on a different and dangerous trajectory. Scientific warnings continue to mount, yet the debate continues and what passes for vision seems to have great difficulty seeing past the next filling station.

The pages that follow contain a blueprint for an alternative vision – one of a world in which human needs and economic development are supported by a robust mix of low-emission energy sources and technological efficiencies, while nature continues to thrive.

WWF's Climate Solutions Vision is offered in the hope that it will help to inform decisions on energy by demonstrating the technological potential for a cleaner, more secure and truly sustainable energy future. Stripped of itstechnicalities, the central message here is that if we can find the will, there is indeed a way. But it is up to us to find it; succeed or fail, it is the central challenge by which future generations will judge our own.

2 WWF REVIEW OF SUSTAINABLE ENERGY SOURCES AND TECHNOLOGIES

The groundwork for this report began with an extensive literature review and expert consultation looking at 25 low- or zero-carbon emission technologies and their application (including efficient end-use technologies and systems) from ecological, social, and economic perspectives. The core list of technologies was confined to those that are currently commercially available; thus, the review did not consider technologies that may yet be developed, or attempt to take account of the potential for dramatic advancements in the technologies available to prevent climate change.

In this respect, the energy review underpinning this report was deliberately conservative: it limited the suite of solutions considered to those available today. Some technologies, such as carbon capture and storage, straddle the line of current availability – they are in limited use today, but their potential for truly large-scale application remains uncertain. The review then considered the potential for each technology or application to provide zero- or low-emission energy, compared with a business-as-usual energy scenario in which 14 gigatonnes (Gt) of carbon would be emitted per year by 2050[8]. This comparison sets the scale and context for alternative technologies to assume a major role in displacing carbon dioxide.

Using the 14Gt C/yr as a reference, the Task Force sought and documented a range of expert input on: the environmental (non-climate) impacts and risks associated with each technology; potential obstacles to implementation; the likely social acceptability of the technology; and relative costs. With information on these points compiled in a matrix, three panels of the Task Force independently ranked the technologies on the basis of environmental risk, social acceptability, and cost, each weighted equally. While such a ranking exercise is necessarily subjective to some degree, the results across the three Task Force panels showed a high degree of consistency.

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[8] Pacala, S & Socolow, R. (2004) Stabilization Wedges: Solving the Climate Problem of the Next 50 Years with Current Technologies. *Science* 13th August, 2004, Vol. 305.

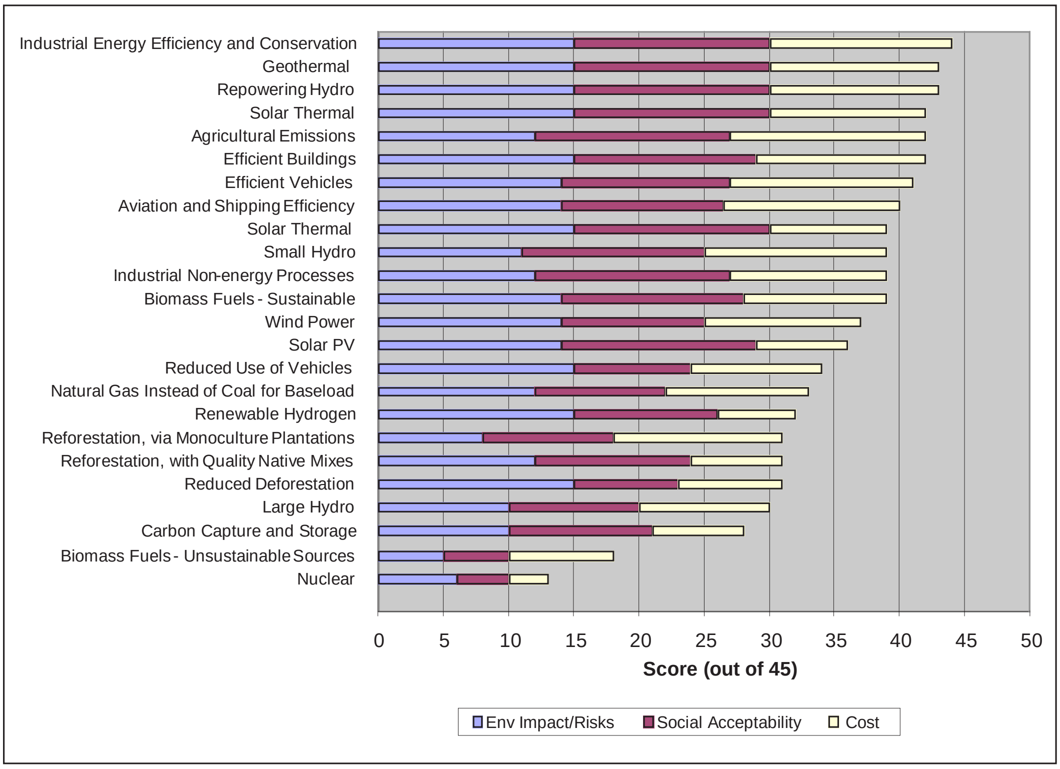

Figure 1. The results of a ranking exercise, scoring a suite of low- and zero-carbon ”technologies” (including technical demand reduction measures) for their merit against three criteria: environmental impact/risks, social acceptability, and cost.

The precise scoring of these technologies was not considered to be critical; the figure above is shown for completeness and to ensure transparency in the Task Force deliberations. This exercise informed the selection (depending on significance) and grouping of certain ”technology” options into three categories characterized, as shown in Figure 2, by:

- Overwhelmingly positive benefits (efficiency solutions dominate this group);
- Some negative impacts, but outweighed by the positive benefits;
- Serious negative impacts, outweighing any positive benefits.

The last group of technologies, which were identified as representing an unacceptable balance of risk over benefit, includes:

- Nuclear power (due to its costs, radiotoxic emissions, safety, and proliferation impacts);
- Unsustainable biomass (*e.g.*, energy crops grown on newly displaced forest land);
- Unsustainable examples of large hydroelectricity (which may flood biodiversity hotspots and fertile lands, force large-scale resettlement of human communities, or seriously disrupt river systems)[9].

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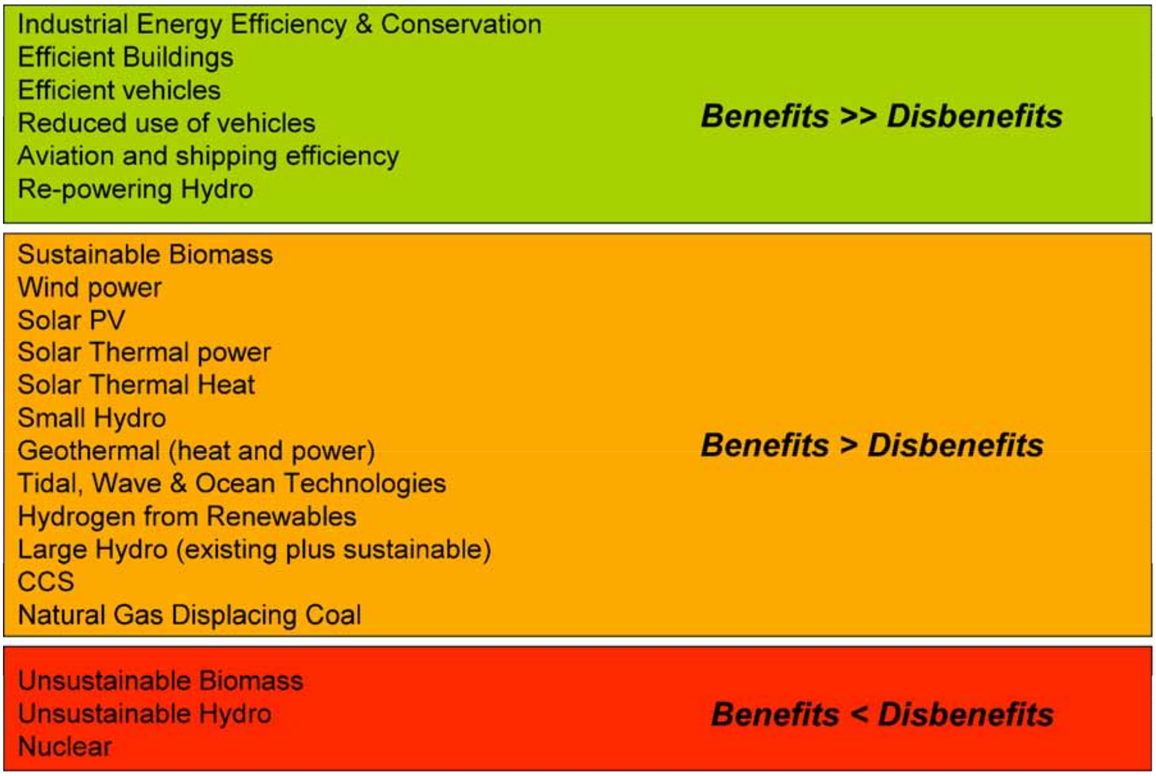
[9] Based on the criteria of the World Commission on Dams (2000): http://www.dams.org/

All of the above could cause major disruption to human populations, as well as to the environment.

Special mention is made here of the decision to exclude nuclear energy and certain kinds of biomass, as the potentials of both have attracted much attention in the climate change debate:



Industrial Energy Efficiency & Conservation Efficient Buildings Efficient vehicles Reduced use of vehicles Aviation and shipping efficiency Re-powering Hydro	***Benefits >> Disbenefits***
Sustainable Biomass Wind power Solar PV Solar Thermal power Solar Thermal Heat Small Hydro Geothermal (heat and power) Tidal, Wave & Ocean Technologies Hydrogen from Renewables Large Hydro (existing plus sustainable) CCS Natural Gas Displacing Coal	***Benefits > Disbenefits***
Unsustainable Biomass Unsustainable Hydro Nuclear	***Benefits < Disbenefits***

Figure 2. WWF grouping of climate solutions technologies based on environmental, social, and economic criteria.

Interest in nuclear energy has seen a resurgence as the technology increasingly is presented by proponents as a low- or no-carbon energy source. *This study shows that there are more than sufficient benign technologies available, without embarking further on nuclear power with its many associated risks*[10].

Biomass, in some respects, represents the opposite case – a technology with a mixed track record at scale, but one that has nonetheless won early support and raised high expectations, including from many in the environmental community. The Task Force considered the high risk of large-scale biomass plantations creating unacceptable environmental impacts, especially when grown in areas recently converted from tropical forest. Accordingly, it concluded that biomass ought not to be considered as a single category, and that separate designations for "sustainable" and "unsustainable" biomass were needed. The Task Force commissioned specific research to assess the possible range of contributions that could be made from *sustainable* biomass at a global level. Still, a significant shift to biomass as an energy source will surely

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[10] For a fuller assessment, see Topic Paper "Nuclear Energy".

place new demands on wild habitats, and may adversely impact the world's poor by driving an increase in food prices. Both these potentials sound a clear note of caution and warrant further attention and ongoing management.

Nonetheless, current levels of biomass, nuclear, and large hydro were included in the model, to reflect existing realities such as plants in existence or under construction, along with additional capacity only as far as judged to be sustainable (none for nuclear) according to WWF's own criteria (see topic papers).

WWF recognizes that there are currently new nuclear plants being commissioned and that others are being decommissioned. The scenario assumes that all existing nuclear plants built or under construction will be run to the end of their economic life, but will not be replaced. This effectively would result in a phase-out of nuclear power by 2050.

3 THE WWF CLIMATE SOLUTIONS MODEL – INPUTS

This section summarizes the major outcomes of a modelling project undertaken for the WWF Global Energy Task Force.

3.1 Modelling Project Objectives

Our starting point is that the following goals should be regarded by the world community as imperative, since failure would in each case give rise to unacceptable consequences:

- To supply sufficient energy services to meet projected global development needs;
- To avoid dangerous climate change and other serious negative social or environmental impacts of energy technologies.

The specific objectives of this project have therefore been:

- To assess the availability of energy solutions to meet these goals in the period to 2050;
- To identify the key energy issues which need to be resolved if this potential is to be realized.

3.2 Defining the Challenge

3.2.1 Meeting global energy services needs

The number of people, the level of their consumption, and the nature of what they consume are all-important ingredients in understanding the challenge that is to be met. In all cases we have tried to take a neutral, mid-range projection of these important trends.

Population. The model assumes a growing world population which peaks at nine billion people in 2050, as forecast by the United Nations Population Project[11].

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[11] United Nations (2004). *World Population Prospects: The 2004 Revisions Population Database*. United Nations Populations Division. http://esa.un.org/unpp/

Consumption. We have assumed an increasing demand for energy services and land production driven by economic development and industrialization in developing countries facing major challenges in the relief of poverty[12], and increasing levels of wealth in all countries.

Energy Demand. For a balanced view of projected energy demand we have used the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES) scenario A1B storyline which is in the mid-range of energy demand projections[13]. However, we have noted that the provision of energy (such as electricity or fuel) is only a means to an important end: the provision of energy services (such as lighting or transportation).

3.2.2 Avoiding dangerous climate change

Two degrees Celsius threshold. We have adopted the position (proposed by environmental scientists, adopted by the European Union[14], and strongly endorsed by WWF) that any human-induced warming greater than two degrees Celsius above pre-industrial levels will be dangerous for the global environment, human society, and national economies[15].

Stabilization target. The future levels of global warming are related to future levels of greenhouse gases in the atmosphere. We have adopted a target of 400ppm (parts per million) carbon dioxide equivalent (CO_2e) for greenhouse gases. This is based on Meinhausen's[16] analysis of the impact of greenhouse emissions on the climate system which suggests such a stabilization provides a high[17] probability of avoiding a two-degrees Celsius warming. In fact, current atmospheric concentrations of greenhouse gases have already exceeded this point; however, the model referenced above indicates a trajectory in which emissions peak at 475ppm

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[12] See Topic Paper "Poverty and Energy" and country papers attached.

[13] IPCC (2000). *Special Report on Emissions Scenarios*. The scenario is characterized as follows: "The A1 storyline is a case of rapid and successful economic development, in which regional average income per capita converge – current distinctions between "poor" and "rich" countries eventually dissolve. The primary dynamics are: Strong commitment to market-based solutions. High savings and commitment to education at the household level. High rates of investment and innovation in education, technology, and institutions at the national and international levels. International mobility of people, ideas, and technology. The transition to economic convergence results from advances in transport and communication technology, shifts in national policies on immigration and education, and international cooperation in the development of national and international institutions that enhance productivity growth and technology diffusion." The A1B sub-scenario uses a "…balanced mix of technologies and supply sources, with technology improvements and resource assumptions such that no single source of energy is overly dominant".

[14] EU Council (2004). Spring European Council 2004 proceedings: "…the Council [...] ACKNOWLEDGES that to meet the ultimate objective of the UNFCCC to prevent dangerous anthropogenic interference with the climate system, overall global temperature increase should not exceed 2ºC above levels; [...]" Spring European Council 2004. Document 7631/04 (annex), p20.

[15] For a fuller statement, see Topic Paper "The 2° C Imperative".

[16] Meinhausen, M. (2004). EU's 2°C Target and Implications for Global Emission Reductions. Swiss Federal Institute of Technology presentation.

[17] This refers to the Meinhausen (2004) estimate that a 400ppm CO_2e stabilization would be consistent with a 74% probability of staying below two degrees Celsius warming (relative to pre-industrial levels).

but stabilize at 400ppm over the long term, due to the action of the biosphere and oceans re-absorbing a portion of current and future anthropogenic emissions[18].

Carbon budget. There is an emerging consensus regarding the level of global emissions reductions required – typically 60% below current levels by 2050 – in order to avoid dangerous climate change. However, it is the total cumulative emissions that are important in this respect, so we have adopted the concept of a global "carbon budget" – the total amount of carbon that can be released from human activity (allowing for natural levels of emission and sequestration) before a particular concentration level is breached.

Land-use emissions. Allowance must also be made for the uncertain contribution of emissions from land uses (of which tropical deforestation will be particularly important, being responsible for a fifth of all greenhouse gas emissions). We have therefore described a "carbon budget" *range* representing the upper and lower allowances of anthropogenic carbon budget, depending on the success or failure of activities to limit emissions in these land-use sectors[19].

Carbon budget range. Meinhausen's modelling indicates that to achieve an atmospheric stabilization target of 400ppm CO_2e requires that emissions be limited to a fossil carbon budget of "about 500Gt C" (gigatonnes of carbon). We have adopted this as the upper limit of allowable emissions. However, this assumes a significant cut in land-use emissions, in the absence of which Meinhausen points out that the carbon budget "could be lower (400 Gt C)". This has therefore been adopted as the alternative upper limit of allowable emissions.

Carbon band. Clearly, such a budget will be spent (emitted) over the course of many years (the model builds the carbon budget over a period of 200 years). The model assumes the way in which the budget might be spent as an indicative band, as shown in Figure 3, consistent with the upper and lower allowances of the total carbon budget. The smooth curves of this band reflect the inertia in the current energy system which resists sudden change.

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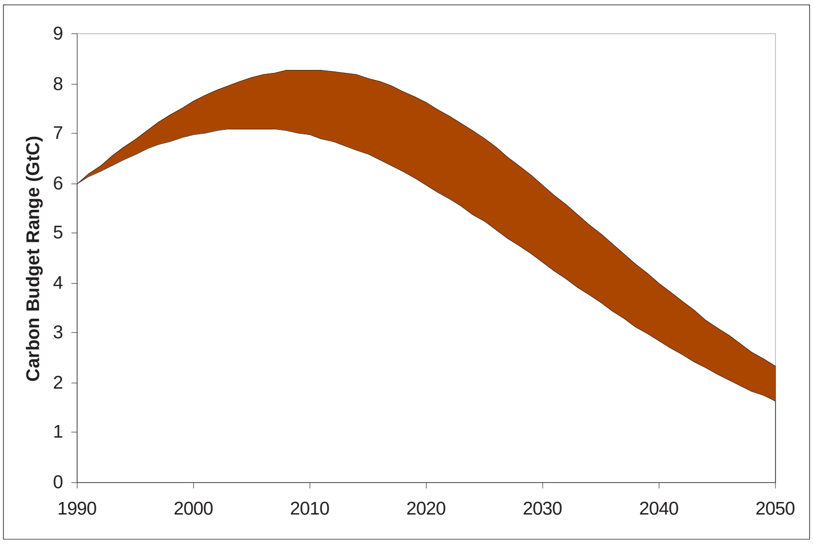
[18] Meinhausen, M. (2006) "What Does A 2 Degree Target Mean for Greenhouse Gas Concentrations?", pp: 265-279, chapter 28 in: *Avoiding Dangerous Climate Change*; Cambridge University Press, 392 pages, 2006.

[19] See Topic Paper "Deforestation".



Note

Figure 3. An indicative "carbon band", showing the difference in the upper limits of annual allowable carbon emissions, from fossil fuels, in GtC per year, for total carbon budgets of 400Gt C and 500Gt C taken out to 2200 (showing the period to 2050 only). The thickness of the band therefore shows the crucial extra flexibility available in anthropogenic emissions if deforestation is successfully controlled.

Other greenhouse gases. We assume here that reductions of carbon dioxide will see other greenhouse gases reduced in equal proportions, provided they are recognized and included in the same regulatory frameworks. So, the model works with carbon dioxide emissions only and does not include other greenhouse gases. However, the carbon dioxide from fossil fuel and deforestation accounts for the majority of all greenhouse gas emissions (62% and 18% respectively[20]). By cutting emissions from these sources, many other GHG emissions (notably methane and nitrous oxide) will be reduced in addition to carbon dioxide. A world that seriously undertakes to reduce the carbon intensity of its energy sources to combat climate change is also likely to cut its non-energy carbon dioxide and other greenhouse gases by employing more innovative agricultural and industrial policies.

Persistent Use of Fossil Fuel without Carbon Capture. The use of carbon capture technology will enable low-emission use of fossil fuels in major applications (see later). The model also allows for an estimate of ongoing fossil-fuel use in a few applications where alternative fuels are not available and/or where carbon capture technology has not been successfully applied. These include a proportion of aviation fuel demand not met by biofuels, and some aspects of industrial manufacturing and other niche applications or locations[21].

3.3 Key Features of the Model

3.3.1 Commercially available industry forcing

The WWF Climate Solutions Model is primarily a resource, technology, and industry feasibility model. It is not an economic model; price and cost have not been used to limit or guide the uptake of technologies. No assumptions or inferences have been made regarding the policies

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[20] Baumert, K.A., Herzog, T., Pershing, J. (2006): *Navigating the numbers – Greenhouse Gas Data and International Climate Policy*; World Resource Institute, Washington USA.

[21] See Topic Paper "Persistent non-CCS fossil-fuel use".

and measures required to achieve the outcomes. However, to ensure that the modelled scenarios are economically plausible and affordable, only energy sources and climate solutions which are currently competitive – or likely to be in the near term – have been selected. In some cases distributed energy technologies priced at point of use (such as solar photovoltaic panels or combined heat and power) have specific cost advantages which the model recognizes. In the case of hydrogen manufactured via renewable energy sources, it is assumed that the added value of storage and creation of flexible, transportable fuels and fuels for high-temperature industrial processes will justify the additional costs.

Although commercial viability has been assumed, this may not be achievable by means of single instruments such as a carbon price alone. However, the level of commercial and public investment needed to drive industrial production and infrastructure development at the scale required will depend on long-term, stable commitments from governments on the pace and depth of greenhouse gas emission constraints.

Lack of economic plausibility is often used to criticize models that include the use of low emissions, higher cost technologies. However, the conclusions of the Stern Review – which was primarily economic – projected that the costs of global warming would severely impact global GDP if left unchecked.

3.3.2 Extending the Pacala-Socolow "wedges" concept[22]

A considerable amount of modelling has been undertaken in the fields of both climate change and energy. Many models are constructed in ways that let scenarios evolve based on costs, such as the price of oil or the cost of carbon. WWF's Climate Solutions Model takes a different approach, focusing on the technology and resource potential of averting dangerous climate change, leaving the political and economic systems to respond to this necessity, rather than the other way round.

A "wedges" model, developed by Pacala and Socolow[23], is widely viewed as an elegant approach and provides an excellent starting point. It divides the task of emissions *stabilization* over 50 years into a set of seven "wedges" (delivered by emissions-avoiding technologies) each of which grows, from a very small contribution today, to a point where it is avoiding the emission of 1Gt C per year by 2050. Its authors point out that many more of these "wedges" are technically available than are required for the task of stabilizing global emissions at today's levels by 2050.

The WWF Climate Solutions Model builds on the Pacala-Socolow "wedges" model by adapting it to go beyond stabilization, to achieve by 2050 the significant reductions in global emissions

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[22] Pacala and Socolow have applied the word "wedge" to mean a very specific level of climate abatement defined by a triangle growing from zero in 2005 to 1Gt C per year of avoided emissions in 2050. The WWF model adopts the same principle of growing wedges, but does not require a linear growth, nor define a prescribed size in 2050. For differentiation, the WWF model refers to "Climate Solution Wedges".

[23] Pacala, S and Socolow, R. (2004) Stabilization Wedges: Solving the Climate Problem of the Next 50 Years with Current Technologies. *Science* 13th August, 2004, Vol. 305.

which the current scientific consensus indicates are needed to avert dangerous climate change. The WWF model:

1 Extends the penetration of climate-saving technologies so as to achieve abatement consistent with a more stringent carbon budget.
2 Draws on a diversity of expert opinion on the potential size and scale of solution wedges (from published analysis, internal research, and commissioned research from specialist consultants) as inputs to the model.
3 Employs a probabilistic approach with these inputs (using the “Monte Carlo” method[24]) so that the results can be considered as probabilities of achieving certain outcomes or risks of failure.
4 Models real world industrial growth behaviour by assuming: that the growth of any technology will follow a typical S-shaped trajectory; that constraints impose a maximum on the rate of sustainable growth; and that the ultimate scale depends on estimated resources and other specific constraints.
5 Seeks to minimize the replacement of any stock or system before the end of its physical or economic life.
6 Allows some solutions to play an interim role by being phased in then phased out as better solutions become available.
7 Excludes energy-technological options deemed by WWF to be inherently unsustainable.
8 Includes a contingency which allows for the possibility that some solutions may encounter significant barriers to development and therefore fail to meet the projections set out in the model.

Considerable analysis and modelling detail supports each of these steps and further explanation is available in a supporting technical document[25].

3.3.3 Top-down and bottom-up

The model combines top-down and bottom-up aspects to capture the best of both ends of the debate about how best to approach future emission cuts – the global requirement for energy and abatement opportunities (“top down”) and the wide range of options for meeting these needs sustainably (“bottom up”).

The top-down aspect of the model is based on the IPCC’s A1B scenario for energy and emissions, which is consistent with Section 3.3.1 above. However, top-down approaches can introduce perversities such as inflated baselines creating an illusion of greater emissions

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[24] The Monte Carlo method is widely used to predict probable outcomes in situations where two or more inputs have a range of possible values. The model is run over and over again with different input values set randomly within their possible range and in accordance with their individual probability distributions. Consequently the results provide a probability of outcome which reflects the combined probability distributions of the inputs. See references in technical summary.

[25] A technical summary of the design of the model can be found in Paper 19 of the Topic Paper Annex to this report.

reduction potential[26]. The bottom-up aspect of the model builds a set of "climate solution wedges" to meet the projected energy services demand, sector by sector. This requires some assumptions about the level and type of consumption, what proportion of energy is used on transport, or in homes or in industry, and so forth.

It has been assumed that in 2050 consumption patterns throughout the world will be similar to those of citizens with developed standards of living today – for example in the OECD. This information is used to ensure that the climate solution wedges are internally consistent and avoid the "double counting" of overlapping abatement opportunities[27]. By considering, in each sector, the total energy services needed for that sector and then the role of possible climate solutions, the climate solution wedges maintain to the best extent possible their connection with the real world.

To contrast the two different approaches: the climate solution wedges can be built from the bottom up to consider the total energy provided in response to the needs of each sector. Or, in the top-down approach used by Pacala and Socolow, each can be seen as a wedge of low- or zero-carbon energy, subtracted from the A1B projection, and displacing conventional fossil-fuel supplies which would otherwise have been used to meet energy needs.

No preference order of solution wedges is implied and if the combined block of potential solution wedges exceeds the estimated energy demand in a given year, the extent of this excess is effectively a contingency/safety margin against failure of individual wedges, underestimation of demand, or future requirements for deeper cuts than currently estimated.

4 THE WWF CLIMATE SOLUTIONS MODEL – OUTPUTS

The WWF Climate Solutions Model has been run to look at a variety of scenarios within the boundaries of the chosen modelling methodology, and the scenario presented here considers what is required to ensure that the goals defined by the WWF Global Energy Task Force _ energy development needs, climate protection, and avoidance of social and environmental impacts _ are met within a safety margin consistent with appropriate risk management.

Importantly, this scenario (see Figures 4 and 5) describes a future in which, due to the long lead times for deploying low-emission technology, global fossil-fuel carbon emissions continue to rise for the next decade. The scenario shows that, in order to remain within the total carbon budget, decisive action is needed within five years to speed up the growth of *all* clean-energy industries. A transition on this scale is needed to avert dangerous warming, and under the model it appears technically and industrially feasible. However, successful delivery will depend on sufficient political will, globally organized, to drive change through a suitable economic and regulatory framework.

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[26] For example, converting an average car to hybrid might save 3 litres per 100km, but if you assume cars in the future are twice as big and would normally use twice as much fuel, then the savings would be 6 litres per 100km. If that were the case, the net consumption rate would have remained unchanged. While it can appear that there are greater emissions avoided, in practice this may not be the case.

[27] For example, abatement from transport could be achieved by more efficient vehicles or a switch to biofuels. However, these measures are not cumulative: if all cars ran on biofuels, greater vehicle efficiency would have no impact on net emissions.

4.1 Managing Risk

The scenario has been constructed with the following requirements:

- Meets the anticipated demand in energy services, with at least a 10% contingency surplus;
- Achieves the objective of avoiding a two degrees Celsius warming by achieving a 400ppm CO2e stabilization;
- Is not unduly dependent on any single energy resource or technology type;
- Can be achieved without resort to unsustainable technologies.

4.2 Build-up of Climate Solution Wedges

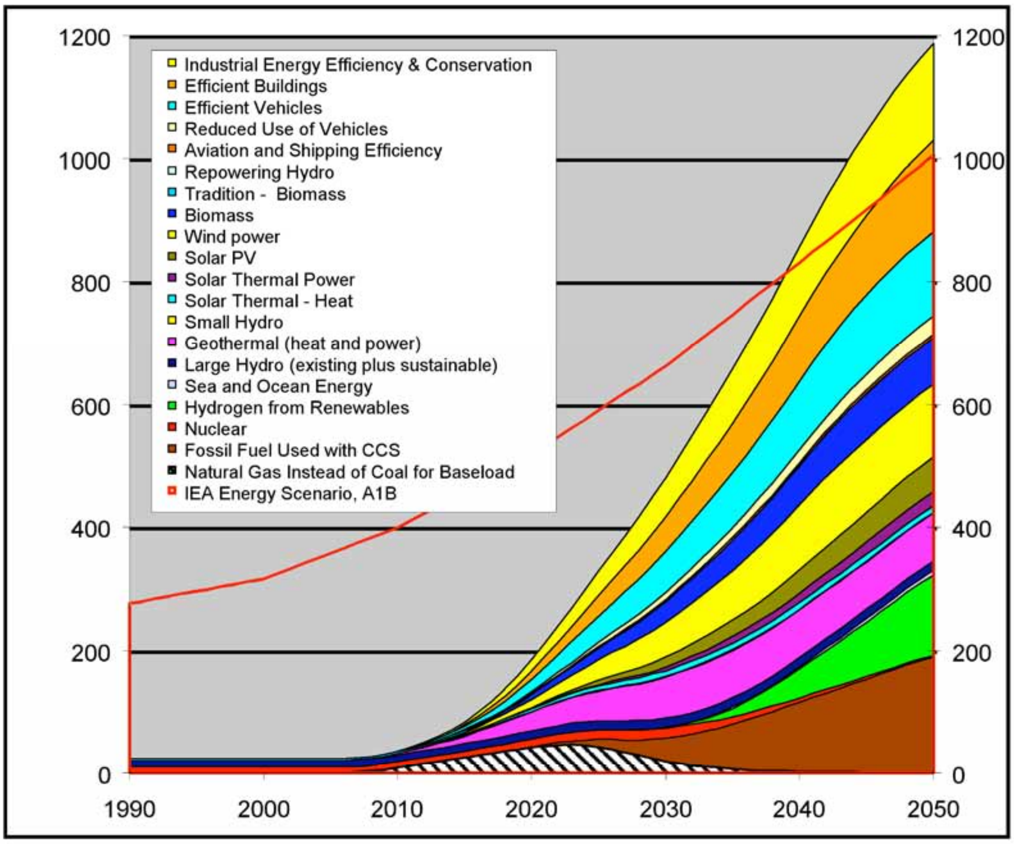

Figure 4. A representative scenario of the Climate Solutions Model depicting technology wedges capable of averting dangerous climate change. Each climate solution wedge grows over time and the sum of all wedges becomes significant as industrial capacity and deployment increase in scale. The top red line refers to the energy demand projection in the SRES A1B scenario. Note that since energy-efficiency technologies are shown alongside energy supply from low-emission sources, the results are expressed in final energy supplied or avoided (rather than primary energy production).

This scenario indicates that a combination of efficiency gains, renewable energy sources and CCS can meet projected energy needs in 2050.

Notes

1 Renewables: Today, only traditional biomass and large hydro are providers of globally significant quantities of renewable energy, though the international growth of others such as wind and solar continues to be exponential and greater than any other energy technologies.

2 Time Lag: The energy-efficiency measures in this simulation have an effect quite early on, making a noticeable impact from 2015 onward. Renewables meaningfully impact a little later and carbon capture and storage (CCS) only starts to penetrate the emissions profile in the period 2020 to 2030. Meanwhile, gas (without CCS) is used heavily in the period 2010 to 2040 to displace the use of coal.

3 Energy for Thermal Processes: There will be a critical constraint on the availability of fuels for industrial thermal processes which can be satisfied only with low-emission levels by hydrogen, biomass, or fossil fuels with CCS.

4 Residual Emissions: If there are no significant failures in the climate solutions available, the only remaining carbon emissions from fossil fuels after about 2040 are those from higher-efficiency aviation (see below) and shipping sectors, a small fraction of non-CCS natural gas and residual emissions from a growing share of CCS-based fossil-fuel use. The model does not include non-energy carbon dioxide (process) emissions, or non-carbon dioxide emissions from other human uses such as agriculture or fluorinated greenhouse gases (F-gases). These are assumed to reduce in rough proportion with carbon dioxide emissions provided that such gases are identified and included in the same regulatory frameworks. However, assuming the contingency is called upon, then the phase out of conventional fossil-fuel use will be delayed by about ten years to 2040 (see Figure 5).

5 Post 2030: Most energy consumption post-2030 is derived from various sources of renewable energies, notably wind, sustainable biomass, geothermal, and various systems for harnessing solar radiation.

6 Hydrogen from Renewables: There are many sources of renewable energy that can supply substantially more energy than the power grids are able to absorb, and harnessing this energy therefore requires storage in another form. Hydrogen is an example of one such energy carrier. The importance of hydrogen generated from a non-specified but wide variety of renewable sources (such as large solar thermal installations, wind energy, and similar large resources otherwise constrained by grid limitations) grows rapidly from 2030. This provides more flexibility for the application and time of use for zero- and low-carbon energy sources, especially if they are intermittent. It also allows a chemical energy form for thermal and transport applications.

7 Aviation: There is currently very high growth in the levels of aviation and therefore the annual emissions of greenhouse gases from air travel. In part this trend reflects the lower levels of taxation applied to aviation fuels and their current exclusion from the Kyoto Protocol. In modelling aviation we have looked at several possible solutions for ensuring that aviation levels can be managed within the carbon budget. The model includes the following provisions:

   a) An ongoing increase in the efficiency of aircraft.
   b) An increase in the operating efficiency of aircraft by maximizing occupancy levels on all flights.
   c) Displacing the use of mineral (fossil fuel) kerosene with direct replacements derived from biofuels.
   d) Avoiding aircraft use where possible through use of alternatives such as high bandwidth teleconferencing, high-speed trains for short distance travel, and other interventions to avoid the need for or uptake of short duration air travel.

   Unlike land-based transport, electrical storage of energy or hydrogen is not yet, and may never be, applicable to air travel. This means that aviation fuels may need to be a priority for biofuel use or there may be a need to factor in residual use of fossil fuels for aviation. The model includes a provision for continued use of some fossil fuels for persistent applications, such as some component of aviation fuels.

4.3 How the Wedges Displace High-Emission Energy

Figure 5 shows how the mix of energy wedges performs relative to the energy that is forecast to be required from the A1B reference scenario.

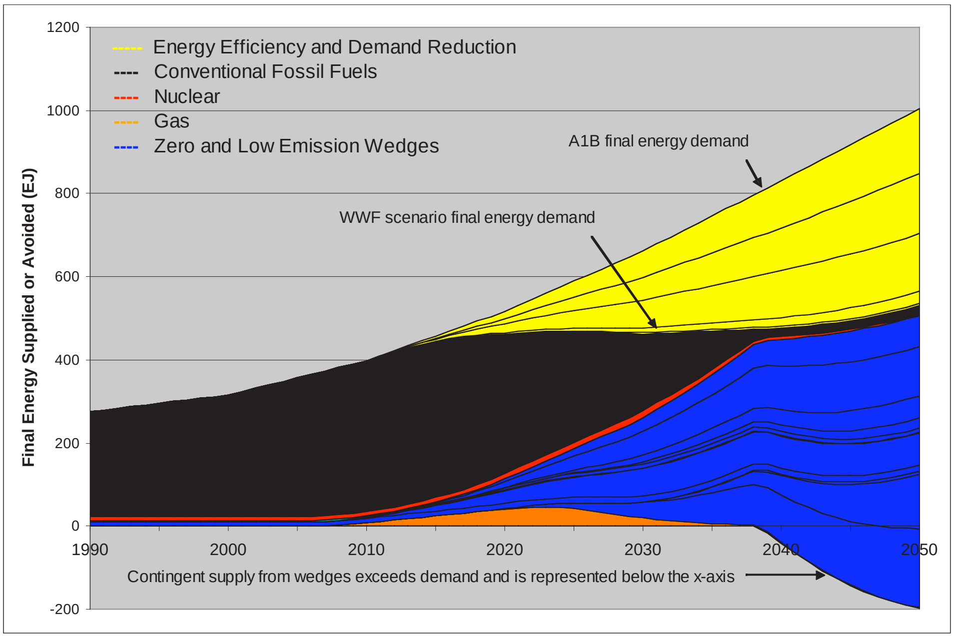

Figure 5. Output of the WWF Climate Solutions Model. Energy efficiency and demand reduction measures (drawing down from the top, in yellow) largely stabilize energy demand by about 2020, allowing a rising demand for the provision of energy services to be met from a more or less level supply of energy (notwithstanding regional variations). Meanwhile zero- and low-emission energy sources are built up (from the bottom, in blue) until about 2040 when, assuming none fail significantly, fossil-fuel use (in black) is reduced to a "persistent" residual level of 20EJ for applications which are hard to replace. Nuclear energy use (in red) is phased out. It may of course be that some wedges under-perform or fail entirely. The scenario provides spare capacity as a contingency, represented by energy supply shown reaching below the x-axis.

In broad terms the scenario shows an energy world dominated by the demand for more energy services over the full period to 2050.

With the seeds of energy solutions sown in the period to 2012, the effects on the energy mix start to become tangible, first with a deliberate expansion of **energy efficiency** (industry, buildings, and in all forms of transport). The overall effect is to cause final energy consumption to plateau from 2020 onwards, while final energy services demand actually increases throughout this period.

Despite starting from a smaller base, the growth of **renewable energy** becomes significant in the period to 2020. In addition, an increase in use of gas is postulated to avoid new coal uptake – creating a "gas bubble" which extends from 2010 to 2040.

As renewable electricity production becomes constrained by about 2040, the growth of **hydrogen** production and distribution allows renewable energy to be both stored and used for end-uses such as transport fuels and domestic and industrial thermal processes.

Most of the remaining phase-out of emissions from conventional fossil fuels is achieved by expansion of **carbon capture and storage** – on both gas and other fossil fuels still used for power and industrial processes.

The scenario is **resilient** to the under-performance of one or more wedges with a 15% contingency; this would even allow for a total failure of fossil fuel CCS.

This scenario shows that it is technologically possible to exceed the projected demand for energy (as moderated by energy-efficiency measures) using the mix of wedges which have been developed with the industrial criteria set out for the model and based on published resource and performance data. Of course, this takes a unified global approach. Some regional perspectives are explored in the background topic papers[28].

The overall effect of this scenario on emissions is shown in Figure 6.

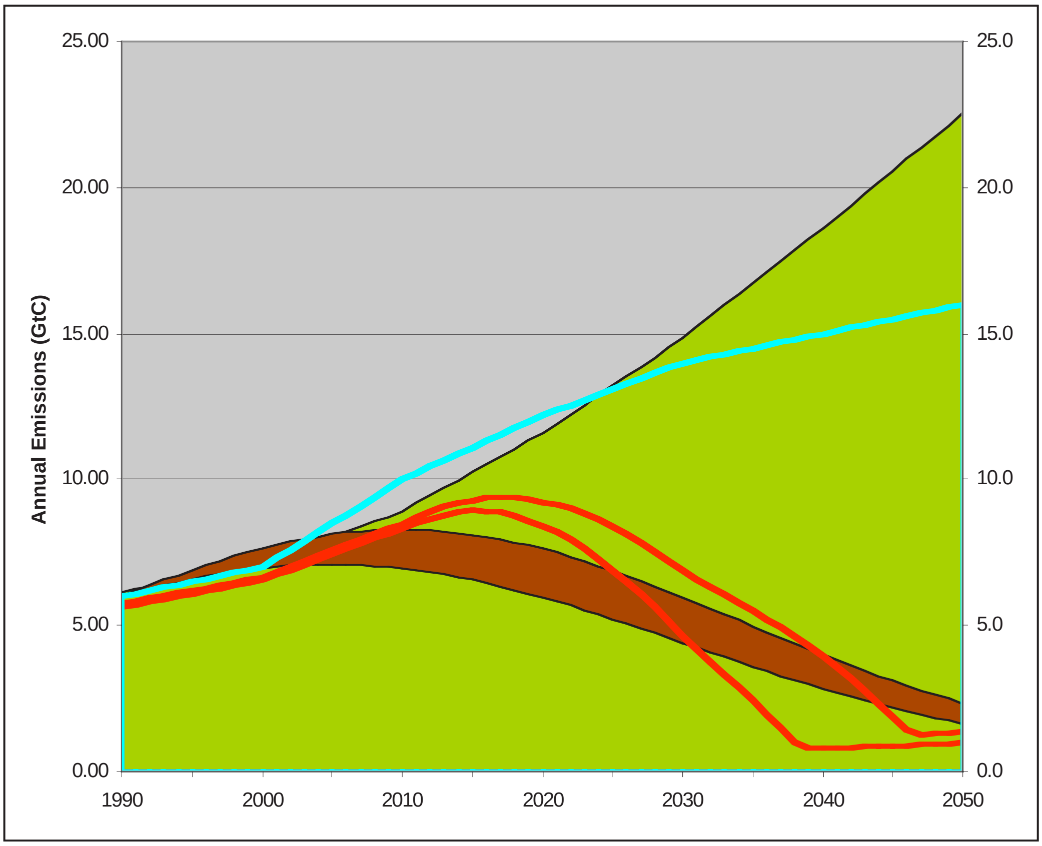

Figure 6. Emissions in the WWF Climate Solutions Model. The diagram shows the range of emissions (the area between red lines) in the scenario presented in this paper. The lower limit of this range shows the technical potential of emissions reduction if all wedges are fully implemented, and the whole "fossil fuel with CCS" wedge (coloured brown in Figure 4 above) comprises plants burning gas (which has lower carbon intensity). Emissions follow the upper limit line if about 80% of the potential is achieved and the "fossil fuel with CCS" wedge is made up of

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[28] See the attached Topic Paper Annex.

(higher carbon intensity) coal plants. Placed against the nominal carbon budget curve (brown, from Figure 3), it is clear that the overall emissions to 2050 of the lower trajectory fall within the total emissions indicated by the upper limit of the budget range (assuming that deforestation is successfully brought under control). Any failure of efforts to halt deforestation (reducing the budget available for energy emissions to the lower limit of the brown band) will reduce the chances of staying within the overall emissions budget, especially if failures or delays in the implementation of solution wedges drive the emissions curve towards the upper limit of the red band. These curves are set against a backdrop (green) of the emissions that would occur if the IPCC's A1B energy scenario were supplied with the current fossil-fuel mix (*i.e.,* at about 0.02GtC/EJ). Also shown is the projected emissions curve for the A1B reference scenario which reaches annual emissions of 16GtC in 2050. The results of the modelling show that, although the point at which global emissions start to decline may not occur until 2015-2020, there is potential to drive deep cuts quickly once the industrial momentum behind transition is underway.

4.4 Key Characteristics of the WWF Scenario

The WWF model and scenario presented show that, within the technological, resource, and industrial constraints built into the model, it is possible to achieve a set of transformations in the energy sector needed to avert dangerous climate change. To achieve this in the model:

- All solution wedges are pursued concurrently; there is inadequate industrial development time to allow for consecutive development;
- Initiation of most solutions occurs between 2007 and 2012, reflecting the fact that some solutions are already underway, though many are not;
- Energy-efficiency technologies are deployed as early as possible to create emissions space while other solutions are evolving in scale;
- The rate of development for most of the zero- and low-emission technologies is pushed to the high end of viable industry growth initially (up to 30% per annum) and maintained at about 20% per annum during their roll-out phase;
- The solution has intrinsic resilience to the failure or under-performance of one or more climate solution wedges; this includes the possible failure of CCS.

5 CONCLUSIONS

5.1 Six Key Solutions

If implemented in parallel, the WWF model shows that the following solutions provide a way to achieve the goal of averting dangerous climate change while avoiding other serious environmental and social consequences. Topic papers (annexed)[29] include further information on these technologies and WWF's definition of "sustainable" for each.

5.1.1 Decoupling energy services demand from energy production

Investment in energy efficiency, at all levels from generation to actual use, is by far the most immediate, effective, and economically beneficial way to reduce emissions, to "buy time" while other technologies are developed[30], and to decouple rising demand for energy services from actual energy production. The model indicates that by 2020-2025 energy efficiencies will make it possible to meet increasing demand for energy services within a stable net demand for

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[29] See the attached annex of topic papers.

[30] See the attached topic paper on "Energy Efficiency".

primary energy production. The priority for developed countries is to retrofit their inefficient capital stock with energy-efficiency measures, and to enable developing countries to leap-frog by investing in much more efficient technologies and systems from the start.

By 2050, the WWF scenario shows the potential for the equivalent of 200EJ[31] per year to be avoided through industrial energy efficiency, plus a similar amount from building efficiency and from a combination of reduced vehicle use and higher-efficiency engines. In total, efficiencies can reduce the projected demand by 468EJ, or 39% annually – equivalent to avoiding emissions of 9.4Gt C/yr – by 2050[32].

5.1.2 Stopping forest loss and degradation

Stopping and reversing deforestation and degradation of forest land (*e.g.*, for charcoal or grazing lands)[33], particularly in tropical countries, emerges as an absolutely crucial element of this scenario[34]. Priority must be placed on reducing emissions rather than on pursuing sequestration. NB: This does not preclude continued sustainable use of forests.

The scenario underscores the need for efforts to curb emissions from land-use change and forestry, contributing a total saving of 100-150Gt C towards achieving the overall carbon budget. Without this contribution, the probability of success is radically reduced.

5.1.3 Concurrent growth of low-emission energy technologies

The model assessed the potential for a variety of low-emission technologies such as wind[35], hydro[36], bioenergy[37], geothermal, solar PV, wave and tidal, and solar thermal. A rapid scaling-up of these technologies is needed, but within a set of environmental and social constraints to ensure their sustainability. In the next 50 years, expansion of sustainable wind, hydro, and bioenergy will be particularly important. Bioenergy for heat and transport holds vast potential but could go terribly wrong if implemented unsustainably – *e.g.,* by clearing biodiverse habitats to plant energy crops. Large hydro dams need also to be deployed with restraint.

By 2050, the scenario includes the equivalent range of 110-250EJ per year from sustainable biomass, with a best estimate at 180EJ/yr. Together, this and other low-emission technologies can provide 513EJ energy per year by 2050, or about 70% of the supply after efficiencies have been applied, and equivalent to avoiding emissions of 10.2Gt C/yr[31].

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[31] Exajoule (EJ) – a quintillion (10^{18}) joules.

[32] Compared with our reference energy demand scenario (IPCC's A1B), supplied at today's average levels of carbon intensity (about 0.02Gt C/EJ).

[33] See Topic Paper ”Deforestation”.

[34] see Topic Paper ”The 2°C Imperative”.

[35] See Topic Paper ”Wind Energy”.

[36] See Topic Paper ”Hydroelectricity”.

[37] See Topic Paper ”Bioenergy”.

5.1.4 Flexible fuels, energy storage and infrastructure

The model shows that the deep cuts in fossil fuel use cannot be achieved without the large volumes of energy from intermittent sources being harnessed through energy storage for better alignment with the timing of demand and for transformation into energy forms needed for transport and high-temperature (chemical) heat. Use of fossil fuels with CCS will also create large volumes of hydrogen gas. Therefore, the results imply a requirement for: (a) major new infrastructure for the production, storage, transportation and use of hydrogen gas; and (b) development of modular, distributed grid-connected power storage infrastructure.

5.1.5 Replacing high-carbon coal with low-carbon natural gas

In the short term, an increase in the use of natural gas[38] as a “transition fuel” can play a significant part in avoiding the locking in of higher emissions from coal, thereby buying more development time for other energy solutions to grow. While this is more applicable in some countries than others, gas should be scaled up in the short term (where it can avoid coal use), without bringing about harmful biodiversity impacts. The even lower carbon emissions for gas used with carbon capture and storage technology are also taken into account. WWF therefore sees natural gas as a bridging fuel with important applications, provided that energy security issues can be resolved.

The scenario includes a provision of natural gas displacing coal which peaks in supply at about 52EJ in 2023. It is assumed that this can then become sequestered within the CCS wedge as technology comes on line.

5.1.6 Moving on carbon capture and storage (CCS)

The WWF model shows the importance of CCS[39] if fossil fuels are to have an ongoing role within a carbon-constrained energy sector. Clearly, while zero- and low-emission technologies are being brought to maturity and widely deployed, coal, oil, and gas will continue to play a part in the energy supply mix in the medium term, for reasons explored elsewhere in this report and in the topic papers annexed. The model shows that, in order to stay within the carbon emissions budget, it is essential that fossil-fuel plants are equipped with carbon capture and storage technology as soon as possible – all by 2050. This requirement has major and immediate implications for the design, planning, and location of new plants, since transport of carbon dioxide to distant storage sites would be very costly.

Overall, fossil fuels with CCS could account for 26% of supply (after efficiency wedges have been implemented) in 2050, avoiding emissions of 3.8Gt C/yr[31].

However, while very important CCS is at best only a partial contributor. The model shows that, since CCS doesn’t capture all emissions, the proportion of fossil fuels in the supply mix will have to be reduced to 15-30% by 2050 (the low figure for coal, higher for gas). These points emphasize the urgency of major investment in zero- or low-carbon technologies in order to stay within the carbon budget.

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[38] See Topic Paper ”Natural Gas”.

[39] See Topic Paper ”Carbon Capture and Storage”.

Also, continued exploitation of fossil fuels, even on a declining scale globally, will inevitably involve the opening of new reserves as old sources are worked out. New developments should be exposed to rigorous conditions to protect environmental and social values.

A range of potential capture efficiencies are included in the probabilistic model. The level of CCS which can be used is sensitive to this capture efficiency and the fuel that is used – its contribution is maximized with gas.

5.2 Three Imperatives

The following factors emerge as of particular importance in securing a successful outcome to this challenge:

5.2.1 Urgency

The remedies for climate change have been discussed at length without sufficient decisive action. Meanwhile, carbon-intensive technologies are rapidly using up the available carbon budget, reducing options and placing the future in jeopardy. Within five years, measures must be in place to drive the urgent development and deployment of benign energy technologies described in this vision. Delays make the transition increasingly difficult and costly, and the risks of failure greater.

5.2.2 A global effort

The challenge identified here, of meeting the world's energy needs safely and sustainably, patently requires a global effort in which every country has a role to play. If the worst threats of climate change are to be avoided, all countries must shoulder the challenge identified here, though each has different circumstances, responsibilities, and priorities, as illustrated by the accompanying examples of Japan, USA, South Africa, Russia, India, EU, China and Brazil[40].

5.2.3 Leadership

Action is needed by governments of the world to agree targets, to collaborate on effective strategies, and to influence and coordinate the investment of many trillions of dollars (which in any event will be invested in energy in the coming decades), so that future needs are met safely and sustainably, as proposed here.

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[40] See the Topic Paper Annex.

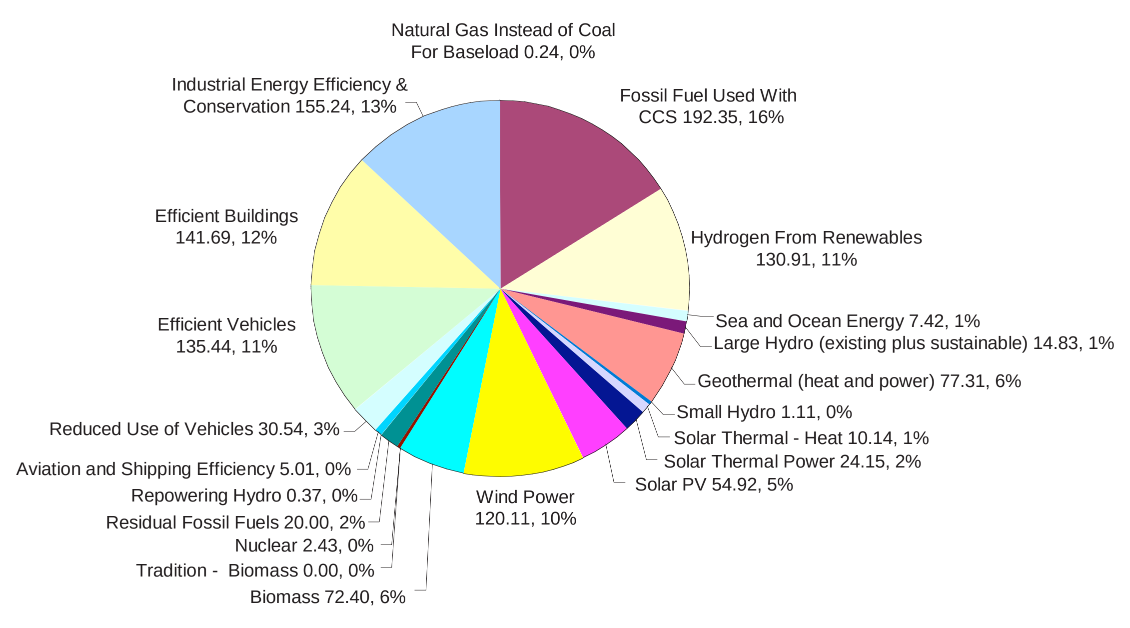

Figure 7. The supply mix. A snapshot of the contribution of each of the "Climate Solution Wedges" in 2050, first in Exajoules and then as a percentage of energy supplied or avoided, compared with the energy demand projection in the IPCC's SRES A1B scenario. Efficiencies reduce that demand by about 40%; of the remaining demand, about 70% can be met by low-carbon technologies, and about 26% by fossil fuels operating with carbon capture and storage. Nuclear, conventional fossil-fuel use without carbon capture, and other small sources make up the last 4%.

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Short Topic Papers

Key themes and technologies

Regional case studies

Technical summaries

Climate Solutions: The WWF Vision for 2050

Short Topic Papers

PART 1 – KEY THEMES AND TECHNOLOGIES **PAGE**

PART 2 – REGIONAL CASE STUDIES

PART 3 – TECHNICAL SUMMARIES

Authors

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Part I Key Themes and Technologies

TOPIC PAPER 1: THE 2°C IMPERATIVE

SIGNIFICANCE

The average global temperature has already risen by 0.74 °C in 2005 compared to 100 years ago and "*eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature.*"[1] Scientists attribute most of this temperature rise to human activities which release carbon dioxide (CO_2) and other greenhouse gases (GHG) into the atmosphere.

According to recent research[2] [3], an average global warming of 2°C or above compared to the pre-Industrial Revolution level would result in dangerous and irreversible impacts, including the following projections:

- **Water shortages**. Globally, more than three billion more people would be at risk as a result of water shortages. The predicted loss of ongoing glacier melt-water in India alone would cause water shortages for 500 million people and for 37% of India's irrigated land;
- **Food insecurity**. More frequent droughts in Africa and elsewhere would lead to lower crop yields, and there would be a general decrease in cereal crop yields extending beyond the tropics to mid-latitude and temperate regions, mainly due to increased evapotranspiration;
- **Health impacts**. Three hundred million people would be at greater risk of malaria and other vector- and water-borne diseases; and the health costs of climate change are projected to double by 2020, partly as a result of heat stress, but primarily because of increased rates of diarrhoea and malnutrition in low-income countries[4];
- **Socio-economic impacts**. Initial estimates of socio-economic losses with moderate temperature increases include gross domestic product (GDP) losses of a few to several GDP percentage points, with net global damage of up to 20% for unmitigated climate change compared to much lower abatement costs in the case of early mitigation action.
- **Effects on ecosystems**. Thirty-five per cent of terrestrial species would be at or near extinction by the year 2050[5], including the loss of unique ecosystems/species (*e.g.,* the Cape region, South Africa).

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[5] Thomas *et al.* (2004) Extinction risk from climate change. *Nature* 427:145-148

CHALLENGES

Research[6] indicates that at 550ppm (parts per million) CO_2 equivalent (CO_2e), the likelihood of exceeding 2°C above pre-industrial levels is very high (63-99% with a mean of 82%). A stabilization at 475ppm would bring with it a 38-90% (mean 64%) probability of exceeding a 2°C target. With a stabilization at 400ppm CO_2e the probability of exceeding 2°C "unlikely", with a range of 8-57% (mean 28%).

Greenhouse concentrations already exceed 400ppm CO_2e. However, there will be some re-absorption by the biosphere (land and oceans) and analysis by Meinhausen indicates that in the short term radiative forcing by greenhouse gases is being offset by aerosol emissions from industry and biomass burning, amongst other things. Figure 1 (c) shows the concentrations pathway for a stabilization at 400ppm CO_2e, following a peak at 475ppm.

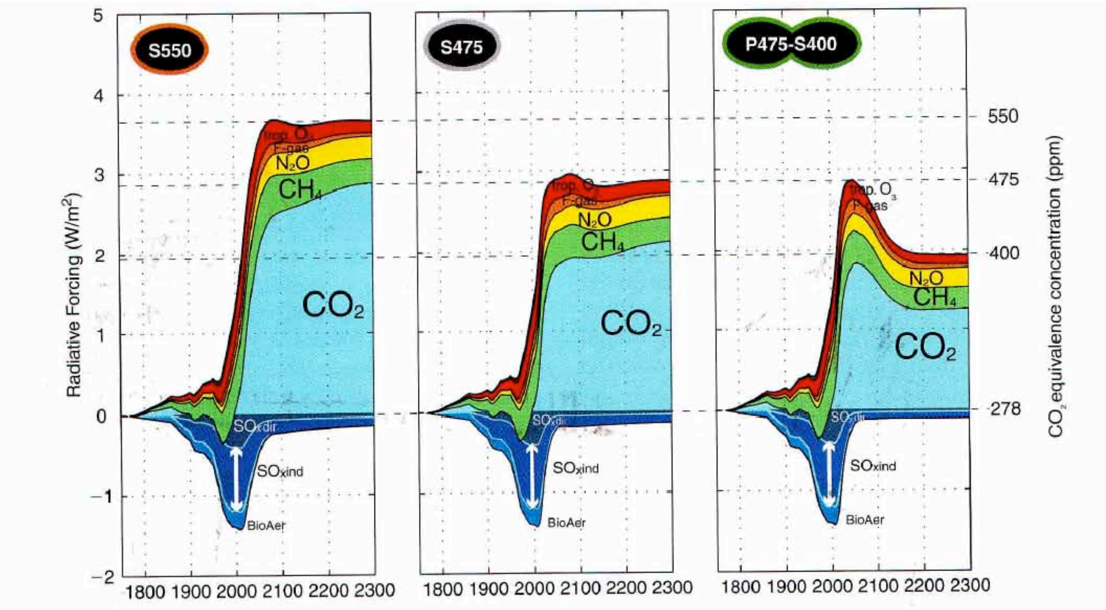

Figure 1. The diagram shows the effects of various greenhouse gases and aerosols and their effect on the radiative force of global warming. The third graph, P475-S400, shows that emissions peak at 475ppm before stabilizing at 400ppm, the reduction being due to the uptake of atmospheric carbon by the ocean and biosphere (from Meinhausen 2006 – see footnote 6).

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[6] Meinhausen, M. (2006) What Does a 2 Degree Target Mean For Greenhouse Gas Concentrations?, pp: 265-279, chapter 28, in: Schellnhuber, H J, Cramer, W, Nakicenovic, N, Wigley, T & Yohe, G. (2006*) Avoiding Dangerous Climate Change*; Cambridge University Press, 392 pp.

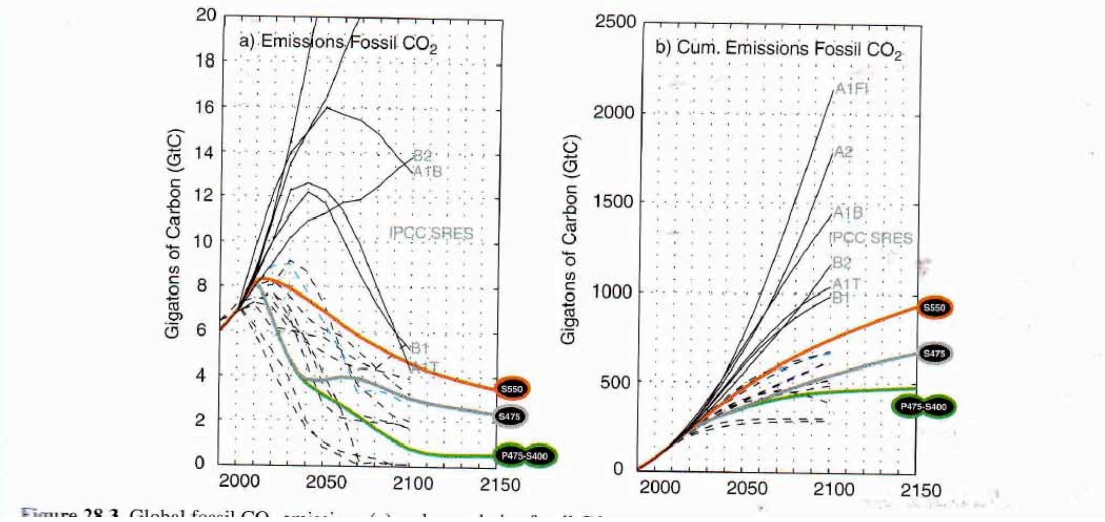
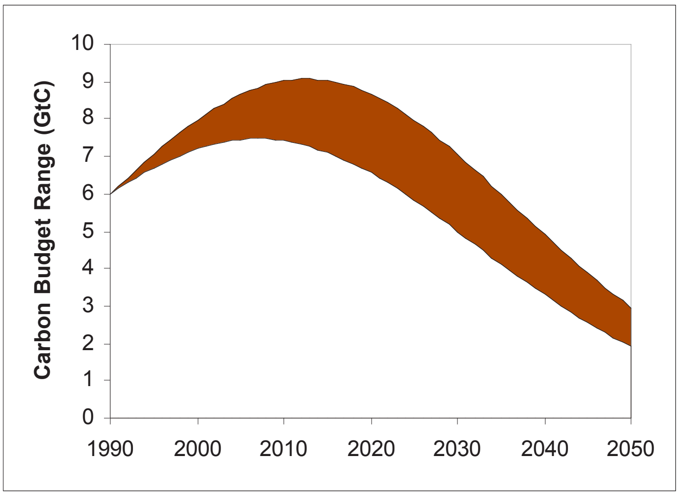


Figure 2. The diagram shows the trajectories of annual emissions and cumulative emissions in the Meinhausen (2006) 400ppm scenario as compared to various other scenarios.

In developing this model, the long-term stabilization goal has been translated into two levels of budget for cumulative fossil carbon emissions, taking account of the high and low estimates for reducing land-use change emissions. Stabilizing at 400ppm CO_2e would require the world to keep within a carbon budget of approximately 500 GtC of fossil emissions (shown by the upper line in the graph below), provided that land-use emissions were successfully controlled. Should land-use emissions not be reduced (through a failure to limit deforestation), the allowable budget of fossil emissions would be reduced by at least 100GtC, so a lower budget of 400GtC has been included (shown by the lower line).



Though the carbon budget used in the model is taken out to 2200, fossil fuel use by 2050 would be somewhat less at between 383GtC for the higher budget and 315GtC for the lower budget. The difference of about 70GtC reflects the different outcomes for land-use change over the half-century.

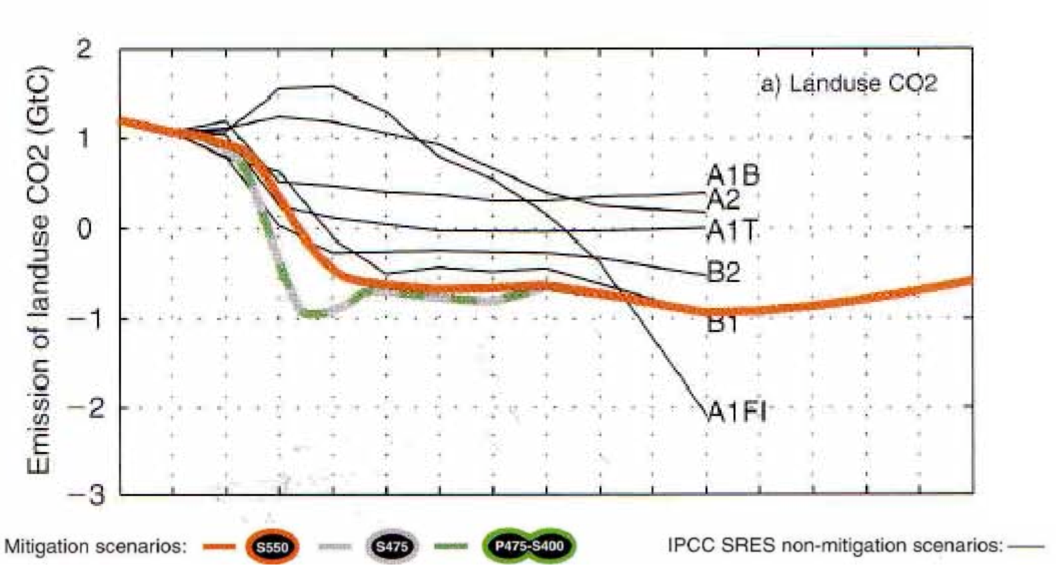


Figure 3. To permit a 500GtC carbon emissions budget, land-use emissions must be reduced over the period to 2050 as per the Meinhausen (2006) 400ppm scenario in the diagram. A failure to do so reduces the budget available to energy and other sectors.

IMPLICATIONS

The amount of carbon dioxide in the atmosphere in 2007 stands at 382ppm, or approximately 425ppm CO_2e (see note below). This has been rising in recent years at a rate of 2ppmv per year. At the same time fossil fuel carbon dioxide emissions have been rising at an unprecedented rate of 3% per annum in the last few years. In order to be able to achieve a global cut of about 50% of all GHG by mid-century compared to 1990 emission levels – considered necessary to stay below 2°C global warming – the critical need is to ensure that global GHG emissions peak and start to decline within the next ten years[7]. As GHGs linger in the atmosphere for decades, radical action – above all in developed countries – is urgent and imperative.

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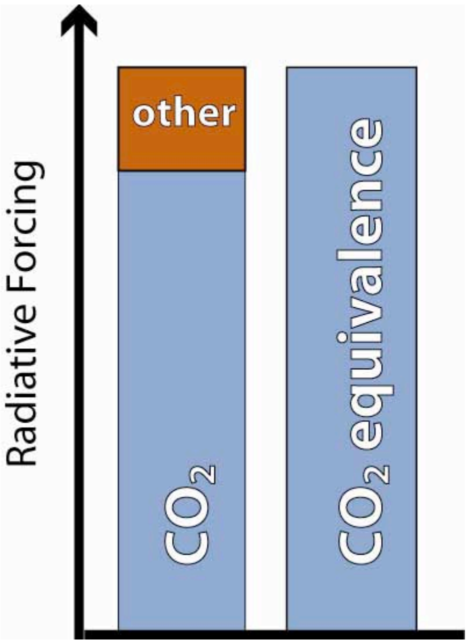
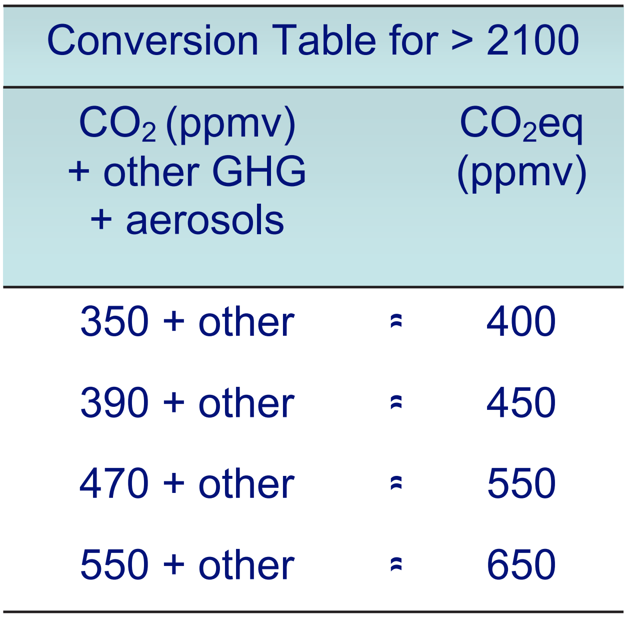
[7] den Elzen, M & Meinhausen, M. (2006) Multi Gas Emissions Pathways for Meeting the EU 2 degree C Climate Target, pp 299-309, chapter 31, in: Schellnhuber, H J, Cramer, W, Nakicenovic, N, Wigley, T & Yohe, G. (2006) *Avoiding Dangerous Climate Change*; Cambridge University Press, 392 pp.

NOTE:

In the model we use the equivalence between carbon dioxide emissions (GtC) or concentrations (ppmv) and total emissions including other gases. In practice, the releases of carbon dioxide and other GHGs can be assumed to stay roughly in proportion; the following table shows an approximate relationship (Meinhausen, M. (2004) EU's 2ºC Target and Implications for Global Emission Reductions. Swiss Federal Institute of Technology presentation).





Conversion Table for > 2100

CO_2 (ppmv) + other GHG + aerosols		CO_2eq (ppmv)
350 + other	≈	400
390 + other	≈	450
470 + other	≈	550
550 + other	≈	650

Topic Paper 2: Deforestation

SIGNIFICANCE

Deforestation is responsible not only for significant ecosystem and species loss, but importantly also for 20% of global greenhouse gas emissions. Ten countries account for 87% of global deforestation, with Brazil and Indonesia alone accounting for 54% of these emissions. Tropical forests, where deforestation is most prevalent, hold over 210GtC, and almost 500GtC in their soils (which is often released in land-use change). Rates of deforestation have remained constant over the last two decades and without significant, concerted action these could result in emissions of 10Gt of carbon dioxide per year for 50-100 years. Forests also absorb carbon dioxide, so increasing forest cover can increase carbon sequestration, but the positive impact of this is far outweighed by the negative impact of deforestation[8] on atmospheric carbon dioxide, let alone wider ecosystem impacts. So, while restoring forest cover is a benefit, the primary focus should be to reduce deforestation[9].

CHALLENGES

- The causes of deforestation are wide ranging and vary by country. They include agricultural expansion, cattle ranching, infrastructure development, and logging. These are driven by both population pressures and increased levels of local and foreign consumption, and exacerbated by poor governance and inadequate land-use planning. Governments and the wide range of market actors must be effectively influenced to reduce these threats.
- Currently available data are provided by national governments and are not globally consistent. Establishing accurate data, and in particular agreeing new globally consistent definitions of deforestation and degradation at a forest biome level, is essential.
- Bioenergy is potentially "CO_2 neutral". However, the expansion of palm oil and tropical crops, such as sugarcane, for biofuel production could become a significant driver of deforestation. Bioenergy developments must therefore be appropriately regulated to prevent further deforestation.

RATE OF CHANGE ACHIEVABLE

It is plausible to halve the current rate of deforestation by 2015 and achieve a zero rate by 2020. This would lead to cumulative emission reductions of 55Gt carbon dioxide by 2020, and 155Gt by 2030. In contrast, to halve the rate of deforestation by 2020, and achieve a zero rate by 2030 would result in cumulative emission reductions of 27Gt carbon dioxide by 2020, and 105Gt by 2030 – a significantly lower benefit.

See topic paper 1 for assumptions made in model.

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[8] Source: IPCC, Special Report 2000.

[9] The sustainable use of forests, while protecting and maintaining their overall structure and ecosystem functions, is not in question.

Halting land clearance is a far more effective intervention than planting trees. Reforestation with fast-growing trees at the rate of three million hectares per year (equal to current rates) would result in a cumulative absorption of only approximately 10Gt carbon dioxide by 2020.

Topic Paper 3: Energy Efficiency (EE)

SIGNIFICANCE

Most societies are massively wasteful of energy. Energy-efficiency (EE) measures across all sectors can play a huge, essential, painless and non-controversial part in ensuring a sustainable energy future. Such conclusions have been reconfirmed many times. The International Energy Agency's (IEA) latest scenarios estimate that, depending on the scenario applied, EE could account for **31-53% of the total carbon dioxide emission reduction** (relative to baseline) in 2050[10]. This is consistent with the findings of the WWF model where energy-efficiency technologies and systems account for a reduction of approximately one-third of energy demand. The European Commission estimates that EE measures could cost-effectively deliver a 20% reduction in today's energy consumption in the European Union (EU) by 2020, with savings of at least 60 billion[11].

Energy use in commercial and residential **buildings** accounts for 35% of today's global final energy consumption; 32% for **industry** and 26% for **transport**. In all sectors, major savings could be achieved by adopting best available technologies, innovative materials and/or new processes and systems, in most case available on the market and at reduced net costs (generally higher investment cost but lower operating cost).

EE measures in **buildings** comprise mainly envelope and insulation materials, lighting and appliances, heating and cooling systems. In the long term, the biggest saving potential can be achieved by setting building codes for **construction** and **renovation** for all buildings. In the short term, major savings from a better energy end-use can be attained. IEA countries could save some 322Mt of CO_2/y by 2010[12] with new policies aimed at residential uses of energy (*e.g.,* early replacement of inefficient appliances, energy labelling systems, or setting minimum requirements for energy-using products).

Industrial EE includes many devices and systems already commercially available, providing the same service or commodity with lower energy input. Due to the multiplicity of industrial production and processes, different technologies and systems (*e.g.,* higher-efficiency motor systems, residual heat recovery, fuel substitution, efficient steam generation and use) are applicable to a range of different sectors and industrial groups. Assessing the potential requires a detailed analysis of each technology and its application.

In the past 25 years, **transport** emissions have grown at approximately twice the rate of EE improvements. Without a significant intervention, global transport GHG emissions will keep growing steadily (50-100% by 2020 in comparison with 1995)[13]. Vehicle efficiency must be further improved (*e.g.,* increased fuel efficiency, minimum efficiency requirement for

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[10] "Energy Technology Perspective – Scenario and Strategies to 2050", International Energy Agency (June 2006), p. 47.

[12] Green Paper of the European Commission on Energy Efficiency, "Doing more with less", COM (2005) 265 final, June 2005.

[12] "Cool appliances – Policy Strategies for Energy-efficient Homes", IEA (2003), p. 14. See also http://www.iea.org/textbase/nptable/Projected%20savings%20by%20end-use.pdf

[13] IPCC III report, p 203.

automobile AC systems, better tyre rolling resistance) but at the same time measures are needed to reduce vehicle use, which would otherwise increase with improved efficiency. Better public transport systems, a modal shift from road to rail, and reduced road freight transport are among the measures to be drawn upon.

In the **power** sector, the best EE potential lies in recovery of waste energy, a large expansion of combined heat and power generation (CHP), and better grid management. Cost-effective measures need to be more broadly adopted[14] to reduce transmission and distribution losses, such as minimum standards for distribution transformers[15], EE obligations on system operators, and cost recovery for investments made on the energy end-use side.

CHALLENGES

There are many barriers to overcome, despite the fact that a widespread dissemination of existing EE technologies would prove cost effective in most cases. **Many of these barriers are regulatory and financial**, **rather than technological**. For example:

- High upfront investments;
- Capital misallocation;
- Split incentives between manufactures and consumers;
- Lack of policy coherence and regulatory incentives (regulation that rewards selling large quantities of low-cost power rather than providing better services and reducing demand);
- Organizational failure (no rewards for cutting energy cost, non-integrated budget for purchase and operating savings);
- Lack of financial schemes to address upfront costs;
- Lack of information/education among professionals and consumers on how to optimize energy savings through purchase, installation, and operation of best available technology;
- Difficulties in marketing energy saving/efficiency.

See paper 20 below for inputs to model.

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[14] IEA estimates that improved end-use efficiency leads to substantial reductions in investment needs for power generation capacity (USD2.9 trillion) and transmission and distribution (USD4.3 trillion).

[15] Saving potential > 20 TWh/a in EU.

Topic Paper 4: Wind Energy

SIGNIFICANCE

Today, wind energy, most of it onshore, has a global generating capacity of about 60GW (about 0.5% of global power), rising potentially to about 1,000GW (12-18% of global power) by 2020. This high growth potential is due to a combination of factors, including:

- An annual growth rate of about 25% already established for many years;
- A rapid decline in turbine manufacturing costs with economies of scale;
- The size and efficiency of new generation wind turbines;
- Expected exploration of the high renewable power potential of offshore wind;
- Increasing concerns regarding climate and security of energy supply, strongly favouring domestic and relatively affordable renewable power such as wind[16].

Europe has the largest share of wind power globally, both in terms of manufacturing and generation. About 75% of global wind power is produced in the EU, most of it in just three countries: Germany, Denmark, and Spain. These all have generous renewable energy support schemes and sophisticated grid management servicing more than 50% of all global wind-generating capacity installed. Outside Europe, developments have been slower off the mark but high current growth rates are expected to be sustained in the United States (>20% pa), India and China (>30% pa)[17].

Wind power currently employs about 65,000 people in the EU, growing to almost 200,000 by 2020 under the expansion scenario[18]. Wind power globally creates 2-10 times more hours of employment than nuclear, natural gas or coal, per unit of electricity generation, thus contributing favourably to sustainable jobs[19].

If the savings in pollution costs are not considered, wind energy generation is relatively expensive (4-8 US cents/kWh globally in 2006), up to nearly three times the lowest unit cost of conventional fossil fuel power production (3-6 US cents/kWh for modern gas or coal without CCS). It is, nevertheless, cheaper than many estimates for current nuclear power production. However, by 2050 costs are predicted to have decreased, placing wind on a level with conventional coal, and probably much cheaper than coal-with-CCS[20]. Currently, offshore wind

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[16] GWEC (Global Wind Energy Council) 2006: *Global Wind Energy Report 2005*.

[17] GWEC, as above.

[18] Industry and employment – windpower, the facts, Vol 3, 2006.

[19] J Goldemberg. (2004) The case for renewable energies; background paper for REC Germany.

[20] Various sources including: EIA/DOE, USA, 2005: International Energy Outlook; IAEA, Redbook, 2005; IPCC, WG III, Fourth Assessment Report 2007, in print.

power at about 10 Euro cents/kWh is still more expensive than onshore. However, a recent large-scale economic analysis has predicted that in 10-15 years offshore costs may be halved[21].

Offshore wind represents the largest development potential. Recent turbine size development of towers of 5MW+ capacity will allow more power to be generated by fewer turbines in wind-parks, including actually replacing existing low-capacity onshore wind turbines. Apart from China and India, the United States will have the most dynamic national wind energy market[22].

In Europe, a large offshore "super grid" ranging up to 3,000km from Scotland to Portuguese Atlantic waters is being planned in order to establish wind power as a real base load alternative to existing large power stations. Appropriate international grid management will reduce the effect of local intermittency – one of the current shortcomings of wind power – allowing wind to provide a reasonably steady and predictable supply of energy around the clock.

See paper 20 for inputs to model.

CHALLENGES

In order to ensure that onshore and offshore wind power generation schemes have a positive impact on the environment and society, WWF has put forward a set of robust criteria for their siting and deployment:

1. Careful siting and operation of wind energy projects can ensure that impacts on biodiversity are minimized and that they are integrated well within the local environment. Every proposal for wind energy projects over a capacity of 20MW or including more than 10 wind turbines should be subject to environmental impact assessment (EIA) before consent is given.
2. EIA should provide a comprehensive analysis of the potential impacts of the proposal upon the community, fauna, and flora. The EIA process should be transparent, involving full consultation with all interested parties early in the process.
3. Proposals for wind farm developments within IUCN category I-II protected areas and/or national parks should not be allowed, unless a comprehensive EIA clearly indicates that the proposed development will not cause adverse effects on the integrity or conservation objectives of the statutory protected area.
4. Wind turbines can have a negative impact upon wildlife if sited in the wrong place. They should not be placed in important bird nesting grounds or migration routes.
5. Research is needed on the precise impacts of large-scale offshore wind developments in marine environments, noting the data from existing offshore wind projects in Europe. However, evidence to date does not suggest a need for undue delay in developments.

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[21] Nitsch, J & Viehbahn, P. (2006). (In German), Strukturell-ökonomischer-ökologischer Vergleich regenerativer Energietechnologien (RE) mit Carbon Capture and Storage-Technologien (CCS).

[22] GWEC, as above

Topic Paper 5: Hydroelectricity

SIGNIFICANCE

This brief covers three related technologies with a proposed capacity of +400GW: repowering old hydro dams (+30GW proposed) and installing new small (+100GW) and medium and large hydro projects (+270GW). Hydroelectricity currently provides nearly 20% of the world's electricity. At particular sites, hydroelectricity can provide low-greenhouse gas emission electricity that is particularly useful for meeting peak loads.

Issues which arise or constraints which should apply to its widespread deployment

- Dams destroy the ecology of river systems by changing the volume, quality, and timing of water flows downstream, and by blocking the movement of wildlife, nutrients, and sediments. Less than 40% of the world's longest rivers remain free-flowing, and there are over 1,400 large dams planned or under construction (*e.g.,* 105 in the Yangtze River basin ecoregion, 162 in northern India).
- Dams have enormous social impacts, with 40-80 million people displaced so far. Large dam proposals at many sites have been opposed by local people.
- Undeveloped (but not necessarily low-impact or sustainable) hydropower capacity is unevenly distributed: 60% in Asia, 17% in Africa, and 13% in South America. Small hydropower is mostly used in decentralized systems.

Development/Deployment potential

Repowering old hydropower dams – retrofitting them with modern equipment that can produce more power – generally is benign and can be an opportunity to reduce the original environmental impacts. While the total contribution is relatively small (+30GW), repowering of dams can happen quickly and form the basis for a broader dialogue between civil society and financiers, industry, and governments. The 30GW contribution is estimated based on the numbers of 20+ year-old hydropower only dams on the International Committee on Large Dams' register and estimating a conservative 10% increased production between now (~20GW) and 2025 (+10GW) based on a mixture of light, medium, and full upgrading opportunities.

Small, low-impact, economically feasible hydropower potential is estimated at 190GW globally, with 47GW developed so far. We have estimated that a realistic development level is around 100GW over 50 years, continuing the current 2GW/yr growth rate.

New dam proposals are controversial. Based on impacts in countries with different degrees of hydropower development, WWF estimates that it may be possible to develop 30% of the economically feasible hydropower capacity in most river basins or nations without unacceptable impacts, in accordance with World Commission on Dams guidelines. Around 740GW has been installed out of a global economically feasible large hydropower capacity of 2,270GW. Around 120GW are currently under construction and 445GW are planned over 30-40 years, including many dams with unacceptable environmental impacts. We estimate that of the 445GW, 250GW of large hydropower sites could be developed with relatively low impacts. Using a similar process, we identify a further 20GW of medium hydropower potential.

See paper 20 for inputs to model.

Criteria used by WWF to define "sustainable"

WWF advocates social and environmental safeguards which are based on the guidelines of the World Commission on Dams (2000): http://www.dams.org/

Topic Paper 6: Bioenergy

Biomass is the totality of plants in the terrestrial and marine biosphere which use carbon dioxide, water, and solar energy to produce organic material; it also includes animals, and agents of decomposition such as bacteria and fungi whose activity releases carbon dioxide into the atmosphere. Bioenergy can be derived from biomass in the form of liquid biofuels (processed usually from energy-rich crops), wastes (including renewable municipal waste), solid biomass (wood, charcoal, and other biomass material), or gases (derived from biomass decomposition).

SIGNIFICANCE

"Globally, biomass currently provides around 46EJ of bioenergy. This share is estimated to be over 10% of global primary energy supply, though the volume of traditional biomass consumed in developing countries is uncertain."[23] Applications vary widely, from traditional biomass use (such as cooking on open fires) in the poorest countries to highly efficient electricity and heat production or transport fuels. About 110EJ to 250EJ produced from biomass (see "Development/deployment") would remove about 8-19Gt carbon per year from the atmosphere[24] if it is used to displace fossil fuels. However, this assumes the same efficiency for all biomass and that it is all produced sustainably and replanted so as to be carbon neutral. Since much biomass is used less efficiently, the actual savings would be lower.

ISSUES AND CONSTRAINTS[25]

Uncontrolled development of bioenergy crops can have dramatic impacts on humans and the environment. What, where, and how the raw materials are produced and processed will define whether bioenergy projects are environmentally and socially sustainable on all fronts.

WWF believes that key principles and criteria[26], which must be taken into account for sustainable bioenergy production and use, include the following:

Bioenergy must deliver greenhouse gas (GHG) and carbon life-cycle benefits over conventional fuels

Energy crops to be used for bioenergy must be selected on the basis of the most efficient carbon (soil and air) and energy balance, from production through to processing and use. This is not always achieved. For example energy-intensive fertilizer input increases nitrous oxide (N_2O) emissions, a highly potent GHG, and intensive cropping may contribute to the release of soil-bound carbon dioxide. Some conventional crops, such as sugarcane or woody biomass, can provide net benefits if sustainably produced and processed, and are already available for use as bioenergy. However, future investments and research should be oriented towards ligno-

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[23] IEA, 2005.

[24] Preliminary results of the WWF potentials study (agriculture potentials) and IPCC results (forestry potentials). WWF is currently running an internal consultation process to check these data.

[25] The Oeko Institut has prepared a first list of criteria for sustainable bioenergy production for WWF in "Sustainability Standards for Bioenergy", 2006 (draft).

[26] These principles and criteria will need to be further defined and are not meant to be exhaustive.

cellulosic or other crops that offer better options to reduce carbon dioxide emissions, as well as a reduced impact on the environment.

Bioenergy developments must ensure positive natural resource use and careful land-use planning

Permanent grasslands, natural forests, natural floodplains, and wetlands and peatlands, important habitats for threatened species and other high conservation value areas (HCVA), must not be converted into intensive forest or farmland, even if to produce a potential environmental good such as a bioenergy crop. Biomass production requires agricultural and forestry management techniques that can guarantee the integrity and/or improvement of soil and water resources, avoiding water and soil pollution, depletion of soil carbon, and over-abstraction of water resources for irrigation.

Competition for land use and social impacts

An unplanned opportunistic rush into bioenergies could lead to damaging land-use competition in some regions. This may involve a range of key environmental needs (floodplains, deforestation, high nature value lands), access to land for poorer or start-up farmers, or competition with food and fibre production. Many of the currently used bioenergy commodities are also food and feed crops. The interest in bioenergy has already led to price increases for several crops, which can challenge the capacity of poor farming communities to continue buying them for their own needs.

RATE OF DEVELOPMENT/DEPLOYMENT

The WWF Climate Solutions model assumes that about 110EJ (low estimate) to 250EJ (high estimate) bioenergy can be produced globally, in a sustainable way. These figures are taken from a "first estimate" study commissioned by WWF in 2006[27].

Forestry bioenergy potentials were taken from existing literature and range from 14EJ to 65EJ.

Agriculture bioenergy potentials range from 96EJ to 185EJ.

- This is a pure supply-side scenario, not taking into account economics or demand-side dynamics such as policy-based and regulatory incentives. Many bioenergy scenarios have been prepared but WWF wanted to make sure that any potentials adopted in its policies could be produced without harming the environment.
- WWF assumed that about 30% of available (*i.e.,* not currently used) arable land could be allocated for future bioenergy production. This percentage is higher in developed economies and lower in some regions such as sub-Saharan Africa. The remaining 70% of arable land should be protected for the purposes of nature conservation and human development. The scenarios excluded land considered marginal for cropping, except for jatropha which is known to thrive on such land.
- Where increased irrigation is required for bioenergy crops, the scenarios allow it up to a level which is renewable. For some regions, where such data were not reliable, no bioenergy developments were accepted.

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[27] Preliminary results of the WWF potentials study (agriculture potentials) and IPCC results (forestry potentials), in prep.

- The scenarios include a conservative "yield gap closure" by 2050, based on the yield for a crop that is expected to be exceeded by only 20% of the countries growing it in 2015, as a conservative reference for 2050.
- Potentials by 2050 are based on estimates of annual increments of arable land for bioenergy cropping from 2006 until 2050.
- The scenarios only look at existing agricultural crops, including where relevant post-harvest residues. Waste that is not derived from crops, 2nd generation crops, algae, etc are not included.
- The main variable that influences the difference in potentials is crop yield. The lower-end potentials assume a maximum diversity of crops in the different regions, assuming that more and less productive crops would be used to produce bioenergy. The higher-end scenarios assume that only the most productive crops would be used. The range of potentials would even be greater (110EJ-340EJ) if the single most productive crop was chosen per region.

This estimate is considered as a "first estimate". Further research would be needed to refine the data.

- The potential estimate should, for example, be compared to demand-side scenarios, including economics, policies, etc.
- More recent and accurate data could be collected, for example on irrigation. Country studies could also help to refine the data.
- Agricultural crops that were not included in the present study – algae, biogas from non-crop waste, "2nd generation" crops – also present potentials that should be assessed.
- The forestry potentials should be refined. These potentials have not been assessed in WWF's study, and data from the literature were used.

See paper 20 for inputs to model.

Topic Paper 7: Natural Gas

GAS AND CLIMATE CHANGE TARGETS

As a source of energy natural gas has a carbon footprint about half that of coal[28].

Currently, coal supplies 23% of the world's primary energy, yet contributes 37% of global GHG emissions[29]. In the power sector, the IEA projects that coal consumption will almost double by 2030, with China and India accounting for 68% of this increase[30]. Whatever the exact figure, it is clear that coal use will increase hugely if alternative sources of energy are not made commercially available.

Natural gas may be part of the medium-term solution. Some modern conventional power plants can be easily modified to switch fuel sources, delivering immediate carbon dioxide savings when substituting coal for gas. Furthermore, modern Combined Cycle Gas Turbine (CCGT) installations emit only 40% of the carbon dioxide produced by a conventional coal-fired power station[31]. So displacing coal with natural gas in the power sector can reduce short- and medium-term emissions, "buying time" for the deployment of truly sustainable zero-emission solutions and reducing the overall atmospheric loading from GHG pollution from coal.

For such an outcome to occur it is critical that gas replaces only coal use and that its use does not slow or hinder renewable energy development in the same markets.

ISSUES AND CONSTRAINTS

Renewable Energy Overlap

In some cases market conditions which price carbon will tend to favour gas (which is a competitive energy supply in most markets) over renewables, which would need a higher carbon price to compete directly with gas. This competition between two low-emission supply sources is highly inefficient and counter productive in the longer term.

Competing Uses

To deliver maximum carbon dioxide abatement potential, the world's finite natural gas resources need to deployed to avoid coal emissions where possible. Competing uses, such as extraction of oil from tar sands, have serious negative consequences for the climate and should be avoided.

Shrinking Sources of Supply

Gas resources have been available in many areas and often close to the markets that use them, such as North Sea gas in Europe. However, as these are used up, the focus moves to the remaining large gas reserves in areas remote from current and future high-growth energy demands. The global leader by volume proven is Russia (47.57 trillion cu m) followed by Iran

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[28] EIA - Natural Gas Issues and Trends 1998.

[29] CO_2 Emissions from Fuel Combustion, 2004 Edition, International Energy Agency.

[30] World Energy Outlook, 2004 Edition, International Energy Agency.

[31] IPCC 3rd Assessment Report, Working Group III, 2001, Cambridge University Press.

(26.62 trillion cu m) and Qatar (25.77 trillion cu m). European production is now in severe decline, with increasing dependency upon Russian supplies. This raises challenges for transportation and energy security.

Transport and Storage

It is more difficult and often more expensive to transport and store gas compared to liquid fuels (such as oil) or solids (such as coal). Traditionally, gas has been transported via pipeline from source to production and then onward to market via other distribution networks. Pipeline investment requires stable long-range contracts, low sovereign risk, harmonization of financial, supply and demand risk, and strong regulatory design with interaction between and across markets. Some networks have existed for over 100 years. In de-regulated markets, there is usually third party ownership of transportation assets outside the controls of producer and end-user. This presents further risk.

On the other hand, liquefied natural gas (LNG) is usually transported in shipping operated by producers or end-users. Russia has an extensive pipeline network linking its reserves to Europe, China, and Japan. By contrast, Qatar has recently commissioned 46 new LNG tankers which can be delivered by South Korean shipbuilders in about three years, compared with a ten-year lead time for pipeline developments.

Methane Leaks

Natural gas consists primarily of methane (CH_4), which is 21 times more potent than carbon dioxide as a greenhouse gas[32]. As such, relatively small leakages of CH_4 throughout the total gas life-cycle of extraction, processing, distribution, storage, and end-use can quickly undermine the potential carbon dioxide abatement advantages.

Energy Security

In the coming decades, the majority of new power generation will be installed in rapidly developing Asian economies such as China and India, which have generous coal deposits but limited gas. Also LNG receiving ports, storage capacity, and transmission infrastructure are very limited, and with energy security a political priority, these countries will naturally favour the development of coal-fired power over increasing reliance on imported gas, unless other compelling reasons or incentives prevail. Similarly, European nations may try to avoid dependence on piped gas from Russia, whose political relations with transit countries such as Ukraine are strained. The emergence of "resource nationalism" also challenges capital flows so that global energy companies become loath to risk having stranded assets. This may slow development of reserves in many markets and shift focus away from gas.

Beyond Pipelines

LNG technology is maturing to the extent that it is now economically competitive with pipelined gas in many instances[33]. With vast reserves and an advantageous geographical location, Qatar is ideally positioned to supply LNG to both Atlantic and Pacific basins, uniting previously discrete regions into a new global gas market, with uncertain consequences for

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[32] Climate Change 2001: Synthesis Report, IPCC.

[33] “Assessing the future challenges of the global gas market”, 23rd World Gas Conference, Amsterdam, 2006.

pricing and market dynamics. Geopolitical relationships are increasingly important with China, Japan, India, and South Korea competing with the United States for LNG supplies.

Technology Risk

There remain a number of technology safety risks with gas. Proximity to market is critical for LNG terminals, requiring that most new facilities be proposed in or near major coastal population centres. While the safety record is largely positive, the potential for a significant LNG accident remains. Such an event would increase the difficulty for development of LNG terminals and therefore affect market development and expansion in the OECD and some Asian countries.

Non-Climate Environmental Impacts

Site-based environmental impacts associated with natural gas include:

- Effects of seismic exploration on cetaceans and fish;
- Loss of benthic habitat such as coral and seagrass from dredging for shipping channels;
- Significantly reducing the breeding success of turtles from light pollution (from coastal LNG infrastructure);
- Damage to coastal habitat such as turtle nesting beaches and bird roosts from the construction of port facilities, and the attendant problem of boat-strikes and the potential for introducing ship-borne marine pests;
- Risk of pollution from airborne emissions and from spills of oil, diesel, and other pollutants during LNG operations;
- Quarantine risks, particularly to islands;
- Clearing of terrestrial habitat for pipelines or LNG facilities.

Detailed, rigorous, and comprehensive environmental impact assessments will be necessary to ensure that switching from coal to natural gas will realize net benefits.

RATE OF DEVELOPMENT/DEPLOYMENT

At year end 2005, an estimated 65 years of proved natural gas reserves remained, based on current consumption[34]. The emergence of LNG as a viable economic option connects traditionally remote gas fields with end-users, enabling the development of a global gas market. The resulting diversification of supplies, coupled with requisite economic incentives for lower-carbon intensity fuels, means future growth rates may exceed historical levels of 2.9% pa, thereby contracting the lifetime of known reserves and or increasing the costs for projected new gas supplies which may be more expensive to extract. Switching from coal to gas for power generation must therefore be viewed as a temporary measure which reduces short- and medium-term emissions, yet is consistent with possible carbon capture and storage in the longer term and the overall carbon budget for 400ppm stabilization.

ESSENTIAL KEY MEASURES FOR THESE EXPECTATIONS TO BE REALIZED

- The world's limited natural gas resources must be used wisely in order to maximize carbon dioxide savings while avoiding CH_4 emissions and wider environmental impacts;

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[34] BP Statistical Review, 2006.

- Investments in natural gas infrastructure are most important in the short term, whether pipeline or LNG, to reduce the take-up of coal, allow source diversification, and alleviate security of supply concerns;
- For imported gas to compete with domestic coal, the full external costs of coal use must be internalized, together with a strengthening of carbon markets and/or other fiscal mechanisms which provide compelling economic incentives for fuel switching. Developing country markets will need to ensure that such measures do not cut across development goals.
- High investment levels with long lead times require confidence and assurance in the market and regulatory environment. Coordination between all stakeholders is critical and offers a role for regulators and governments to support investment.

TOPIC PAPER 8: CARBON CAPTURE AND STORAGE (CCS)

SIGNIFICANCE

Carbon capture and storage (CCS) is a relatively new way of reducing carbon dioxide emissions into the atmosphere. It refers to various technologies which initially may be applied on a large scale with large carbon dioxide point sources, and may in future be applicable on a smaller scale. "Carbon capture" involves separating between 40% and 95% carbon dioxide during or before mining of any fossil fuel (pre-combustion capture). It can also occur during a gasification/decarbonization process of the fuel used. Gasification of coal (IGCC) for instance results in hydrogen (H_2) as the "combustible" product. All other pollutants including carbon dioxide are separated and can be removed. Carbon dioxide can also be removed during and after combustion in a fossil fuel-fired power station (post-combustion capture). In the future, carbon capture may be also possible for non-energy CO_2-emitting sources such as cement and steel production.

The "storage" part of CCS refers to the process of (re)-injecting the carbon dioxide into deep geological layers, thus isolating it from the atmosphere for a long time. Between capture and storage, liquid carbon dioxide is transported to the geological storage site (*e.g.,* via conventional pipelines or ships).

Although CCS is new, its components are not. For instance, pre-combustion capture is widely applied in fertilizer manufacturing and production of H_2 as a chemical feedstock[35].

WWF sees CCS as mitigating the negative consequences of the possible renaissance of carbon-intensive "King Coal" in times of more costly and apparently less reliable supply of other fuels.

Coal is more carbon-intensive than oil, and much more so than gas, so it is less desirable from an emissions point of view. But almost 60% of global natural gas reserves occur in three nations: Iran, Russia, and Qatar. Based on current production rates, economic reserves of gas are expected to last for 65 years. In the similar case of oil, about three-quarters of all reserves occur in seven nations, including Russia, Venezuela, Saudi Arabia, and other OPEC Gulf nations whose economic reserves are expected to last for another 40 years.

In comparison to oil and gas reserves, coal is much more abundantly available – especially in those countries which are large energy consumers such as the United States, China, India, Russia, and Europe. Here, political concerns on security of supply and the high costs of nuclear fuels may continue to drive an interest in coal – at least for some time. In the last four years, global coal consumption has risen by 22%[36].

Long-term fuel supply scenarios see coal gaining ground, to more than double its power production contribution to the global electricity mix from 1,230GW in 2004 to 2,560GW

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[35] IPCC Special Report (SR), 2005: CCS, summary for policy makers and technical summary, ISBN 92-9169-119-4.

[36] BP Statistical Review of World Energy, 2006.

capacity by 2030. This "business-as-usual" scenario will increase the emissions from coal-fired power generation alone from about 7.6 to 13Gt carbon dioxide in the same period. An "alternative" scenario foresees an increase to "only" about 10Gt carbon dioxide emissions[37]. In both scenarios, around 60% of all coal-fired power stations in the world will be in China and the United States.

But this all may be just the tip of the iceberg. Use of carbon-intensive tar sands and oil shales as well as coal-to-liquids technologies may gain enormous ground in future in times of high oil and gas prices – not included in the IEA scenarios quoted above. For instance, recent plans to produce about 300 million tons (Mt) petroleum per annum from coal in the USA is likely to require more than 600Mt coal, giving rise to almost two billion tons of carbon dioxide emissions – roughly equal to half of EU emissions. China's coal liquefaction is also growing; the plan to produce 50Mt oil from coal will involve additional emissions of around 300Mt carbon dioxide.

If the 2⑤C target is to be met, most of this very carbon-intensive conversion to liquid fuels must be avoided.

CCS can also be applied to biomass, potentially reducing *atmospheric concentrations,* if the harvest and combustion of biomass is in equilibrium with carbon dioxide being sequestered by growing plants, in which case carbon capture and storage would *additionally* reduce emissions from this carbon-neutral fuel. Assuming sustainable biomass production, it has been found that the use of both fossil fuel and biomass CCS will reduce overall costs of stabilizing atmospheric carbon dioxide by 40-80% compared with a technology mix relying on non-CCS technologies alone[38].

For efficiency, carbon capture technologies require prior removal of other pollutants in the exhaust stream, thus contributing further to clean air policies – especially important for those regions in the world where a high share of coal in the energy mix causes serious pollution.

CHALLENGES

There are, however, a wide range of issues that must be dealt with before CCS can be considered a mature and reliable part of the solution. These include:

Proof of Efficacy

Carbon capture and storage of emissions from coal-fired power stations is still in its infancy and as such needs to be shown to be effective at commercial scales.

Storage

There are a range of potential storage sites, each with its own challenges. A detailed mapping of storage capacity in key countries is needed. According to the IPCC[39], sufficient storage capacity of at least 1,700Gt carbon dioxide is available on a global scale, almost all of it from either saline aquifers or depleted or ageing oil/gas fields.

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[37] World Energy Outlook 2006, IEA, 2006.

[38] C Azar *et al.* (2006) CCS from fossil fuels and biomass, in: *Climatic Change* 74:47-79.

[39] IPCC, 2005: CCS, summary for policy makers; p. 31.

WWF believes that due to a range of factors, the ocean and the marine environment are not a safe place to store carbon. Widespread dissolution of carbon dioxide will further reduce the pH-value in oceans and contribute to acidification and additional stress to the global marine environment. Also, atmospheric gassing out of carbon dioxide is projected to be in the range of 30-80% in open ocean injection depths of 800-3,000m within a period of 500 years[40]. Globally, ten geological carbon storage sites are already being used, with many more planned.

Permanence

As regards the most important question of permanence of stored carbon, the IPCC states: *"Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1000 years"*[41].

In any case, a sound regulatory framework is needed in all countries seeking to use CCS or individual components of it. This should include as a minimum an independent and consensual site selection process for safe storage and provision for long-term monitoring, immediate preparedness for fixing leakages, and a liability regime.

Biodiversity Impacts

As with all large-scale technologies, and in particular with storing carbon dioxide underground in geological layers, an independent environmental impact assessment needs to be undertaken and made available to stakeholders. In the case of saline aquifers, acidification of drinking water and any contact with freshwater resources above ground need to be carefully avoided.

Full Energy Balance

However, even if storage works safely, CCS is not 100% fossil free as there is an energy "penalty" of 10-40% resulting mainly from the carbon capture process which is rather energy-intensive. This in turn contributes to increased power generation costs of CCS plants of up to 100% (4-10 US cents/kWh for coal and gas technologies). These additional costs place CCS on the same level as current global wind power production costs[42].

The case for CCS is not made in order to prolong the life of fossil fuels, which currently provide more than two-thirds of global energy. Even in highly ambitious scenarios which cut global energy demand quite substantially compared to any business-as-usual projection, the world's energy demand will still grow by 50% or more by 2100. It is likely that the inertia and pressure will persist for fossil fuels to continue to supply a major share of the increased demand[43],[44]. Therefore, as the WWF Climate Solutions Model demonstrates, CCS could allow fossil fuels to play a significant role in future energy production, with very much lower emissions.

See paper 20 for inputs to model.

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[40] IPCC; as above, p. 35.

[41] IPCC; as above, p. 13.

[42] IPCC, as above ; p. 9.

[43] C Azar *et al.* (2006) CCS from fossil fuels and biomass, in: *Climatic Change* 74:47-79.

[44] M Hoogwwijk & N Hoehne (2005) Comparison of scenarios for keeping temperature below 2 degree; briefing paper for WWF.

Topic Paper 9: Nuclear Energy

SIGNIFICANCE

Nuclear fission, the conventional means for generating nuclear power, remains among the most controversial and contested sources of energy. In the past 50 years, nuclear energy has risen to generate 16% of global electricity (roughly 6.5% of world primary energy consumption) from nearly 450 reactors in 30 countries, including Europe, Asia, and the United States. The International Energy Agency (IEA) recently projected a large growth of nuclear by 2030[45]. However, within OECD countries, a decline of net nuclear capacity of about 3% is projected by 2030 in the "business-as-usual scenario" or an increase of about 20% until 2030 in the "alternative" scenario"[46]. In China, growth in nuclear capacity from currently 6GW to 31-50GW nuclear capacity is predicted by 2030[47]. But nuclear may still only contribute 3-6% of all electricity generated in China by 2030. Similarly in India, nuclear-positive estimates project future nuclear to cover less than 10% of all electricity needs in country by 2030[48]. In order to save 1Gt carbon emissions, displacing 770GW of fossil fuel energy, approximately 1,200 new reactors of conventional capacity would need to be built.

Public and political support for nuclear energy, which in many western countries has waned in recent years, is seeing some resurgence as concerns over climate change and energy supply security intensify. In many OECD countries, a powerful lobby is invoking nuclear's claim to be a "low or no-carbon" fuel as a basis for promoting a new generation of reactors. While nuclear energy is unquestionably low-carbon, the real debate is whether other concerns over safety, public acceptability, and particularly cost militate in favour of pursuing alternative technologies for controlling carbon emissions, and what the trade-offs among those options may be.

Security of supply arguments are used to favour nuclear in particular where expensive low-carbon natural gas is imported from countries that are seen by others as less reliable geo-politically in the mid and long term. However, nuclear enthusiasms may cool when considering the delays affecting the only reactor currently under construction in Western Europe. Following the go-ahead from the Finnish Parliament in 2002, the 1,600MW reactor is now scheduled to start electricity generation two years late, in early 2011. This kind of time and cost overrun has a severe effect of the competitiveness of capital-intensive nuclear power plants.

WWF has on record long opposed nuclear power on environmental grounds (*see Caring for the Earth*, 1990). However, in developing the analysis for its 2050 Energy Vision, all available technological options were weighed without regard to prior positioning, and tracked by environmental impacts and risk, implementability, social acceptability, and cost. Of some 23 different low-carbon energy technologies, nuclear fared poorest for a variety of factors, in part

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[45] Despite some regional differences, business-as-usual scenarios of the IEA project an increase of nuclear capacity to about 416GW by the year 2030 compared to 364GW today. The "alternative" scenario forecasts an even bigger growth to 519GW (IEA, 2006: World Energy Outlook, Paris).

[46] IEA 2006, as above.

[47] IEA 2006, as above.

for safety and nuclear proliferation issues and the social acceptability concerns they imply – but also because of the opportunity costs of significant shift of capital and energy contracts to nuclear.

CHALLENGES

Briefly summarizing the analysis: the chief environmental concern remains nuclear energy's generation of radioactive wastes that stay dangerous for up to 25,000 years and which must be contained and actively managed. Related safety concerns include radiotoxic emissions from fuel mining and processing, transport, routine releases during use, and the prospect of leaks in accidents, or in potential attacks on facilities. It is noteworthy that these concerns, at least in situations short of a Chernobyl-type situation, sit more squarely in the realm of human health than as a threat to biodiversity.

Implementability faces obstacles relating both to the long build-time and regulatory delays that have led to 20 years elapsing from the start of planning to operation. For instance, since 2000, China, Russia, and Ukraine have announced plans to build 32, 40, and 12 reactors respectively by 2020. Of this total of 84 reactors, only nine have started construction[49]. Build-time overruns have been common, and though improved nuclear designs could speed implementation, unanticipated problems or delays seem equally possible. In the United States, 51 repeated shutdowns for a year or longer led to power shortages and soaring costs. Implementability will also face emerging issues related to new concerns over terrorism and geopolitical stability, and any significant shift to developing-country deployment would require regulatory infrastructure, capacity-building, and development of supporting industry.

Public acceptability reflects many of the foregoing concerns, but varies significantly by country. In the United States and in much of Europe, public opposition is such that new plants have become nearly impossible to commission. (In the USA, the last licence for a new nuclear plant was issued in 1973.) But even within Europe, there is considerable diversity on this point. France, for example, generates 75% of its electricity from nuclear energy, selling excess power off its grid to neighbouring countries that will not host nuclear plants themselves. And critically, countries such as China, with the greatest likelihood of undertaking a major shift to nuclear power, may face the least opposition among their publics.

Economically, nuclear energy is difficult to "cost" for a number of reasons. Historically it has been heavily subsidized, through direct government support and by limitations on liability. In direct terms nuclear has received high if not the highest rate of subsidy of all fuels within many OECD countries. Between 1947 and 1999 in the USA alone, nuclear received US$145bn – or 96% of all energy subsidies. This compares with subsidies for solar of US$4.5bn and wind US$1.2bn between 1975 and 1999[50]. In the former EU-15, nuclear subsidies still amount to 2bn per year[51].

Future costs – decommissioning and management of wastes – are not factored into current pricing and appear likely to increase substantially over time. The cost of any accidents will be

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[49] "Gerd Rosenkranz, "Deutsche Umwelthilfe", 2006.

[50] Renewable Energy Policy Project (REPP), July 2000.

[51] EEA Technical Report 34, Energy Subsidies in the European Union, 2004.

large but borne by governments (in the USA, about US$600bn for a single major accident). (One study suggested that a successful terrorist attack on a reactor near New York could cause up to US$2 trillion damage, in addition to 44,000 short-term and 500,000 long-term deaths[52].)

These market distortions make it difficult to price nuclear energy in comparison with the full life-cycle cost of other carbon-saving energy options. But even analysis by “nuclear-friendly” institutions estimates the global average capital costs for nuclear at about US$2m per installed MW, or roughly twice as much as wind power and five times more expensive than natural gas combined cycle[53]. Nuclear energy is sufficiently capital intensive that a massive build-up could starve other renewable-energy options from receiving necessary funding, leading to a higher overall carbon intensity than a robust mix of renewable technology options that does not include nuclear. Whether this can change with advances in design construction – *e.g.,* so-called "pebble-bed" reactors or with recently heralded progress on fusion (as opposed to fission) reactors – remains to be seen. (Fusion is not expected to be available for another 30 years, although this has been said for three decades.) But among currently deployed commercial technologies, scaling up nuclear power is not an effective course to avert carbon emissions.

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[52] “Chernobyl on the Hudson?: The Health and Economic Impacts of a Terrorist Attack at the Indian Point Nuclear Plant”, Union of Concerned Scientists, 2004.

[53] IEA, 2003: World Energy Investment Outlook (Paris) at p. 349.

Topic Paper 10: Poverty and Energy

SIGNIFICANCE

The world's poor are victims at both ends of the energy story. They have little access to energy themselves, but they bear an undeservedly large share of the impact of others' access. Halving poverty by 2015 is a Millennium Development Goal (MDG). Access to energy is key. At the same time, the threat of climate change brings huge extra pressures onto the world's poor, especially where their health is already compromised by HIV/AIDS. A report by Christian Aid[54] warns that climate change threatens the development goals of billions of the world's poorest people, for example by increasing the prevalence and intensity of malaria and other diseases in Africa, inducing persistent drought and its connections to conflict in Kenya, or floods and sea-level rise in Bangladesh.

CHALLENGES

Affordable, adequate, and reliable modern energy supplies are still beyond the reach of some two billion people. At the same time, current methods of producing, distributing, and using energy have environmental and health impacts that increasingly endanger the welfare of communities and biodiversity worldwide, while problems of oil and gas supply security are linked to increasing regional political instability, raising further risks for the poor.

Current electricity supply policies and energy development paradigms have failed to address these energy-poverty issues adequately. Analyses repeatedly return to the same conclusions. A new approach is needed to energy services for the rural poor based, in most developing countries, on decentralized, renewable, locally managed energy generation and distribution systems which are demand-led and affordable. (China, however, is succeeding with grid-connected electricity supply for rural areas, heavily subsidized by urban consumers.)

The Christian Aid report concludes that a renewable energy revolution can power clean, sustainable development. However, it says, great care is needed with the options chosen. Another report, by WWF with support from Oxfam[55], shows in case studies from Zambia and Kenya how hydropower can deliver maximum benefits with minimal negative impact. But it also highlights the legacy of environmental and social problems linked to existing hydropower and therefore urges a cautious approach.

All studies emphasize the need for the developed world to commit to a very explicit contribution of major cuts in its own emissions, and major investments for the developing world to help their transition to a sustainable energy future. Very basic energy needs can be met technically without adding significantly to emission levels. Professor Robert Socolow[56] asserts that energy services to meet basic human needs (electricity and cooking fuel) for 2.6 billion

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[54] *The Climate of Poverty: Facts, Fears and Hope*. Christian Aid, 2007, at: http://www.christian-aid.org.uk/indepth/605caweek/index.htm

[55] *Meeting Africa's Energy Needs – the Costs and Benefits of Hydropower*. WWF 2006, at: http://assets.panda.org/downloads/africahydropowerreport2006.pdf

[56] Prof Robert Socolow: pers. comm.

people would only make a minimal relative impact on global emissions, even if these services were supplied at current rates of carbon intensity.

The WWF *Climate Solutions* Vision is based on the IPCC's A1B scenario, postulating a convergence of "rich" and "poor" countries so that these distinctions eventually dissolve. It anticipates a threefold increase in the average provision of energy services over the period to 2050. In practice this means that on average citizens in 2050 would consume energy services equivalent to the average in the OECD today. The key difference, however, is that approximately half of the energy is required for the equivalent level of energy service.

Global cooperation – vital for meeting these challenges – depends on spreading the burden of change in an equitable way. The rich must allow for major growth in energy provision for the poor, while proposing a decisive reductions in consumption patterns in the developed world, and appropriate modification of energy development patterns in the emerging economies[57].

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[57] One model for such an approach is proposed in the concept of "Greenhouse Development Rights" (Athanasiou, T, Kartha, S & Baer, P. (2006) "Greenhouse Development Rights: An approach to the global climate regime that takes climate protection seriously while also preserving the right to human development").

Part II Regional Case Studies

The coming half-century will see unprecedented economic development and therefore more demands on limited resources. The process of convergence between the standards of living of people in developed countries today and those in countries emerging from poverty will involve **all people and all countries** in protecting the climate.

The following eight regional case studies illustrate the diversity of challenges involved. The eight examples span the full spectrum of the United Nation's human development index. They include countries rich in energy supplies, like Russia, and others almost entirely dependent on imported energy, such as Japan. Some of the heaviest energy users like the USA are contrasted with the least energy intensive economies and populations such as China and India. Brazil faces the task of tackling major land-use change emissions, but has taken a major international lead on biofuels, while Japan shows leadership in energy efficiency driven by energy security constraints, and the European Union illustrates the progress which can be made in regional collaboration. China provides great scope to leap-frog into high-tech, well planned, low-emission cities, while South Africa can use its economic dominance to stimulate the development of new technologies and distributed renewable energy generation throughout the African continent.

These cases illustrate how every country has leadership potential – regardless of its level of development, energy resources, or technology prowess – in driving the transition to a prosperous low-carbon future.

For reference, key comparative indices are tabulated below (data from CAIT[58]). Note that the last year for which complete comparative data was available for all of countries was 2000; this is shown in blue. Current data, where available, are shown as an additional box at the top of the column.

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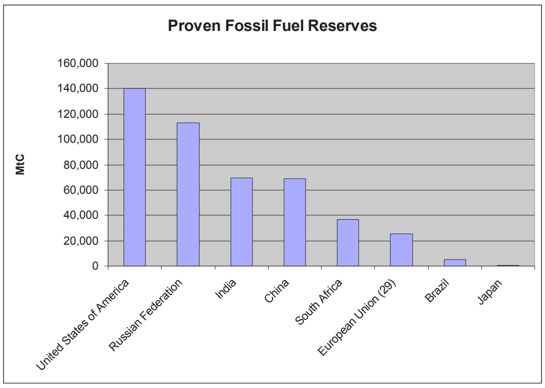
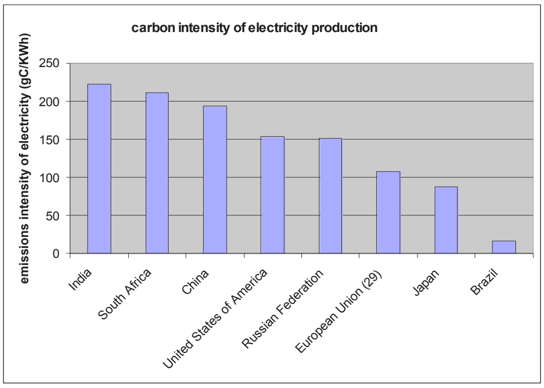
[58] Climate Analysis Indicators Tool Version 4 (2007). World Resources Institute online data-base. http://cait.wri.org/ (accessed March 2007).

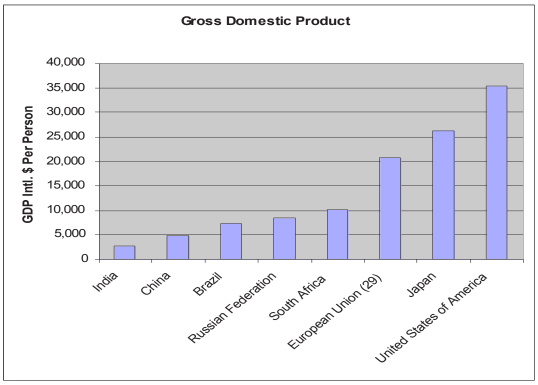
	Greenhouse Emissions from Land Use Change and Forestry		Carbon Intensity of electricity production		Greenhouse Intensity of the Economy(excludes land use changes)		GDP/person		Annual GHG per Capita (Excludes land use change)		National GHG emissions from Energy	
	Most recent available data (CAIT)	[MtCO2]	Most recent available data (CAIT)	[gCO2/kWh]	Most recent available data (CAIT)	[tCO2/Mill Intl $]	Most recent available data (CAIT)	[Intl $/person]	Most recent available data (CAIT)	[tons CO2/person]	Most recent available data (CAIT)	[Mt CO2]
USA	2000	-402.8	2003	560.3	2003	561.7	2003	35 373	2003	19.9	2003	5752.3
Russian Federation	2000	54.2	2003	553	2003	1282.7	2003	8 524	2003	10.9	2003	1526.8
Brazil	2000	1372.1	2003	60.2	2003	250.7	2003	7 306	2003	1.8	2003	306.7
China	2000	-47.3	2003	706.9	2003	702.9	2003	4 966	2003	3.5	2003	3719.5
India	2000	-40.3	2003	813.4	2003	395	2003	2 731	2003	1.1	2003	1 051,1
South Africa	2000	1.7	2003	772.9	2003	830.1	2003	10 055	2003	8.3	2003	318.3
EU	2000	-20.9	2003	385.2	2003	369.1	2003	23 770	2003	8.8	2003	3889.2
Japan	2000	4.4	2003	320.1	2003	375.4	2003	26 270	2003	9.9	2003	1201.4

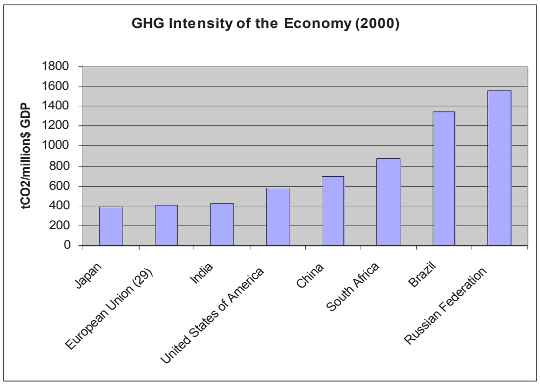
* All data from http://cait.wir.org as on 4 May 2007
** In 2005, total U.S. GHG emissions were 7 260.4 Tg CO2 Eq, GHG emissions from Energy 6 201.9 Tg CO2 Eq (Inventory of U.S. GHG Emissions and sinks 1990-2005. Retrieved 4 May 2007 from http://www.epa.gov/climatechange/emissions/downloads06/07ES.pdf)

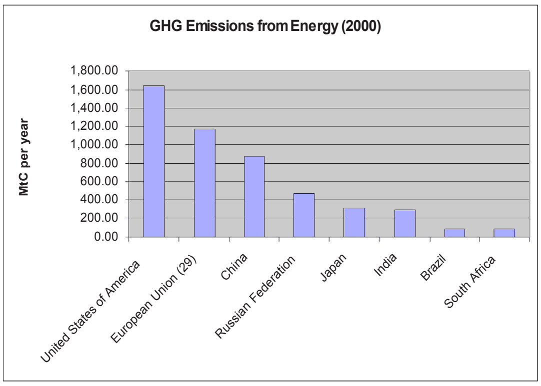
Note: Emissions can be described in terms of carbon dioxide (CO_2) or carbon (C). Emissions are measured in metric tonnes. The atomic weight of carbon is 12, and the molecular weight of carbon dioxide is 44, so 1.00 tonne of carbon dioxide contains 0.27 tonnes of carbon.

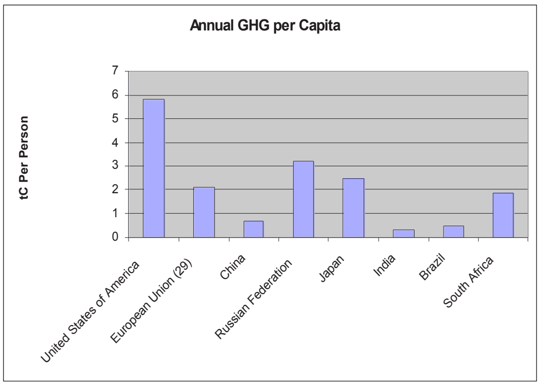

Proven Fossil Fuel Reserves
MtC
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
United States of America
Russian Federation
India
China
South Africa
European Union (29)
Brazil
Japan

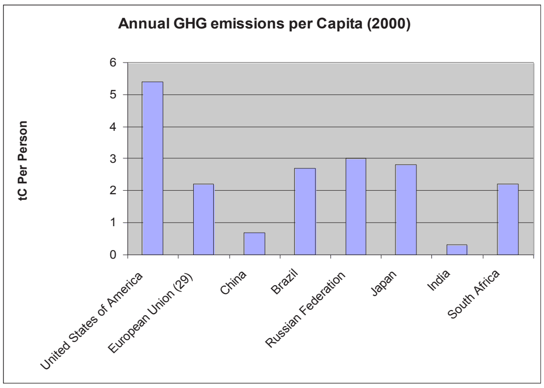

carbon intensity of electricity production
emissions intensity of electricity (gC/KWh)
250
200
150
100
50
0
India
South Africa
China
United States of America
Russian Federation
European Union (29)
Japan
Brazil

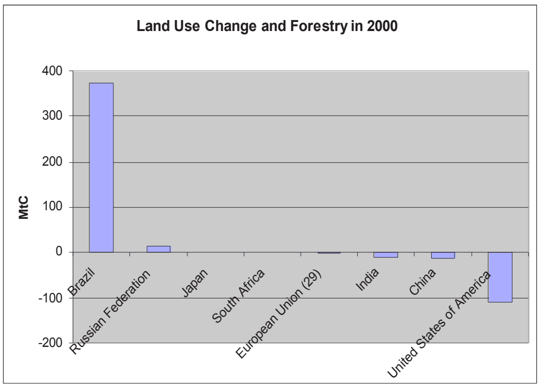

Gross Domestic Product
GDP Intl. $ Per Person
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
India
China
Brazil
Russian Federation
South Africa
European Union (29)
Japan
United States of America


GHG Intensity of the Economy (2000)
tCO2/million$ GDP
1800
1600
1400
1200
1000
800
600
400
200
0
Japan
European Union (29)
India
United States of America
China
South Africa
Brazil
Russian Federation


GHG Emissions from Energy (2000)
MtC per year
1,800.00
1,600.00
1,400.00
1,200.00
1,000.00
800.00
600.00
400.00
200.00
0.00
United States of America
European Union (29)
China
Russian Federation
Japan
India
Brazil
South Africa


Annual GHG per Capita
tC Per Person
7
6
5
4
3
2
1
0
United States of America
European Union (29)
China
Russian Federation
Japan
India
Brazil
South Africa


Annual GHG emissions per Capita (2000)
tC Per Person
6
5
4
3
2
1
0
United States of America
European Union (29)
China
Brazil
Russian Federation
Japan
India
South Africa


Land Use Change and Forestry in 2000
MtC
400
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Brazil
Russian Federation
Japan
South Africa
European Union (29)
India
China
United States of America

Topic Paper 11: Japan

THE SIGNIFICANCE OF JAPAN

Japan is the world's third largest economy and fourth largest emitter of greenhouse gases[59]. It is a major manufacturer domestically and internationally and therefore a significant investor and disseminator of high-technology products. Japan is also a significant economy within Asia and has the ability to assert regional influence and leadership. The flip-side is that there are many regional tensions over fossil-fuel assets which would be alleviated by an ongoing reduction in their use.

ENERGY IN JAPAN

Due to its scarce resources, Japan relies on imports for more than 95% of primary energy supply and is the world's second largest importer of oil. In order to attain energy security, Japan has endeavoured to improve energy efficiency and diversify energy sources. Japan's official dream is to create its own, nuclear, power supply by reprocessing spent nuclear fuel and "re-using" the retrieved plutonium in fast-breeder reactors to produce more energy (plutonium). Nuclear energy has also become the central pillar in the Japanese government's policy to combat climate change. In 2006, with 55 reactors in operation, about 30% of electricity comes from nuclear energy and the government plans to increase the share further, despite very strong public resistance.

Energy efficiency is the area in which both Japanese government and industry take most pride. The two oil crises in the 1970s made Japan place extra emphasis on improving energy efficiency. An Energy Conservation Law has been playing a major role in this improvement. Among the measures implemented under the law, the "Top Runner Standard" is considered a unique and effective measure. The government sets efficiency targets on identified product categories, based on consultation with industry and experts. Those targets are set in such a way that all the products in the category achieve at least the same level of efficiency as the most efficient product at the time.

The government is determined to keep Japan's status as the "front-runner" in energy efficiency. The New National Energy Strategy, published in 2006, sets a target to increase the country's energy efficiency by at least 30% by 2030.

In the meantime, renewable energies have been largely dismissed as unreliable, and R&D budgets for renewables are minimal compared to other countries or to the spending on domestic nuclear development. The government introduced a Japanese version of the Renewable Portfolio Standards (RPS) but the target is negligibly low: 1.35% of the total electricity sold by power companies by 2010, revised to 1.6% by 2014. Wind power has been gaining competitiveness recently but power companies have set a ceiling on buying wind power owing to its intermittency, and growth of wind energy in Japan is therefore unlikely. Even the number of solar rooftops, for which Japan had long held world No.1 status, has been taken over by Germany with its "Feed-in Law" in 2005.

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[59] *Handbook of Energy & Economic Statistics in Japan*, 2006, by Energy Data and Modelling Center.

JAPAN'S EMISSIONS PROFILE

Japan's base year emissions[60] were 1,261.4MtCO$_2$e. By 2004, its GHG emissions had increased to 1,355.2Mt or 7.4 % above the base year. Of this, carbon dioxide emissions were 1,285.8Mt, or 12.4% above the 1990 level. Carbon dioxide emissions per capita have also increased from 9.26t per capita to 10.07t per capita – up 8.8% since 1990.

Of carbon dioxide emissions, the largest share comes from the industry (30.3% [36.2%][61]) and energy (29.7% [6.3%]) sectors. These are followed by the transport (19.8% [20.3%]), commercial (8.2% [17.6%]), and residential (5% [13.0%]) sectors[62].

Since 1990, the commercial sector has shown the largest growth rate (26.9%), followed by transport (20.6%), energy (20%), and residential (5%). The industry sector has decreased its emissions by 0.1% but it should be noted that the Japanese economy was in recession in the 1990s.

According to Kiko Network's survey and analysis of emissions from factories/sites regulated by the Energy Conservation Law, the 50 biggest factories emit 20% of the total carbon dioxide emissions in Japan. Some big factories (including cement, petroleum, chemical) did not disclose their data, but it can be assumed that the 200 biggest factories emit about half of the total emissions of Japan (Kiko Network Report, July 2005).

POTENTIAL FOR LEADERSHIP: CATALYST FOR ASIA'S DEVELOPMENT TOWARDS CLEAN ENERGY FUTURE?

Japan stands in a very important position in the international context of climate policy. First, it is a major industrialized country and, as the host of the Kyoto conference, it has a special commitment to the treaty. Second, it lies in Asia, the region where the largest emissions will arise in future. Japan has both opportunities and difficulties in the region.

Japan could extend its leadership in the following areas to help move Asia towards a clean energy future, which will enable the country to take the lead in international climate negotiations for a future framework for preventing dangerous climate change.

Energy Efficiency

This is an important area where Japan could make a major contribution in the development of a clean energy future for Asia. For example, there is great potential for the Japanese steel industry and coal power companies to export their energy-efficient technology to China, where they claim that GHG emissions could be reduced much more cost-effectively than in Japan.

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[60] 1990 for CO_2, CH_4, and N_2O, and 1995 for HFCs, PFCs, and SF_6

[61] Figures in square brackets refer to "allocated" emission shares, which means the share of indirect emissions. Indirect emissions are the proportion of emissions from power generation by electric utilities allocated to the final demand sector in accordance with electricity consumption.

[62] "Greenhouse Emissions Data of Japan" (2004), by Greenhouse Gas Inventory Office of Japan, http://www-gio.nies.go.jp/aboutghg/nir/nir-e.html

Public Transportation

In spite of its small land surface, Japan has developed a relatively advanced transportation system, especially around large cities with large populations. Energy per unit of GDP in the transport sector is relatively small compared to other major industrialized countries, and this could be a model for Asia's public transportation development.

Automobile Technology

As shown with hybrid engine technology, Japan is taking the lead in developing fuel-efficient vehicles. This technology could be transferred to other Asian countries both for preventing air pollution and reducing carbon dioxide emissions.

Japan's leadership in technology development provides other excellent opportunities for climate change leadership both regionally and globally. The country's existing manufacturing base also provides a basis for technology dissemination; for example, in energy efficiency of household appliances. Key additional leadership areas could include:

- Directing domestic and international capital investment towards climate-friendly solutions;
- Using domestic and international buying power in manufactured goods, timber, and food products to support more sustainable production processes, including energy issues;
- Development and deployment of electric and hydrogen vehicles;
- Hydrogen technology and distribution;
- PV industry development;
- Energy efficiency in transport, buildings, and industry;
- Managing the transfer of best available energy-efficient technology to Japan's trading partners so as to help achieve low-emission goals;
- Carbon capture and storage demonstration
- Greater investment in ocean power technology development;
- Energy storage.

Topic Paper 12: United States of America

THE SIGNIFICANCE OF THE USA

As the world's largest emitter of greenhouse gases, the USA will play a central role in avoiding dangerous climate change, both through its own contribution to GHG emissions reductions, and through its potential to influence the political and technological responses to the problem worldwide. The USA is currently responsible for about 23% of global carbon dioxide emissions and is the world's largest consumer of energy. It is also a top importer – of manufactured goods, timber, and food products – all of which exert "upstream" impacts on climate change.

In addition to its own energy-intensive economy, the United States has a leading role in shaping technological, cultural, and commercial trends elsewhere in the world. Much of mainstream American culture, from Starbucks to i-Pods, is picked up in some form in other countries and so is much of its technology. With two of the world's largest car companies, decisions made in Detroit, such as the big push into light trucks and SUVs, find expression elsewhere, as when GM "Hummers" are seen on highways in Europe. The high concentration of international investment capital and multinational businesses in the United States is another facet of its potential influence. Engagement from Wal-Mart to Wall Street promises to have a profound effect on implementation of virtually all of the energy wedges discussed in this report.

ENERGY IN THE USA

The United States is highly energy intensive in many aspects of its economy. This of course provides a great opportunity for efficiency gains. The energy mix in the USA is dominated by fossil fuels, but it has also been a leading country in many types of renewable energy development.

The USA has been successful in reducing emission intensity per GDP, but the ongoing growth in the economy means that actual emissions have continued to climb, underscoring the need to decouple emissions from economic growth. With an urban structure shaped strongly by the car and cheap fuel, the shift to low-energy and low-emission transport will be a further challenge. Also, energy security is increasingly a major issue given the dependence on foreign imports of fossil fuels.

Emissions Profile

Fossil energy combustion is by far the leading source of US greenhouse emissions, accounting for 5.7 million metric tons of carbon dioxide emissions in 2004. Of this, nearly 2.3 million metric tons came from electricity generation, and about 1.9 million metric tons from transportation. Both categories are growing, now more than 20% above 1990 levels.

Per capita emissions in the USA are not only one of the highest of any developed country, but also approximately tenfold those of China.

Potential for Leadership

Although the United States, at the federal level, has declined to ratify the Kyoto Protocol and has been largely absent in the international process, progress at state and municipal levels has moved steadily forward, filling the leadership void. California, for example, has enacted its own legislation to control greenhouse gases from new cars, and its governor, Arnold Schwarzenegger, recently announced agreement with Britain's Tony Blair on a new trans-Atlantic market in greenhouse gases aimed at promoting green technologies and cutting emissions. The move was seen as a way to side-step opposition by the Bush Administration.

Despite White House resistance, the political and economic damage from Hurricane Katrina and the steadily accumulating weight of scientific evidence on other climate impacts has led to an expectation that Congress must act soon, possibly to enact a national cap-and-trade system to govern US emissions. Should Congress do so, it will lay a vital domestic foundation for the next administration to re-engage in the post-Kyoto process.

If anything positive can result from the United States' six-year absence from the Kyoto talks, it is that when the USA returns to the table in earnest (as it must), it could reinvigorate the international process, with benefits in speeding the pace of technology change to a lower carbon energy sector.

The areas where the USA can show definitive leadership and fundamentally alter the trajectory of future emissions are numerous and include:

- Directing domestic and international capital investment towards climate-friendly solutions;
- Using domestic and international buying power in manufactured goods, timber, and food products to support more sustainable production processes, including energy issues;
- Transition of the transport sector to public transport, and electric and hydrogen vehicles;
- Hydrogen technology and distribution;
- Renewable energy industry development;
- Energy efficiency in transport, buildings, and industry;
- Ensuring that, where industry is transferred to lower labour-cost markets, the change is used also to achieve multiple low-emission goals.

Topic Paper 13: Republic of South Africa

THE SIGNIFICANCE OF SOUTH AFRICA

South Africa is important for three reasons:

1 A high-growth nation leading regional economic development;
2 High dependence on coal, and an emissions-intensive economy;
3 A developing country with significant exposure to climate change impacts.

South Africa is the economic powerhouse of sub-Saharan Africa, with a GDP comprising around 25% of the entire continent's GDP. Government policy aims to raise economic growth from 5% to 6%, halving poverty and unemployment by 2014, using strong economic growth to eradicate poverty.

Climate change – affecting disease vectors, drought, flooding and therefore food security – represents a real threat to the well-being of a population already widely affected by HIV/AIDS.

South Africa therefore has an important role in meeting economic and population development goals while taking appropriate action on climate change.

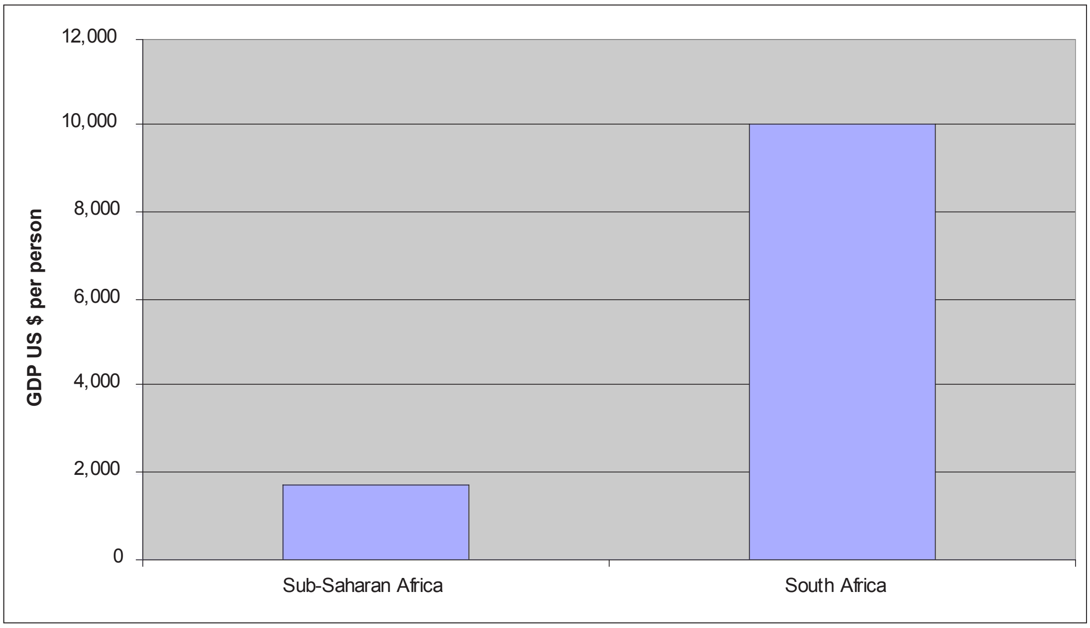

Figure 1. Comparison of per capita GDP in South Africa, and the average for sub-Saharan Africa[63].

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[63] Citation: Climate Analysis Indicators Tool (CAIT) Version 4.0. (Washington, DC: World Resources Institute, 2007.)

ENERGY IN SOUTH AFRICA

"South Africa has several features that it shares with countries such as India and China: it is poor but growing; it faces rising demand for energy and in particular electricity; and it is naturally endowed with large coal supplies that dominate its power generation mix" (Bradley *et al.*, WRI 2005).

The country has the world's seventh largest amount of recoverable coal reserves (54.6 billion short tons), approximately 5% of the world total[64]. Seventy per cent of all South Africa's energy [DME, 2005b], and 93% of its electricity, is produced from coal (NER 2004)**.**

The South African economy is comparatively energy-intensive[65]. Energy comprises about 15% of South Africa's GDP, creating employment for about 250,000 people (the peak demand on the integrated system totals 32GW). The economy is dominated by large-scale, energy-intensive primary mineral beneficiation and mining industries using energy for direct thermal processes at relatively low cost, and absorbing the majority of available investment.

South Africa also has an active nuclear industry with expansion plans using either Pebble Bed Modular Reactor (PBMR) technology (already being pursued) or new pressurized water reactors (PWRs) such as the existing Koeberg station.

Commercial supply of energy to households is an ongoing challenge. So far, only an estimated seven million of South Africa's 11 million households have electricity, and 80% of schools and many clinics still lack supply (US DOE EIA, 2003). Household consumption represents some 17% of the country's net use; 50% of this is obtained from fuel-wood, primarily in rural areas, with the rest from coal (18%), illuminating paraffin (7%), and a small amount from liquid petroleum gas.

GHG EMISSIONS PROFILE OF SOUTH AFRICA

South Africa contributes only 1.4% of annual global carbon dioxide emissions, but per capita emissions are high for a developing country[66]. Its position half way between rich and poor country status highlights its importance as a trend-setter for the continent.

There is no consolidated projection of South Africa's *future* GHG emissions, but work in progress will probably confirm the basic pattern, with the largest share of future emissions continuing to come from bulk energy supply (45% of the total). This highlights the opportunities for emissions abatement in Africa; currently 80% of GHG emissions come from energy supply and use.

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[64] South Africa Country Analysis Brief US DOE EIA 2005.

[65] Total primary energy supply of 11.7MJ per US$ of GDP on a purchasing power parity basis, compared to 7.9MJ/$ for Asia and 6.7MJ/$ for Latin America. (Winkler.H: Energy for Sustainable Development, Volume XI, No.1, 2007).

[66] CO_2 emissions of 6.7 tonnes per capita, comparable to the OECD average of about 11tCO2/cap., far higher than the non-OECD average of 1.7tCO2/cap. (Winkler.H Energy for Sustainable Development, Volume XI, No.1, 2007).

SOUTH AFRICAN LEADERSHIP ON DEVELOPMENT, ENERGY AND CLIMATE

Like most developing countries, South Africa faces a double bind in relation to climate change – development priorities limit its ability to take on mitigation reduction commitments, but the country is also vulnerable to the impacts of climate change and has an interest in urgent action.

Politically, South Africa has taken a proactive role in seeking to bridge the gap between developed and developing countries[5]. South Africa's National Climate Change Response Strategy is centred around sustainable development[10]. Approaches to mitigation that take **local sustainable development** benefits seriously are likely to work best (from job creation and poverty alleviation to reducing local air pollution). Its regional geopolitical leadership provides the ability to expand and disseminate successful models for development, energy, and climate protection.

The emissions profile makes clear that the core challenge to achieve low emissions is to diversify energy supply to reduce the dependence on coal. "Securing supply through diversity" has been a major energy policy goal since 1998[6]. Important specific opportunities include:

- **Replacement of old electricity generation capacity with diversified renewables and gas**. Just over 1,000MW per year of additional capacity is required for the next 20 years. The "baseline" plan is for six new coal-fired power stations of c3,600MW each, but four of the six could be replaced by other options: renewables, energy efficiency, imported gas, or sustainable hydroelectricity.
- **Transitioning from non-commercial fuel to clean commercial fuels.** The current dependence of many households on wood fuels is likely to change with development and urbanization. This provides an opportunity to engage supplies of low-emission power and zero-emission fuels such as hydrogen, and also to implement diversified/decentralized approaches to the provision of energy.
- **Energy efficiency** has the greatest near-term potential. The South African government has a target of energy-efficiency improvement of 12% by 2014[8]. Industry is committed to a reduced energy consumption of 15% by 2015.
- **Solar Thermal Leadership.** This is South Africa's major solar radiation resource which means that the country could become a location for global leadership in thermal electric (STE) technologies. Some studies show significant growth potential of STE in South Africa, assuming learning rates[7] in keeping with the ETF model. Large-scale STE with local manufacturing capacity would be for the domestic grid, but could also be used to export to neighbouring countries.
- **Carbon capture and storage (CCS).** Cleaning up the base-load of coal will require CCS, if it is cost-effective, and if social and environmental concerns can be resolved. South Africa also has an active industry in the area of the coal-to-liquids (CTL) – a very emissions-intensive technology. Most of these emissions could be avoided by the use of CCS. However, it should be noted that the use of the resulting fuels, say in the transport sector, would have similar emission-intensity to oil-derived fuels.
- **Biofuels** are of increasing interest. The potential is not as large as in Brazil, owing to constraints on arable land, water, and competition for food production. But biodiesel to displace oil-based diesel is an option. Up to 35PJ is possible by 2025 without displacing food production[7].

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[2] RSA (Republic of South Africa), South Africa: Initial National Communication under the United Nations Framework Convention on Climate Change. Submitted at COP-9. (Pretoria, 2004.) unfccc.int/resource/docs/natc/zafnc01.pdf

[3] Winkler, H, Spalding-Fecher, R & Tyani, L. (2001) What could potential carbon emissions allocation schemes and targets mean for South Africa? (Energy & Development Research Centre, University of Cape Town, 2001); WRI (World Resources Institute), Climate Analysis Indicators Tool (CAIT), version 3.0. (Washington DC, 2005.) http://cait.wri.org/

[4] IEA (International Energy Agency), Key World Energy Statistics from the IEA. (IEA, Paris, 2004.)

[5] Van Schalkwyk, M. (2006) Ministerial indaba on climate action. Chair's Summary. Kapama Lodge, South Africa, 17 to 21 June, 2006. (Department of Environmental Affairs and Tourism, 2006.) http://www.environment.gov.za/HotIssues/2006/Climate_Change_Indaba/cc_indaba.html.

[6] DME (Department of Minerals and Energy), White Paper on Energy Policy for South Africa. (DME, Pretoria, 1998.) http://www.dme.gov.za

[7] Winkler, H. (Ed.) (2006) *Energy policies for sustainable development in South Africa: Options for the future. ISBN: 0-620-36294-4.* (Energy Research Centre, Cape Town, 2006.)

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[11] Winkler, H. (2006) Energy policies for sustainable development in South Africa's residential and electricity sectors: Implications for mitigating climate change. PhD Thesis, University of Cape Town.

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Topic Paper 14: Russia

THE SIGNIFICANCE OF RUSSIA

Russia and its neighbours have historically been leading industrial national and technology providers. In more recent times, Russia has become an energy "super power" on account of its large reserves of gas and oil which have underpinned European energy consumption. Oil, gas, and metals make up two-thirds of Russia's export income and a quarter of GDP. Indeed, the country has very large oil reserves and production is second only to Saudi Arabia[67]. Russia finds itself as a central player in energy pipelines and infrastructure that go both east and west.

While Russian industrial output is rebuilding after a period of recession, the overall population is declining by about 0.4% per year.

ENERGY

Russia is significant in terms of its energy exports, but it is also important to recognize its internal energy usage. Russia sits at the high end of the spectrum in terms of energy intensity. This increased less than GDP in the 1990s, but faster during the economic recovery of the early 2000s. In contrast, energy utilities have become less efficient in supplying energy due to lack of modernization. As a result, municipal and state-owned sector energy efficiency has not improved over the last 15 years.

Sectoral distribution of GHG emissions (in CO_2 equivalent) was stable in the period 1990-2004, with energy emitting 83.0% in 1990 and 84.6% in 2004, industry 4.3% and 5.1%, agriculture 10.8% and 7.3%, and waste 1.9% and 3.1% respectively[68].

Energy for electricity and heat generation dominate primary energy use. However, with recent GDP growth at 6-7% per year in recent years, GHG growth has been significantly lower at about 1%[69]. The main contributions to GDP are: oil and gas, services and trade, and heavy industry, so only the last component is linked to significant GHG emissions. These emissions are mainly determined by, firstly, electricity and heat production, which is almost stable owing to the declining population, and, secondly, by transport, which is growing albeit relatively slowly.

Currently, energy saving, natural gas, and nuclear are considered by the government and private companies to be the main tools of energy development in the coming decades, while there is very little discussion on future decarbonization.

Russia also has a considerable nuclear legacy, with 31 operating power stations. Five new ones are proposed. Proposals to develop more nuclear supply, to free up more gas for export sale, are controversial.

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[67] Key World Energy Statistics, International Energy Agency, 2006. www.iea.org

[68] Fourth Russian National Communication to the UNFCCC, 2006. www.unfccc.int

[69] Fourth Russian National Communication to the UNFCCC, 2006. www.unfccc.int

EMISSIONS

According to official data, in 2004 Russian GHG emissions fell by one-third between 1990 and 2004, while the Russian Kyoto commitment is a zero reduction from 1990 levels in 2008-2012. In 1990, Russian GHG emissions were 2,960Mt CO_2-eq. After a sharp decrease in GHG emissions caused by economic decline in the 1990s, Russian emissions have been slowly growing from 2000 (1,991Mt CO_2-eq in 2000 and 2,074Mt CO_2-eq in 2004).

Per capita emission in 1990 was about 20t CO_2-eq per year, falling to 14.4t CO_2-eq per year in 2004.

LEADERSHIP POTENTIAL

Energy efficiency of economy

Energy-saving potential is up to 40% of current energy demand. Electricity production uses low domestic natural gas prices while selling electricity by state-regulated tariffs. Meanwhile, the metallurgy sector is trying to reduce energy costs by installing its own energy generation facilities, which should be much more efficient. In service, food production, and some other sectors energy efficiency can improve as a result of the introduction of modern, imported technologies and products. The subsidized prices in the municipal energy sector present opportunities to get better price indicators to consumers, which would assist with reduced use and better efficiency.

Natural gas use

Russia has over a quarter (26.6%) of the world gas resources[70] – greater than any other country – and about 28% of extracted Russian gas is exported. In 2004, the Russian share in global gas export was about 22% (including export to former USSR countries). Oil and gas exports are becoming the main source of income for the State Budget and repayment of Russian external debts. Huge gas resources and a well-developed system of gas pipelines guarantee a key role in the global gas market, with a focus on export to the EU and China. This clearly provides a major opportunity to use gas to avoid the uptake of coal in other countries. On the other hand, Russian government and state-owned energy monopolist RAO UES Rossii have indicated plans to increase coal use to free up more gas for export sale. This is very controversial and will certainly lead to considerable growth in GHG emissions[71].

Biomass use

In Russia, biomass used for energy or heat production is mainly timber waste or non-commercial fuel-wood. The market for wood-chips is already growing rapidly in NW Russia (mainly wood granules – pellets for export to Europe). Modern and ecologically sound technologies for wood and other biomass use are in use in some places.

The estimate of total wood biomass (oil to biomass switch potential) in NW Russia is about 400Mt CO_2/year, including 8.8Mt.c.e heavy oil and 5.7Mt.c.e diesel oil. This type of fuel switch in heat generation will become most economically reasonable in the near future.

Strategic use of gas assets

Russia can also play a significant role in underpinning energy security in many regions, especially through the strategic use of its gas assets and pipeline infrastructure.

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[70] According to BP's Statistical Review of World Energy, 2005.

[71] Presentation of RAO UES Rossii Chairman, Mr Chubais, 13 February 2007, http://www.rao-ees.ru/ru/news/speech/confer/show.cgi?prez130207abc.htm

Topic Paper 15: India

THE SIGNIFICANCE OF INDIA

India will undergo enormous change over the coming half-century as its population (already a sixth of the world total) grows to eclipse that of China, and as it seeks to eradicate poverty through economic development and the widespread provision of commercial energy. How India manages these changes will have a major impact on the health of the global climate.

The challenges are huge, especially in a climate-constrained world, in supplying adequate energy to support the growth of wealthy industrial and commercial sectors, and responding to the rising demand for personal vehicles, while also meeting the needs of the 650 million people living in rural areas, roughly 350 million of whom currently have no commercial energy supplies.

India is highly vulnerable to climate change, its rural population largely reliant on rain- and melt-water-fed agriculture. Issues range from food security and freshwater availability to flooding and cyclones, as well as heat waves and droughts.

ENERGY

In India, a land of extreme contrasts, the very low values of per capita energy consumption, electricity generation, and emissions – of both GHGs and other pollutants ("India Energy Outlook, KPMG, 2006") – hide the high demand from urban, industrial and largely coal-based power sectors, and of the growing sector of affluent and upper-middle class consumers. The third of the population without access to commercial energy do not contribute to emissions but do contribute to, and suffer from, carbon dioxide, smoke, and particulate emissions from inefficient energy sources.

EMISSIONS PROFILE

An assessment of the current and projected trends of GHG emissions from India and some selected countries indicates that although Indian emissions grew at the rate of 4% per annum in the 1990-2000 period and are projected to grow further to meet national development needs, the absolute level of GHG emissions in 2020 will still be less than 5% of global emissions. Per capita emissions will still be lower than most developed countries, and lower than the global average (Sharma *et al.,* 2006[72]).

Nevertheless, reference scenarios suggest that total carbon dioxide emissions in India may grow by 280% between 1990 and 2030. This implies that India's rank in terms of total GHG emissions will be very high. Coal power and related carbon dioxide emissions will more than double and overtake those of the EU by 2030[73]. Controlling the emission intensity of this growth will be an important contribution to climate protection.

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[72] Sharma, S, Bhattacharya, S & Garg, A. (2006) Greenhouse Gas Emissions from India: A Perspective, in: *Current Science*, Vol. 90, No. 3, 10 February 2006.

[73] IEA, 2004; World Energy Outlook, Paris, pp. 415ff.

LEADERSHIP

India has a unique opportunity to find solutions which can meet the immediate needs of poverty reduction and economic and industrial growth without sacrificing the longer-term objectives of energy security and climate change.

- **Size matters**. As one of the world's only two billion-people economies – and a vibrant democracy – India has an influential status in international fora.
- **Commitment**. India's successful engagement within the Clean Development Mechanism shows its willingness to work with the global community to tackle the problem of climate change. This engagement also brings with it responsibility and a high degree of interest towards ensuring that there is no gap between the two commitment periods of the Kyoto Protocol. There is an increasing interest within industry with regard to the carbon market and opportunities to engage in it.
- **Decentralized and distributed generation**. India's experience in harnessing renewable energy technologies (RETs) for rural electricity supply linked to job creation is a powerful business model for ensuring economically, socially, and ecologically viable development of rural areas of the Third World, and is attracting a great deal of interest from many countries in Asia, Africa, and South America.
- **Renewable energy technologies (RETs)**. India is today in a position to play a major role in the large-scale commercialization of RETs such as large and small biomass and biogas technologies, wind generators, small hydro, solar thermal, solar PV, energy-efficient lighting systems, and much more. The country could be an especially attractive partner for other developing countries as technology provider, equipment supplier, and capacity builder. There is definite scope for joint R&D between S-S-N for developing techniques for cost-effective large-scale deployment of these technologies, especially if_attention can be given to the two weak spots: deployment and maintenance ("India Energy Outlook, KPMG, 2006/ RET Outlook" Based on MNES website).
- **Urbanization and IT**. The expansion and development of Indian cities provides a great opportunity to find ways for the country's citizens to live and work in ways that are far more efficient and less polluting than many existing cities. The major IT infrastructure and skill base in India is already allowing Indian companies to access and service global markets without the need to fly people around the world. Ensuring that even within cities commuting distances are minimized, public transport is available, and new buildings are highly efficient will all contribute to an ongoing low-emission legacy in India.
- **Carbon capture and storage**. While India is not yet at the forefront of carbon capture and storage technology development, its current dependence on coal and large reserves makes it important that CCS is proven, and if successful, promoted. India has started several national programmes to develop and commercialize clean coal technologies, backed by international cooperation programmes in the public and private sectors. However, "clean coal" is not the most efficient and climate-friendly coal technology and more advanced carbon dioxide sequestration/conversion technologies should also be taken up as a priority.
- **Sustainable hydroelectric power**. A great deal more development and design is needed to evolve socially and ecologically better solutions for hydropower systems that minimize large dislocation of local populations and associated impacts on fragile ecosystems.

- **Industrial energy efficiency**. While the government programme on energy efficiency has not made a very big impact, three factors are pushing the energy-saving programmes: (a) liberalization of the economic and industrial sectors is forcing Indian industry to be more competitive; (b) foreign ownership of manufacturing or processing industries (in both joint-venture partnerships and 100% owned) can bring in new energy-efficient technologies (although some multinationals are poor environmental performers and some home-grown companies are already world leaders in renewables); and (c) the carbon credits market under the Kyoto Protocol's Clean Development Mechanism is promoting energy savings – by providing incentives and access to partial funding for meeting the "Incremental Costs" – in areas which would otherwise not do so. The small and medium industrial sector and the agricultural sector, however, are still rather energy inefficient and major efforts can be made to make them energy efficient which will significantly reduce India's GHG emissions.

Topic Paper 16: European Union

THE SIGNIFICANCE OF THE EU

With the European Union (EU) having many harmonized laws on energy and emissions which impact on the action of many countries and over 500 million people, its potential to drive change towards a secure climate is highly significant. The EU's current expansion (which makes some trends a little difficult to explain) creates opportunities to influence and invest in the workings of accession countries and many of its new neighbours. It has now taken a historic decision to cap GHG emissions by up to 30% by 2020 by mandating 20% supplies from renewable energy also by 2020. This decision could be the hugely influential precursor to a new global deal for 2012 climate targets in order to say below 2⑤C global warming.

The EU is responsible for a major volume of the world's technical innovation and has large volumes of capital for internal and external investment that can help to shape the future.

Like the USA, the EU is a major importer of many goods which have an upstream climate change impact – manufactured goods, timber, and foods. Judicious use of this buying power can significantly affect the sustainability of production around the world.

ENERGY

The overall profile of individual EU countries' climate policy and energy performance is extremely diverse. Reductions of GHG emissions of more than 10% (UK, Germany) through climate measures compare with large increases in other countries such as Spain, Italy, Ireland, The Netherlands, and Finland. The economic decline in Eastern European new EU member states in the early 1990s led to industrial closure and consequent huge decline in energy demand and therefore emissions – now in the process of increasing again.

In terms of energy supply, while some countries have embarked on nuclear programmes, others have phased nuclear out. Some continue to rely strongly on coal, while many others have combined renewables in their mix, and a few have embarked increasingly on natural gas and other fuels. Oil is the key primary energy product used in the EU (39%), followed by natural gas (23% and growing rapidly) and coal (19% but declining by almost a third since 1990). Nuclear accounts for 14% and renewable energy for only 7% of all primary energy used.

The EU's high dependence on imported fossil fuels will be exacerbated by dwindling internal reserves. This is adding impetus to the drive to harness indigenous resources from renewables, especially wind, biomass, and solar, as well as fuelling interest in newer technologies such as solar thermal power and ocean and wave energy.

EMISSIONS

The EU 25's total greenhouse gas emissions amounted to almost 5Gt CO_2 equivalents in 2004 – about 12% of all global GHG emissions. Energy-related carbon dioxide emissions account for 82% of these.

Compared to 1990, the EU25 and EU15 GHG emissions are almost 5% and 0.6% below those of 1990, respectively. As regards carbon dioxide only, emissions declined by 1% in the EU25, but in fact increased by 4.4% in the EU15 between 1990 and 2004, showing that the economic engines of Europe have not yet stabilized their emissions.

With 8.4t CO_2 per capita, the EU's annual emissions from fossil fuels are one of the lowest in the OECD (compared to 20t in the US) but still nine and three times that of China and India, respectively. Also, the EU's energy intensity (energy used/unit GDP) is better than average in the OECD, and almost 100% better than that of the US[74].

In the EU25, the largest share of all GHG emissions come from electricity and steam production (33%), transport (19% – its share has grown by 20% since 1990), industry (14%), and households (10%). Non-energy related and non-CO_2 emissions account for 18% of all emissions[75].

Past policies in cutting non-CO_2 emissions such as from waste or the agricultural sector have been much more successful than cutting carbon from fossil fuels. In recent years, the trend has shown an increase of all emissions in the EU25, posing a serious question as to whether at least the EU15 is able to meet its Kyoto target of a cut of 8% by 2008/2012.[76]

EUROPEAN LEADERSHIP

Forecasts of "business-as-usual" energy demand development in the world see the EU's relative share of global emissions shrink in the future, regardless of its own climate actions, as emerging economies continue to grow. Nevertheless, using its quite powerful political tools, the EU – or rather *some* member states and *some* sectors – are already leaders towards a truly carbon-free future. Examples are:

- Sweden (decision to phase out oil in transport by 2020 through transport efficiency and biofuels);
- The wind energy sector in Europe which represents 80% of all global wind investments;
- German and Spanish "feed-in" tariffs;
- The strong solar push though various measures in Spain, Austria, and Germany;
- Implementation of biomass heat in Scandinavia and Austria;
- Expansion of efficient combined heat and power (CHP) in Denmark and The Netherlands;
- The strong commitment in France to cut emissions by 75% by 2050;
- The recent policy and investment push for sustainable carbon capture and storage (CCS) by various actors;
- The very encouraging public debate about climate change issues generally in the EU.

In addition, the *European Union* has been leading efforts to introduce the 2⑤C threshold into the international climate negotiations for a post-2012 regime. The EU has led on renewable energy targets by obligating member states to have 21% of all electricity by 2010 from

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[74] IEA 2005: Key World Energy Statistics

[75] EEA 2006, as above

[76] EEA 2006: Technical report No 6/2006, Annual European Community greenhouse gas inventory

renewable power, and this has now been extended to 20% renewable in all energy-consuming sectors by 2020.

The EU Emissions Trading Scheme (ETS) is groundbreaking in its attempts to create a solid cap and trade system. Further efforts are required, however, to ensure that the system is improved through stronger caps and clear architecture that encourage a low-carbon future. Efforts to agree binding measures for 20% in primary energy savings by 2020 through various measures in energy efficiency will be critical for the near future.

The areas of technology development and deployment that Europe can influence covers virtually every single climate solution considered in the WWF model, both internally and externally through its international investments and purchasing power.

Topic Paper 17: China

THE SIGNIFICANCE OF CHINA

As a developing country, China takes social and economic development and poverty elimination as its overriding priorities. China may support the quadrupling of its GDP by doubling its energy consumption, which will inevitably lead to major increases in carbon dioxide emissions unless this demand is met by much lower emission technologies.

With the world's largest population and with a period of rapid industrialization and urbanization now underway, the choices made by China will be very important in the avoidance of 2⑤C global warming.

ENERGY IN CHINA

China has a coal-dominated energy resource endowment; coal making up 96% of the proven fossil fuel reserve. In contrast, petroleum and natural gas together only account for 4%. China's share of the world total coal, hydropower, oil, and natural gas reserves in 1999 are respectively 11.6%, 13.4%, 3.4% and 0.9%[77].

Home-produced coal dominates China's energy mix, assisting in energy security but challenging CO_2 emission control efforts. China is both the largest consumer and producer of coal and the largest producer of hydropower in the world[78](BP, 2006). In 2005, total energy consumption in China is about 1386 Mtoe, of which coal was 2140 Mt, oil 300 Mt, Natural gas 50 Billion Cubic Meter, hydropower 40.1 billion kWh and nuclear power 52.3 billion kWh[79](CNSB, 2005).

China reported a net import of 117 million tons of crude oil in 2004, representing an import dependence rate of 40% [80](Zhang, 2005). The oil price rocketing on the international market has made energy security a major concern in China.

Energy security pressures, environmental considerations and distributed energy demands have made China move quickly into renewable energy. Historically it has been a world leader in small hydro systems, but now wind farming, solar hot water and solar PV are big industries in China.

EMISSIONS PROFILE

China, due to its large population and coal-dominated energy structure, emitted 3759.9 million tonnes of carbon dioxide from fuel combustion in 2003[81] and was ranked as the world's second

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[77] LBNL (Lawrence Berkeley National Laboratory), May 2004, China Energy Databook v.6.0.

[78] BP World Energy Statistics 2006.

[79] CNSB (China National Statistics Bureau), 2005 National Economic and Social Development Statistic Communique (February 2006).

[80] Zhang Guobao, Vice Minister of the National Development and Reform Commission, made a speech on behalf of the Chinese government on 14th September 2005 (http://www.gov.cn/xwfb/2005-09/14/content_31342.htm).

biggest carbon dioxide emitter, accounting for 14.9% of world energy-related carbon dioxide emissions. The IEA estimates that by 2010, China will surpass the United States and become the world's biggest carbon dioxide emitter; however, China's per capita carbon dioxide emissions from energy combustion were 2.9 tonnes in 2003, about 72% of the world average level in the same year[82].

In its 11th five-year plan, China for the first time explicitly set the tasks of *controlling greenhouse gas emissions*.

LEADERSHIP

Renewable Energy Technology and Deployment

In the medium- and long-term (2020) plan for renewable energy development and energy conservation, China stipulates that renewable energy will reach 10% of China's total primary energy consumption by 2010 and 15% by 2020, and the energy-intensity of GDP is planned to decrease by 43% during the period 2002 to 2020. Meanwhile, energy use per capita in 2004 was only 1.08 tonnes of oil equivalent, about two-thirds of the world average and 13.4% of that in the United States. These represent outstanding targets for a country which is still very much a poor country on average.

Commitment and Showing How to Decouple Emissions and GDP

If China were to meet its energy conservation target by 2020, it would avoid the emission of some 3.4 billion tonnes of CO_2 from 2003 to 2020[83]. This shows the strong commitment of China to decouple economic growth from carbon emissions.

Energy Efficiency

To reach the energy conservation target set in the 11th five-year plan, that energy intensity per GDP unit will decrease by 20% by 2010 in comparison with that in 2005, the National Reform and Planning Commission has signed energy conservation-obligatory agreements with 30 provincial and municipal governments and 14 state-owned enterprises[84]. On this basis, the provincial and municipal governments will sign an obligatory agreement with the high energy-intensity enterprises located in their precincts. The achievement of the energy-efficiency target is linked with performance evaluation of provincial governors and state-owned enterprises[85].

Key exporter of energy efficiency technologies

China is the largest energy-efficient light bulb producer in the world. In 2005, the total production reached 1.76 billion accounting for 90% of world total, 70% of which is exported to other countries (Ma, 2006).

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[81] IEA (International Energy Agency), CO_2 Emissions from Fuel Combustion, 1971- 2003 (2005 Edition).

[82] IEA (International Energy Agency), World Energy Outlook 2006.

[83] Wang Yanjia (2006) Energy Efficiency Policy and CO_2 in China's Industry: Tapping the potential. Tsinghua University.

[84] Press Release at Xinhua Net from the National Energy Conservation Workshop on 26 July 2006 (http://news.xinhuanet.com/newscenter/2006-07/26/content_4881272.htm).

[85] Ma Kai, Minister of the National Development and Reform Commission, gave a speech at the National Energy Conservation Workshop on 26 July 2006 (http://hzs.ndrc.gov.cn/).

Leap-frogging Technology on Coal

To deal with the pollution caused from the use of the main energy source, coal, China has demonstrated advanced clean-coal technology, such as Integrated Gasification Combined Cycling (IGCC), and now is exploring the feasibility of carbon capture and storage. The first Green Coal Power Company, with shareholders from the top eight state-owned power companies, was founded at the end of 2005. It is planned for this company to demonstrate and promote advanced coal power generation technologies with near-zero emissions of CO_2 and other pollutants within 15 years.

Urbanization

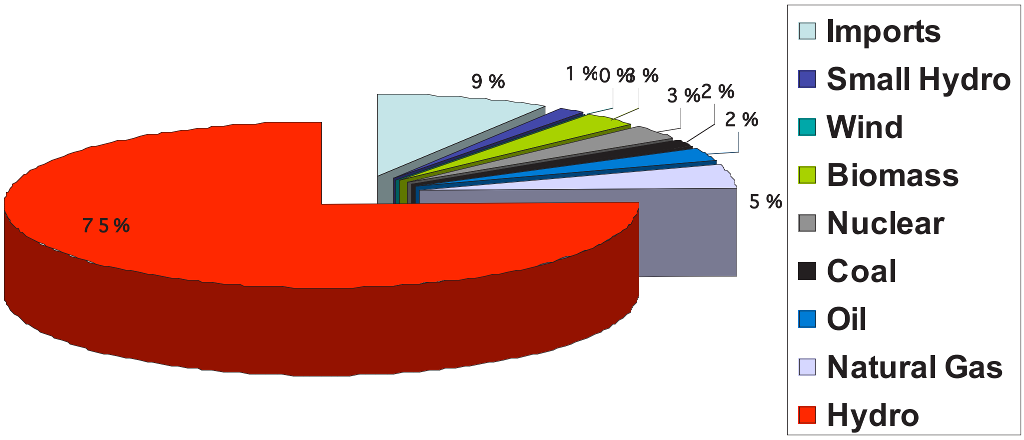
The expansion and development of China’s cities is a major opportunity to decouple how people live and work in China from GHG emissions. This can be achieved with high building and appliance efficiencies combined with ensuring that even within cities commuting distances are minimized and public transport is well used.

Topic Paper 18: Brazil

THE SIGNIFICANCE OF BRAZIL

Brazil's economy and land mass dominate Latin America and its regional and international influence cannot be underestimated. Among the ten biggest economies in the world, Brazil is the third largest user of energy and the biggest producer of ethanol. Although economic growth has been modest in recent years, Brazil is heavily present in the international political and economic arenas owing, among other things, to its trade surplus, competitive industries, energy abundance, and an enormous environmental wealth; it is the steward of the world's largest remnant tropical rainforest and of almost 14% of the world's superficial freshwater.

ENERGY IN BRAZIL



Source: Balanço Energético Nacional, 2005

Electricity represents the second biggest source of energy for the Brazilian people (18%), behind petroleum and its sub-products (39%). Hydropower still dominates the electricity matrix, providing 75% of total electricity, although in recent years thermoelectricity has gained a stronger foothold, moving from 7.5% of market share in 1980 to 17.2% in 2004. The part played by unconventional renewable energy is still modest, notwithstanding the country's enormous potential.

EMISSIONS

In 2000, Brazil's greenhouse gas emissions totalled about two billion tons of CO_2 equivalent. In contrast to most developed countries, it is land-use change such as deforestation which represents the biggest emitting sector, with 62% of total emissions, followed by the agricultural sector with 20% and the transport sector with 6% (WRI, 2006). Nonetheless, yearly emissions are highly volatile given changes in deforestation rates. In 2002, for example, 70% of emissions came from land-use change. To put this into an international perspective, Brazil ranks eighteenth in the world for carbon dioxide emissions from the energy sector, but fourth if total emissions are considered.

Given the uncertainties about the GHG emissions from land-use changes, it is very difficult to make forecasts about future emissions. While 2006 saw a 30% reduction (possibly due to lower beef and soy prices, but also to policy interventions; Ângelo, 2006), the second year of consecutive reduction, there is no evidence of a long-term declining trend in land-use change. On the contrary, in the absence of large-scale incentives and support for effective national initiatives to reduce deforestation, rates will increase as the Brazilian government struggles to contain illegal logging pressures and provide growth for the Amazon region and the country as a whole (building and paving highways into the core of the Amazon and large infrastructure projects; IPAM, 2005; Brazil Federal Government, 2007). As for the energy sector, WWF-Brazil projects emissions to increase by almost 200% between 2000 and 2020, up to 72Mt carbon dioxide per annum in a business-as-usual scenario.

LEADERSHIP

Brazil has already implemented a number of successful emission reduction policies for reasons other than climate protection. The country has the potential for global leadership in three areas: energy efficiency, ethanol production, and forest protection.

Energy Efficiency

Brazil has long had governmental programmes for energy efficiency, including Procel, launched in 1985. By 2004, with a total budget of R$760 million, Procel achieved savings of more than 19TWh, equivalent to over 2% of the country's power use, thereby avoiding more than 5,255MW of new capacity and saving more than R$13 billion in foregone investments in generation, transmission, and distribution (Procel, 2007). Following electricity rationing in 2001-2002, with very short notice Brazilians reduced consumption by almost 20% (compared to 2000 levels). WWF research has shown there is potential to reduce power demand growth by 40% over the next 15 years[86], resulting in an annual CO_2 emissions reduction of about 26Mt (WWF Brazil, 2006). However, over the last few years energy-efficiency promotion has been a low political priority, with the government intent on focusing on supply-side construction to satisfy the country's future energy needs (Brazil Federal Government, 2007).

Biofuels

Launched in 1975, Proalcool, Brazil's ethanol programme, remains to date the largest commercial application of biofuel for transport in the world. It succeeded in demonstrating large-scale ethanol production from sugarcane and its use for car engines[87]. Were Brazil to double its ethanol programme by 2015, this would result in a reduction of 10Mt carbon per year (Goldemberg & Meira Filho, 2005). However, the challenge ahead is to ensure that sugar

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[86] Two-thirds on the demand side, mainly industrial motors, appliances and solar water heating, and the remaining one-third on the supply side, including re-powering and distributed generation.

[87] Its benefits also included savings worth about US$100 billion in hard currency, over a million jobs created in rural Brazil, around 1,350GWh per year of electricity produced from sugar bagasse, and an estimated saving of 574 million tons of CO_2 since 1975, or roughly 10% of Brazil's CO_2 emissions over that period (IEA, 2004).

production expands[88] only on degraded and abandoned land and does not result in further tropical deforestation and loss of biodiversity, or damage to river ecosystems from excessive water use for irrigation.

Halting Deforestation

Finally, given the country's high deforestation rates, the urgent development of Brazil's capacity to reduce and eventually halt deforestation of its tropical rainforests is of great importance, for its own long-term sustainable development, for global and regional climate protection, and as an example to other countries. The major challenge is to support economic alternatives to extensive forest clearing, increase funding to enforce environmental legislation and implement protected areas, and build institutional capacity in remote forest regions. Under the future international climate regime, Brazil could table a deforestation emissions reduction target and receive positive incentives to achieve it. For instance, using data from Prodes (2005), PointCarbon (2006), and Ângelo (2006), a further 10% yearly reduction in deforestation rates could represent US$1.8 billion in yearly added income[89] for the country.

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[88] A fivefold increase from 5 to 35 million hectares is projected by 2025 to meet future growth in world ethanol demand (NAE 2005).

[89] For Motta (2002), carbon finance would be sufficient to invert perverse local incentives, leading the way to a more sustainable use of the forest's resources.

Part III Technical Summaries

Topic Paper 19: Design of the Model

INTRODUCTION

The WWF Energy Wedge Model uses probabilistic risk management tools to model the likelihood that global warming can be safely and successfully mitigated by a suite of appropriate technologies, systems, and resources.

The model makes the assumption that any climate change action will have to be compatible with other international development goals, including industrialization, poverty eradication/economic development, and energy security, as well as continuing global population growth.

The model assumes that there will be global action on emissions reductions, though the timing and effectiveness of action is explored in various scenarios. The model builds on the work of Pacala & Socolow[90], developing the concept of "wedges" which either avoid energy use, or create energy without emissions, or have low associated emissions.

The WWF model has been developed to test the plausibility and time constraints of implementing deep greenhouse gas emission cuts. In the WWF Model these "climate solution wedges" are developed concurrently subject to a set of defining characteristics which determine the boundaries of the scale and speed of their development. However, unlike Pacala & Socolow's wedges, the shape and size of these "climate solution wedges" are based on typical or plausible industry development characteristics and limitations, as well as reviews of published work on resources, performance, and in some cases new research undertaken for the WWF Energy Task Force.

Another feature of this model is the use of Monte Carlo[91] simulations to allow a range of estimates for any given variable to be accommodated and reflected in the outputs. Thus, every input and output can be expressed as a *range* described by a probability distribution.

The model deliberately avoids the use of a carbon price. Instead, it is assumed that the price adjusts to respond to the government-imposed requirements of emission reduction or technology forcing – not the other way round. Furthermore, a carbon price has not been used as

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[90] Pacala, S & Socolow, R. (2004) Stabilization Wedges: Solving the Climate Problem of the Next 50 Years with Current Technologies. *Science* 13th August, 2004, Vol. 305.

[91] See Hammersley, J M & Handscomb, D C. (1964) *Monte Carlo Methods*. John Wiley & Sons, New York.
Binder, K & Heerman, D W. (1992) **Monte Carlo Simulation in Statistical Physics**, An Introduction, *Springer-Verlag*, Berlin, 129 pp.; McCracken, D D. (1955) **The Monte Carlo Method**, *Scientific American*, May, pp. 90-96; Morgan, M Granger & Henrion, M. (1990) **Uncertainty – A guide to dealing with uncertainty in Qualitative Risk and Policy Analysis**, Cambridge University Press.

it does not allow for the complexities of industry development processes, front end capital investment, and the resultant dynamics in the economy.

This model is not an economic model in the form presented. However, is should be noted that all the “solutions technologies” considered are commercially available today. Most energy sources are competitive with – and all have current or future net cost projections less than – the price of nuclear energy, based on the MIT analysis of nuclear costs[92]. The use of energy storage and conversion to new fuels such as hydrogen will present additional costs. However, these are fundamental to the provision of energy on demand, fuels, and industrial heat and these additional values will be the basis of meeting additional costs.

It is possible for this model to be extended to provide full costings.

A COMPARISON WITH CONVENTIONAL MODELLING APPROACHES

There are a number of methodologies for modelling future emissions. The most complex link estimates of world energy consumption, trade, economic growth, and political responses to climate change. The outputs most sought after are estimates of reductions in emissions, implied carbon prices, and effects on GDP.

Most models equilibrate technologies via market pricing and using technology cost/learning curves with the aim of achieving economic allocative efficiency at any specific carbon price and time.

By their nature, most economic models are designed to explore changes from the status quo and do not deal with ongoing transformational change which includes significant structural shifts. Economic models do not easily model the kind of stimulated entrepreneurial activity that arises in response to the need to transform, change, and survive when business is faced with an exogenous threat/opportunity.

The range of models and scenarios currently available to consider how to address climate change tend to assume limits due to implied economic constraints long before realizing the resource or industry development constraints and opportunities. Typically, the impact of change is seen as dampening the economy, in contrast to much experience from forced innovation – viz the USA, Germany, and Japan, which are all innovation-driven economies.

Limiting the analysis of how to achieve deep cuts through innovation because of economic constraints does not seem sensible. Conventional models tend to extrapolate today’s structural shape into a very similar shape tomorrow. (Imagine the inaccuracy of insights which might be achieved from the best of today’s economic models if they relied only on data known in 1950.) Much of today’s technology from aircraft to computers has been born of forced innovation combined with market take-up. This is the approach taken in this model.

The WWF model is based on the following assumptions:

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[92] MIT (2003) The Future of Nuclear Power – An Interdisciplinary Study. Release July 2003. Published by MIT. http://web.mit.edu/nuclearpower/

1 Increasing global demand for energy will be driven by a combination of population growth, poverty eradication through economic growth and industrialization in developing countries, and continued economic development in developed countries;

2 The economic impact of global warming greater than 2⑤C above pre-industrial levels will greatly exceed the cost of standard commercially available interventions that would avoid such a rise;

3 There is a relationship between emissions and temperature which allows a “carbon budget” to be derived consistent with a low risk of global temperature increases exceeding 2⑤C;

4 Estimates of resources, industry growth rates, and other parameters relevant to achieving reduction in emissions are intrinsically uncertain and also subject to varied opinion;

5 The rate and scale of investment, industry growth, and resource exploitation are subject to well-known commercial constraints and boundaries;

6 Precautionary risk management requires a portfolio of proven solutions and not an over-dependence on one or more magic bullets (“green”, “brown”, or “black”). The possibility of a sudden breakthrough of a new, significant, commercial energy solution, however plausible, is disregarded;

7 A growing world population will peak at nine billion in about 2050 as forecast by the United Nations Population Prospects (2004);

8 World energy requirement will approximately follow projections in the IPCC SRES A1B storyline – a mid-line path in the SRES series of projections.

METHOD

Two-Degree Carbon Budget

We have established a carbon emissions budget of 500GtC (Fossil Fuels) (see item 3 above) as necessary to stabilize carbon dioxide concentrations at a level which is predicted to keep the climate below a 2⑤C rise. This is reduced to 400GtC if emissions from land use and forestry are not successfully constrained. This analysis is based on the work of Meinhausen as discussed earlier in this report, which considers the affects of multiple gases and the processes of removal of GHG from the atmosphere in the oceans and biosphere.

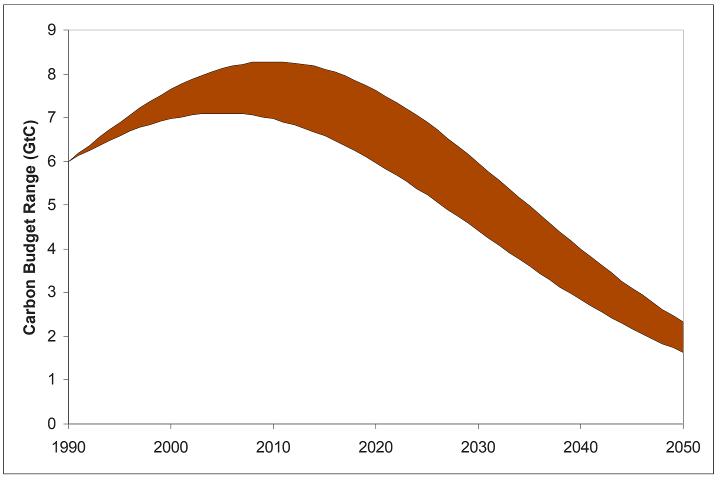


Figure 1. An indicative "carbon band", showing the difference in the upper limits of annual allowable carbon emissions, from fossil fuels, in GtC per year, for total carbon budgets of 400GtC and 500GtC taken out to 2200 (showing the period to 2050 only). The thickness of the band shows the crucial extra flexibility available in anthropogenic emissions if deforestation is successfully controlled.

The band uses a smooth pathway which recognizes that the world's economies have significant intrinsic inertia and that sharp changes are not feasible, economically, technologically, or politically.

Ranges of Data as Inputs

We have investigated many sources of information about "solutions wedges" providing zero- or low-emissions energy or avoided energy use across all sectors. As this information develops over time, the model allows for new information to be included.

Proponents of any one solution tend to be optimistic regarding the contribution and timing of their proposed intervention, while others tend to be more disparaging. Rather that make a judgment, we have elected to use ranges of data which reflect the diversity of opinion.

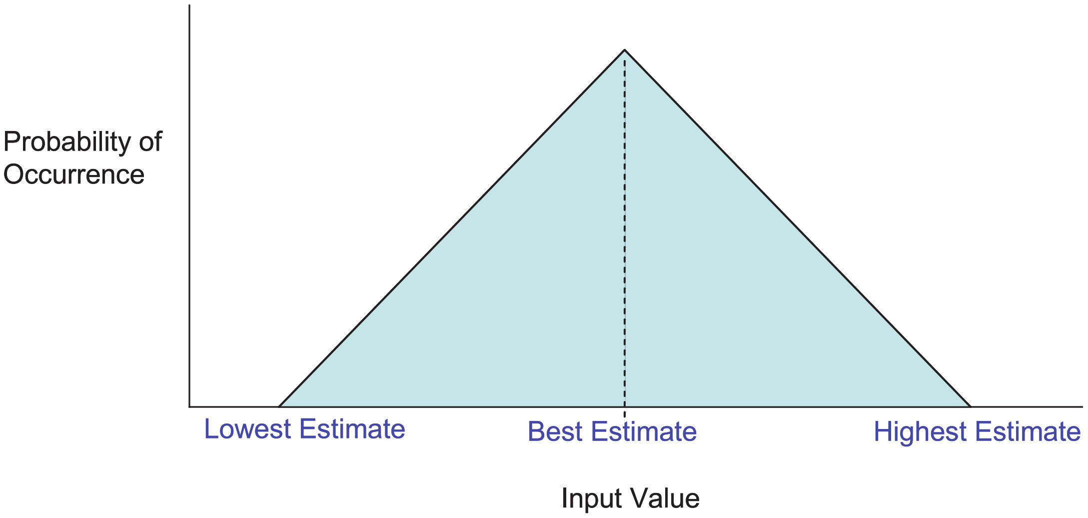


Figure 2. Ranges of input data are entered into the model as ranges. The probability distribution used is triangular, and defined completely by the lowest, best, and highest estimates.

All such ranges of data are entered into the model as a "triangular" probability distribution defined by the lowest, highest, and best estimate for any given variable (Figure 2). We have also sought to have a broad range of independent sources for any given variable.

Trapezoid Solution Deployment

Whereas Pacala & Socolow simplify the growth of a new technology to a wedge with linear growth, in practice any innovation into the market follows a standard sigmoid or "*S*" curve, as shown in Figure 3.

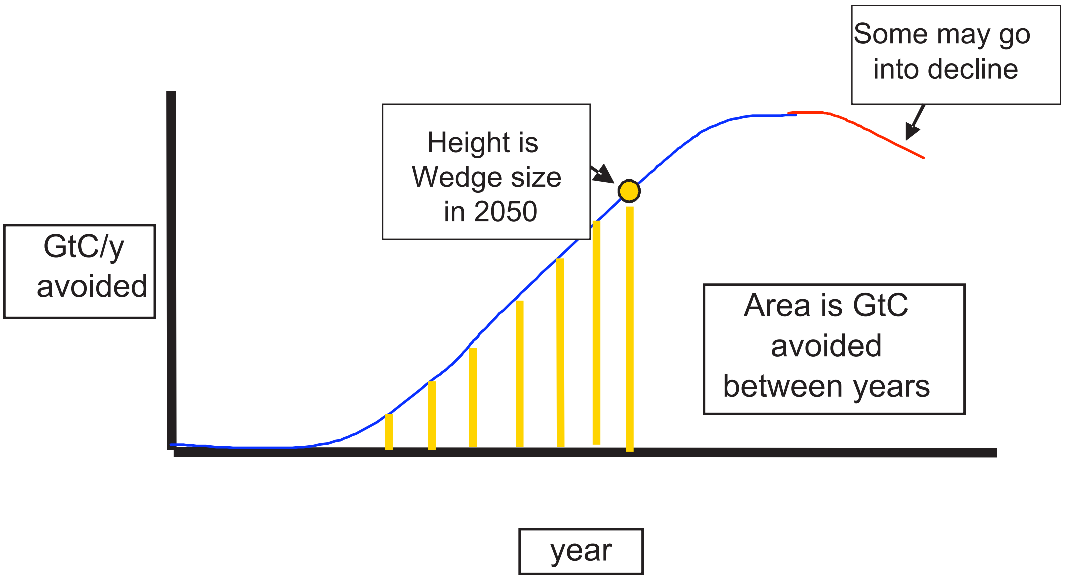


Figure 3. Emissions abated as a new technology grows.

Such a profile is underpinned by a technology or solution which starts from a small base, providing negligible energy, though there may be considerable investment and growth occurring in this phase. Over time the solution starts to make an increasingly significant contribution (the ramp up). This will plateau to a steady level of development as the industry matures (the period of near linear growth). As the unexploited resources diminish or other constraints impinge, the growth of the industry will gradually reduce (the ramp down). In some cases, such as the silting-up of large hydroelectric dams or the phase-out of nuclear energy, there may be an industry contraction.

A Trapezoid Approximation of Growth

The "S" curve above shows the cumulative effect of an installation or industry that grows quickly at the start, reaches a steady state, and ultimately contracts. In terms of the growth phases, these would be best described by a "bell"-shaped curve; however, in the WWF model this is approximated as a trapezoid as shown in Figure 4.

In the model, each solution is described in units most appropriate for the technology or resource; *e.g.*, number of megawatts of wind turbines installed, or million tonnes of oil equivalent avoided through more efficient vehicles.

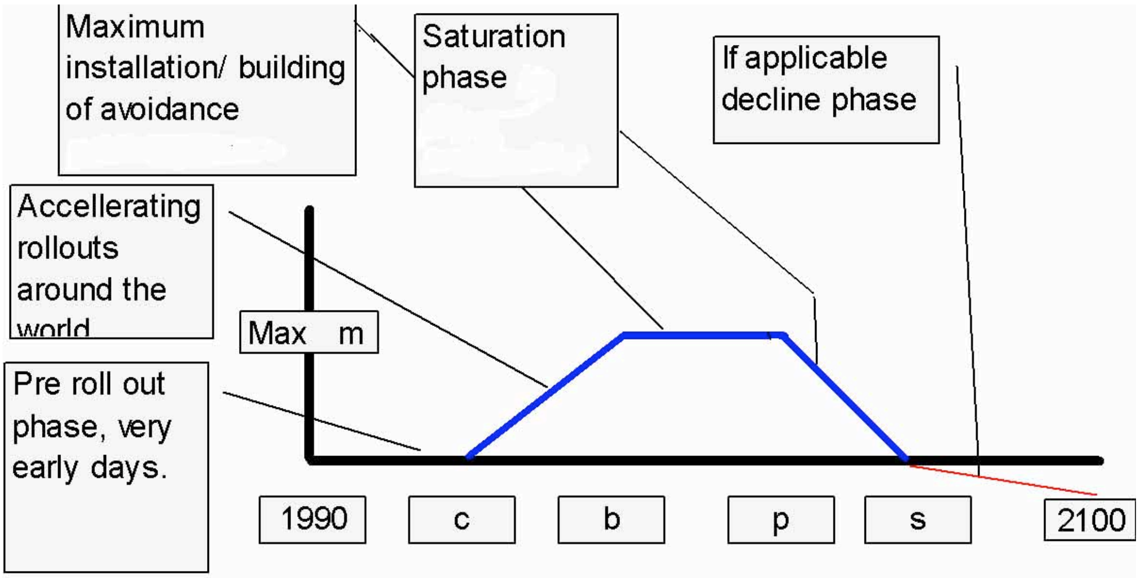


Figure 4. Trapezoid approximation for industrial growth. Any climate solution trapezoid can be fully defined by the set of variables c, b, p, s, and m.

Any climate solution trapezoid can be fully defined by the set of variables c, b, p, s, and m (Figure 4). However, these variables are not put directly into the model because in many cases they are not known. For example, it is hard to estimate the point at which the growth of industrial energy-efficiency implementation will turn down. Instead, more easily estimated parameters are used such as the turnover rate of industrial equipment or available resource, current installed capacity, standard or forced growth rates for each of the phases of development, or the year in which commercial roll-out commences. Combining these various "knowns" in simultaneous equations (which will be different for different climate solutions) allow variables c, b p, s, and m to be calculated, and the shape of the trapezoid and the "S" curve of cumulative annual energy production from each solution wedge to be estimated.

Monte Carlo Method for Combining Variables

Working with many inputs which are in fact ranges of data creates a challenge to combine the outcomes into a meaningful result.

A common system for addressing such a challenge is the Monte Carlo technique which allows for the combining of multiple variables with probability distributions. Essentially, the Monte Carlo component of the model picks a single number within the range of each variable and executes a calculation that creates a single answer. This would be the result if the inputs were fixed in a certain way. But the model is run over and over again with different combinations of inputs, which are both random and reflect their probability of occurrence. The result then is a histogram of results for the outputs of the model, which are in effect probability distributions for the results.

In summary, the Monte Carlo technique allows multiple inputs with various probability distributions to be combined to create outputs with their own probability distributions.

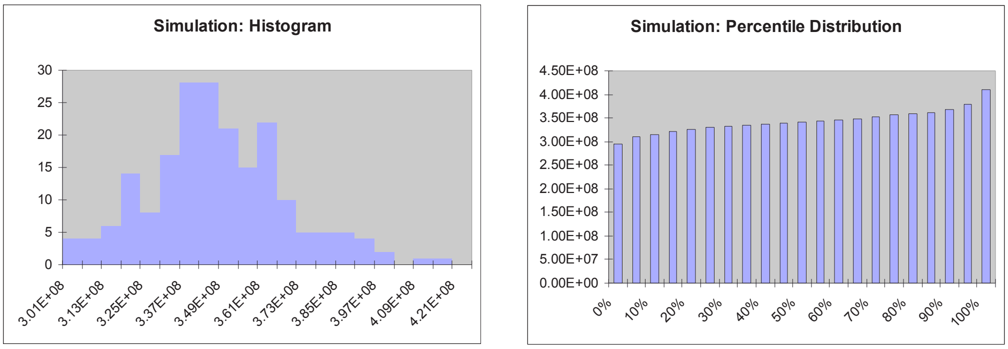


Figure 5. Example distribution for an output for a sample run of the model, presented as a histogram and percentile distribution. These indicate the range of possible outcomes, the most likely outcome and a probability distribution for any given output.

Bottom-Up Approach

As discussed above, we have noted that global demand for energy will be driven by population and economic/industrial development; and we have taken as a given the SRES-A1B estimate for energy and emissions.

We have taken a bottom-up approach of building up a set of “solutions wedges” to meet the projected demand and sectoral energy mix of citizens with developed standards of living.

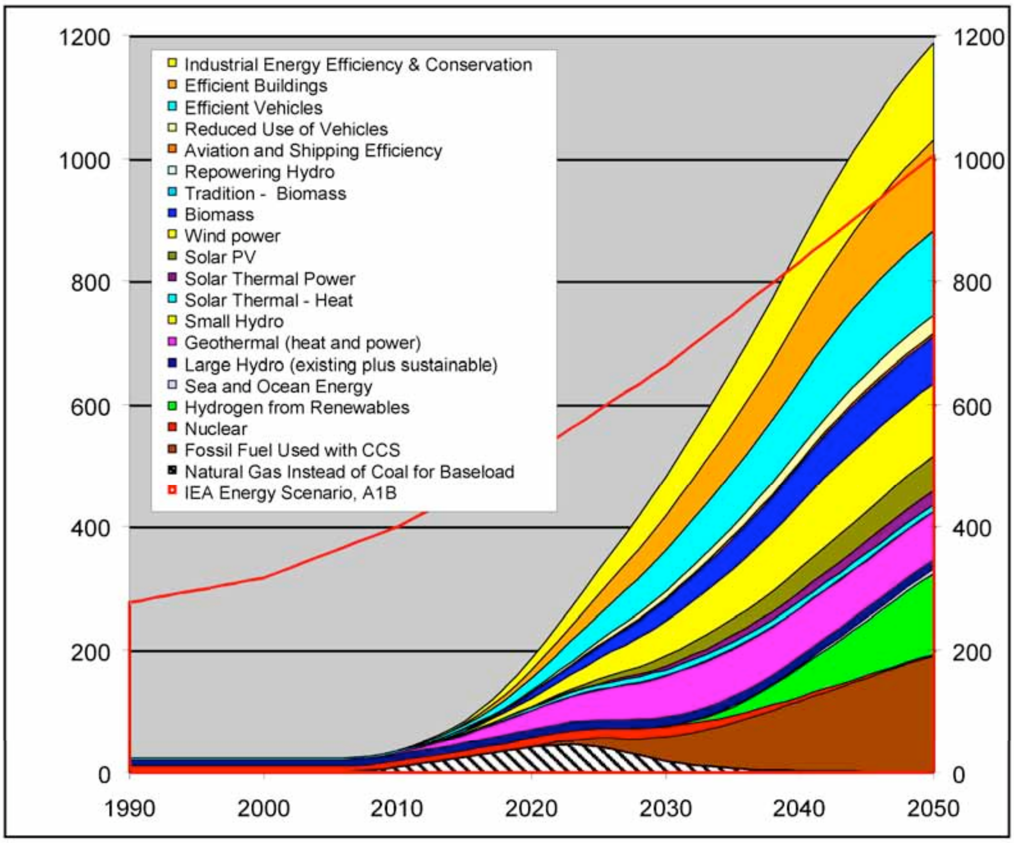


Figure 6. A representative scenario of the Climate Solutions Model depicting technology wedges capable of averting dangerous climate change. Each climate solution wedge grows over time and the sum of all wedges becomes significant as industrial capacity and deployment increase in scale. The top red line refers to the energy demand projection in the SRES A1B scenario. Note that since energy-efficiency technologies are shown alongside energy supply from low-emission sources, the results are expressed in final energy supplied or avoided (rather than primary energy production).

We have also considered a top-down approach to look at how such wedges displace fossil fuels (and emissions). To show this, the “built up” wedges are subtracted form the energy projection to provide a single overview of Avoided Energy Use, Zero Emissions energy creation, Low-Emission Energy Creation, and the Residual Energy Requirement assumed to be provided from an un-sequestered mix of fossil fuels.

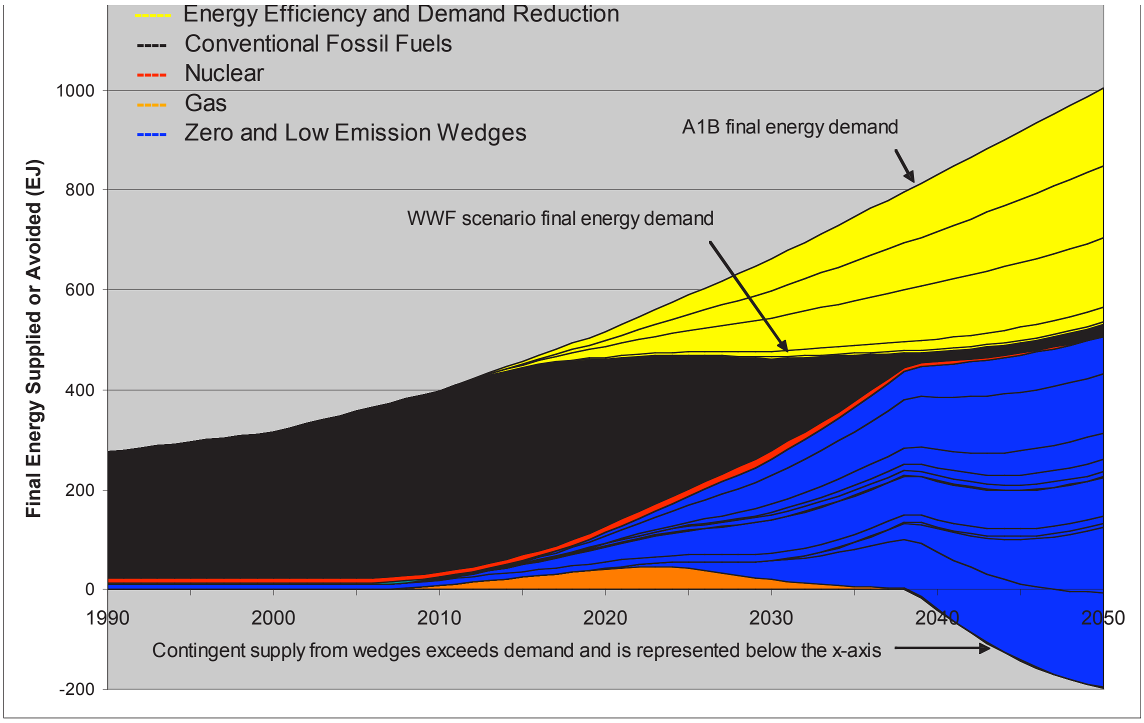


Figure 7. Output of the WWF Climate Solutions Model. Energy efficiency and demand reduction measures (drawing down from the top, in yellow) largely stabilize energy demand by about 2020, allowing a rising demand for the provision of energy services to be met from a more or less level supply of energy (notwithstanding regional variations). Meanwhile, zero- and low-emission energy sources are built up (from the bottom, in blue) until about 2040 when, assuming none fail significantly, fossil fuel use (in black) is reduced to a "persistent" residual level of 20EJ for applications which are hard to replace. Nuclear energy use (in red) is phased out. It may of course be that some wedges under-perform or fail entirely. The scenario provides spare capacity as a contingency, represented by energy supply shown reaching below the x-axis.

Calculating Carbon Emission Pathways

From the final energy mix, including the residual use of fossil fuels and emissions from CCS, it is then possible to calculate the resultant annual carbon emissions, illustrated below, against a carbon budget consistent with emission constraints for a 400ppm stabilization, for comparison.

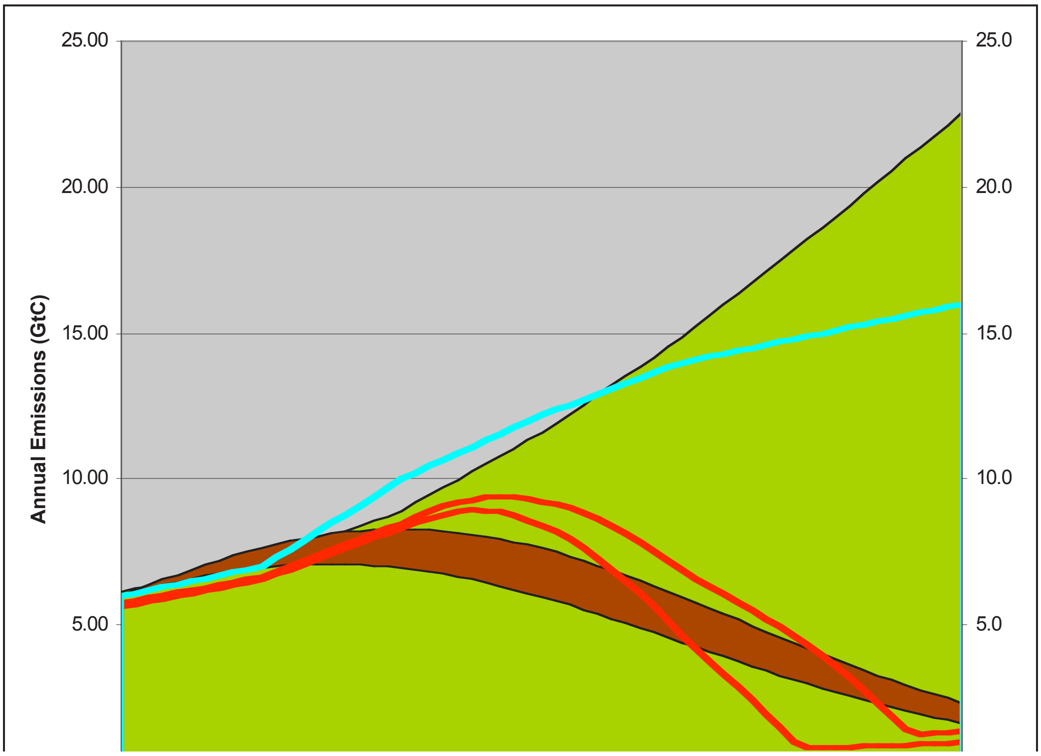


Figure 8. Emissions in the WWF Climate Solutions Model. The diagram shows the range of emissions (between red lines) in the scenario presented in this paper. The lower red limit of this range shows the technical potential of emissions reduction if all wedges are fully implemented, and the whole "fossil fuel with CCS" wedge (coloured brown in the figure) comprises plants burning gas (which has lower carbon intensity). Emissions follow the upper limit line if about 80% of the potential is achieved and the "fossil fuel with CCS" wedge is made up of (higher carbon intensity) coal plants. Placed against the nominal carbon budget curve (brown, from Figure 3), the overall emissions to 2050 of the lower trajectory falls within the total emissions indicated by the upper limit of the budget range (*i.e.,* allowable if deforestation is successfully brought under control). Any failure of efforts to halt deforestation (reducing the budget available for energy emissions to the lower line of the brown band) will reduce the chances of staying within the overall emissions budget, especially if failures or delays in the implementation of solution wedges drive the emissions curve towards the upper limit of the red band. These curves are set against a backdrop (green) of the emissions that would occur if the IPCC's A1B energy scenario were supplied with the *current* fossil fuel mix (*i.e.,* at about 0.02GtC/EJ). Also shown is the projected emissions curve for the A1B reference scenario which reaches annual emissions of 16GtC in 2050. The results of the modelling show that, although the point at which global emissions start to decline may not occur until 2015-2020, there is potential to drive deep cuts quickly once the industrial momentum behind transition is underway.

Expressing the Results

The results as presented are useful in providing a qualitative understanding of what may be a plausible trajectory for energy and emissions under various scenarios. However, a critical measure of success is whether, in the given period, the cumulative emissions have stayed below the budget associated with a 400ppm stabilization.

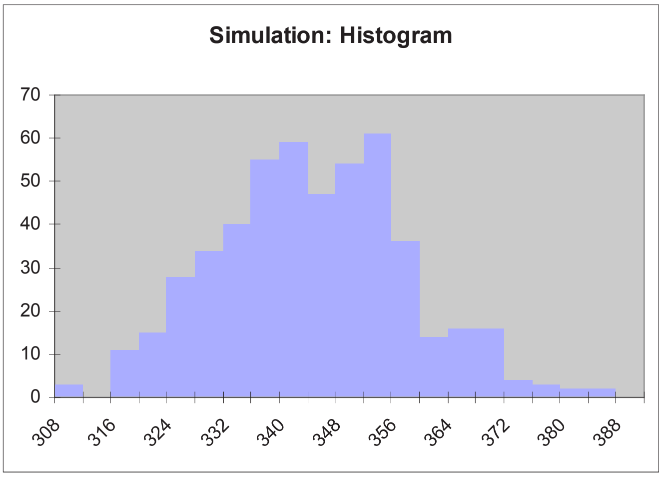


Figure 9. Sample histogram showing the amount of carbon (GtC) released in the period 1990-2050 on the x-axis. Each run of the model returns a new result and the y-axis shows the number of individual results in each possible outcome "bin". This overall shape is effectively the resulting probability distribution of an output (in this example centred about 348GtC), based on all of the input variable probabilities combined in the model and run under the Monte Carlo simulation.

The model allows the probability of achieving the emissions reduction task to be considered over a given period and the results for the period 1990-2050 are shown in the following diagram. These compare the cumulative emissions to 2050 in the scenario with the cumulative carbon emissions in the carbon budget.

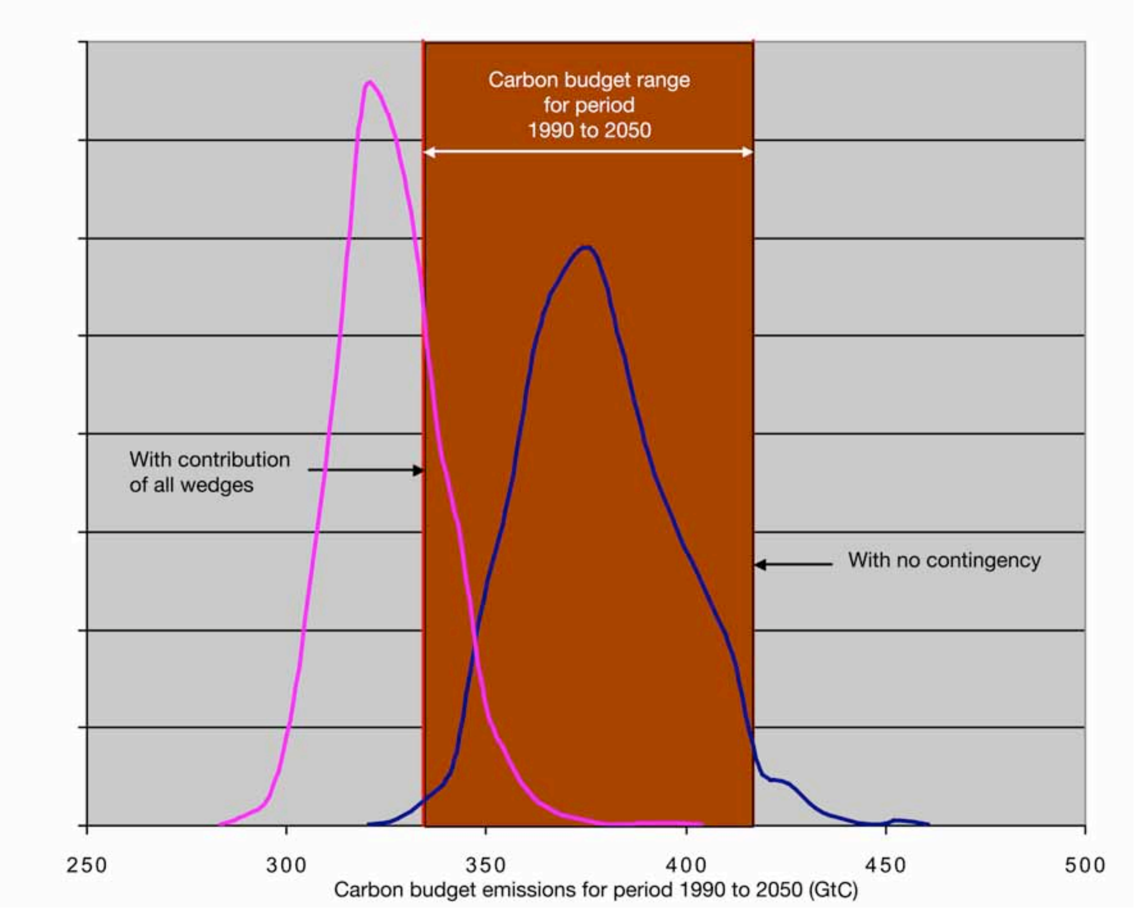


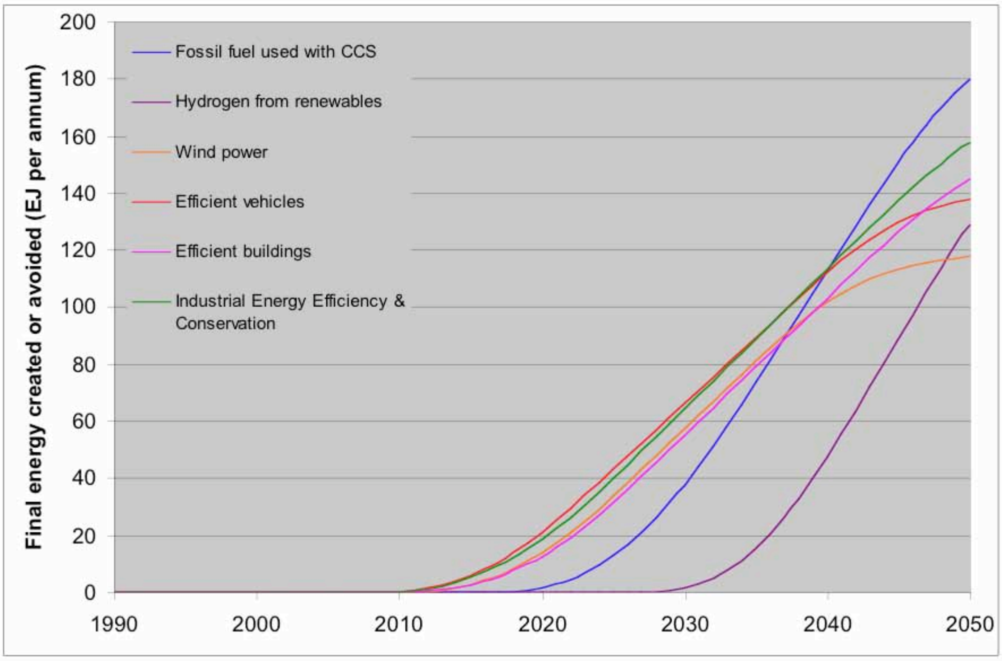
Figure 10.[SR3] **Probability distribution of carbon emissions staying within the 400GtC and 500GtC budgets for the period 1990-2050 in WWF's Climate Solutions scenario. Note that the total budget is spent over the period 1990 to 2200; however, this figure considers the component of the budget in the period to 2050. The 400GtC budget to 2200 corresponds to a budget of 340GtC to 2050, and the 500GtC budget to 2200 corresponds to a budget of 415GtC to 2050. The pink and blue lines represent the outputs of multiple runs of the Monte Carlo model (as number of hits). The blue and pink lines correspond to the upper and lower limits (respectively) of the red band in Figure 8.**

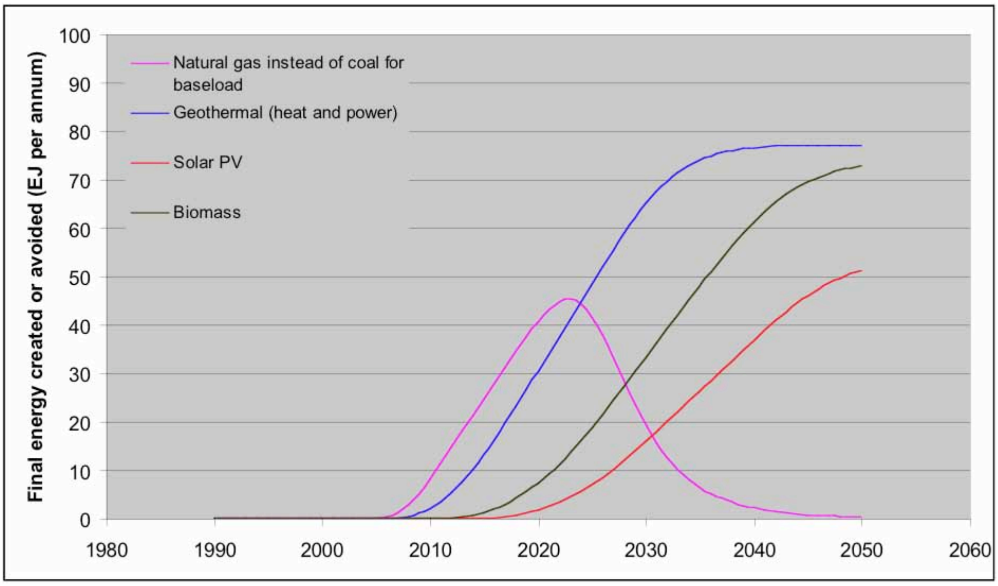
As stated earlier, the size of the carbon budget consistent with avoiding 2⑤C of warming will depend on the extent to which land clearance is addressed. Figure 10 shows a greater than 95% probability of staying within the carbon budget of 500GtC, but this budget assumes that emissions from land clearance are fully controlled. However, if land-use emissions are not properly addressed, the scenario shows the probability of staying within the lower 400GtC budget is considerably reduced.

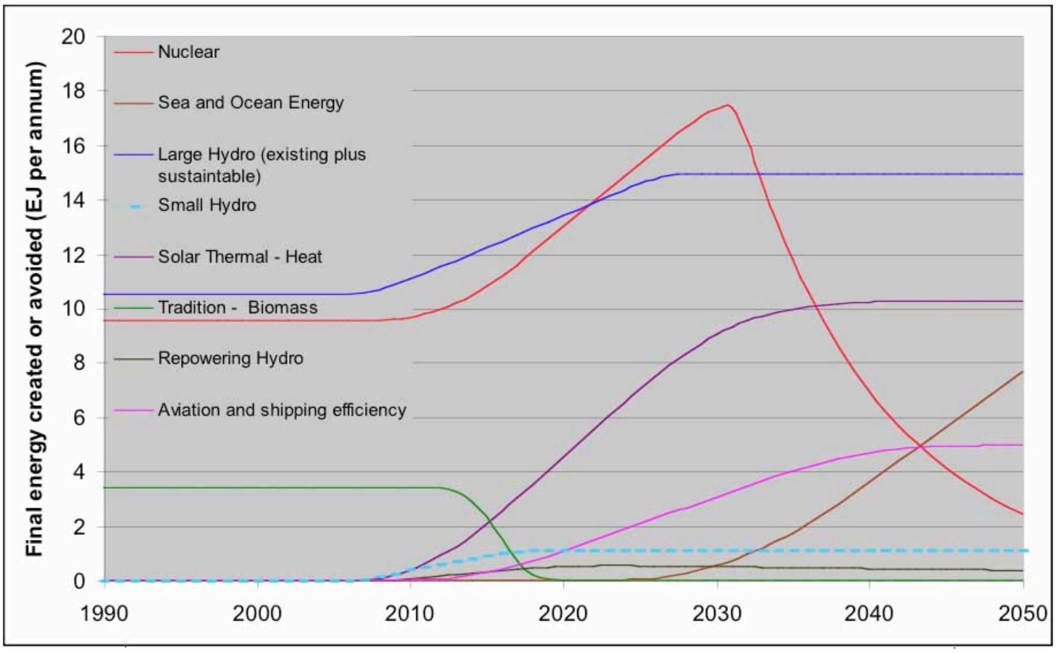
Topic Paper 20: Summary of Input Data

The WWF model has been designed to use ranges of data and plausible parameters to help define the Climate Solution Wedges out to 2050. In some cases this might include resources such as the amount of biomass available; in others it may be the fraction of energy use for a sector that can be reduced with efficiency measures; and so on. The growth rates of some wedges can be defined by plausible growth rates and others by technology turnover.

The outputs for final energy provision or avoidance over time of each of the Climate Solutions wedges used in the presented scenario are shown below.






Final energy created or avoided (EJ per annum)
20
18
16
14
12
10
8
6
4
2
0
1990
2000
2010
2020
2030
2040
2050
Nuclear
Sea and Ocean Energy
Large Hydro (existing plus sustaintable)
Small Hydro
Solar Thermal - Heat
Tradition - Biomass
Repowering Hydro
Aviation and shipping efficiency

Topic Paper 21: Persistent Use of Non-CCS Fossil Fuel

This study confirms the need to replace fossil-fuel energy as widely as possible, across all its applications – including electricity, heat, and transport.

It is important to recognize that the type, application, and location of use of the energy makes replacement more challenging and in some cases not even possible using existing commercial technologies.

For example, aviation fuels are not easily replaced by hydrogen or standard biofuels such as ethanol and biodiesel. There are solutions such as biokerosene which is a direct replacement[93], but this is not yet used in commercial volumes. Aviation currently uses 2% of all fossil fuels burnt or 12% of all transport fuels[94,95].

The Climate Solution Wedges used in the WWF model includes a wedge of fossil fuels with CCS, but there are likely to be other persistent uses of fossil fuels where alternatives and/or suitable carbon capture technologies may not be available. In order to allow for emissions from sources that may be difficult to completely replace, we have included a "persistent non-CCS fossil fuel use" provision in the model. This is an allocation of possible ongoing fossil fuel use in 2050 which could include a variety of sources including a proportion of aviation fuels, some aspects of industrial manufacturing, and other niche applications.

In this model, we use an estimation of 20EJ of oil as a persistent fossil fuel use; that is 5% of current energy supply, and 2% of the "plateau" final energy supply from 2025 onwards.

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[93] The first flight made using biofuels was in the 1980s using pure biokerosene in an EMBRAER turbo prop powered aircraft between the cities of São José dos Campos and Brasília using commercial product Prosene (patent PI 8007957) www.tecbio.com.br [accessed March 2007].

[94] http://www.atag.org [accessed March 2007].

[95] By way of comparison, in the OECD in 2003, emission levels from aviation consumption were of the order of 3-4% of energy emissions. If, in 2050, aviation represented a similar proportion of energy services use globally as for the OECD in 2003, the total energy demand from aviation would be of the order 30EJ per year globally. With efficiency improvements, such as increased load factor and reduced travel for business, the model incorporates a reduction factor range of 10-25%.

Technologies and sustainable energy resources known or available today are sufficient to meet the growing demand for energy, and protect the world from dangerous climatic change.

However, the first steps must be taken by governments currently in power. The future depends on them making critical decisions in the next five years.

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by:

- conserving the world's biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption.

WWF

for a living planet®

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