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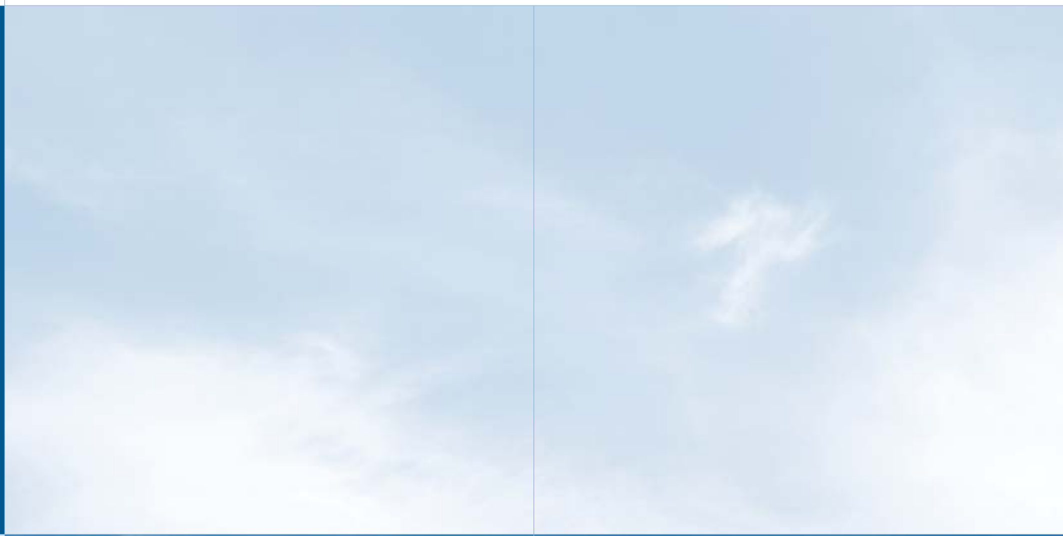
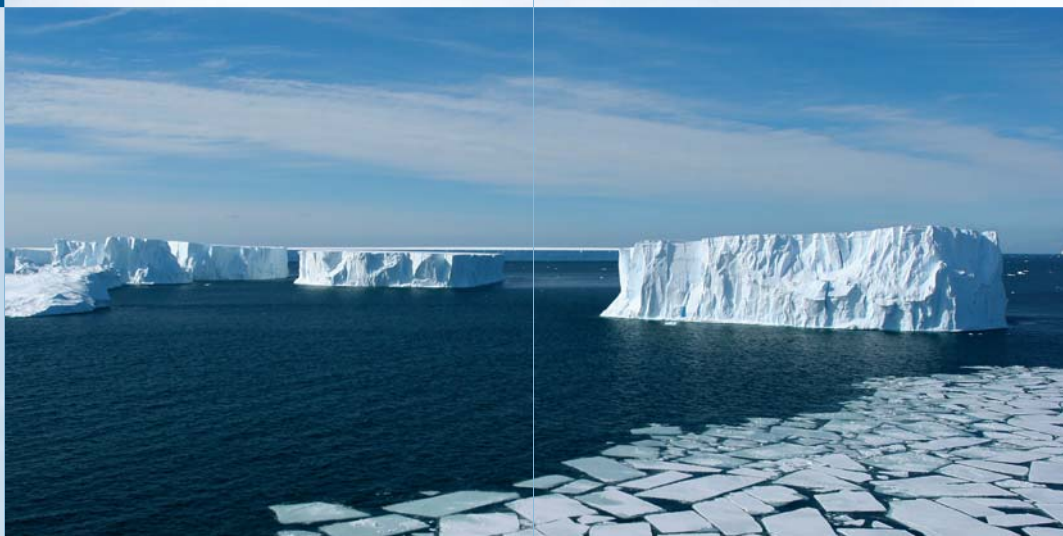
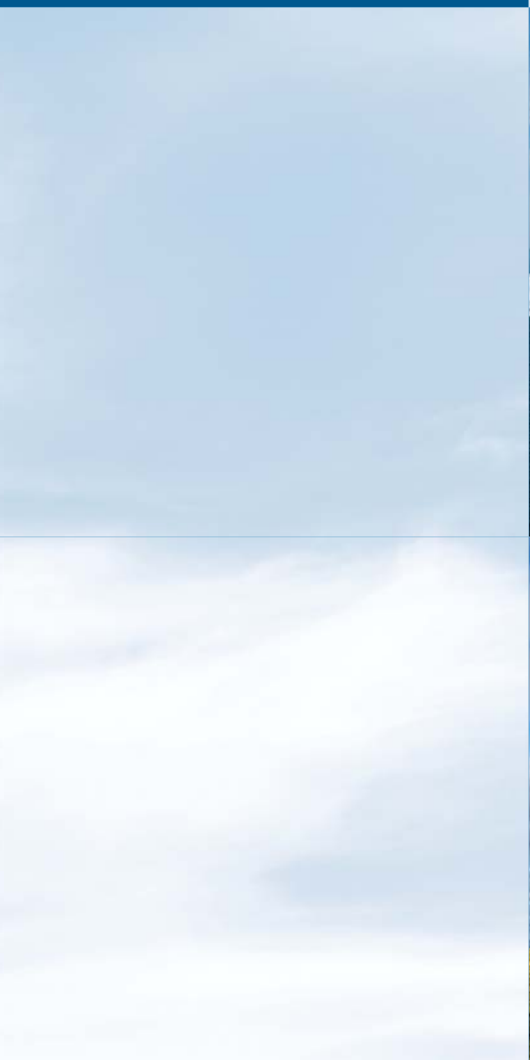
Energy and Climate Change

World Energy Council 2007

Promoting the sustainable supply and use of energy for the greatest benefit of all







Energy and Climate Change

Officers of the World Energy Council

Energy and Climate Change Study
World Energy Council 2007

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Foreword

Climate change, and more specifically the carbon emissions from energy production and use, is one of the more vexing problems facing society today. The Intergovernmental Panel on Climate Change (IPCC) has just completed its latest assessment on the state of the science of climate change, on the potential consequences related to this change, and on the mitigation steps that could be implemented beginning now, particularly in the energy sector. Few people now doubt that anthropogenic climate change is real or that steps must be taken to deal with it. The World Energy Council has long recognized this serious concern and that in its role as the world's leading international energy organization, it can address the concerns of how to provide adequate energy for human well-being while sustaining our overall quality of life. It has now performed and published 15 reports and working papers on this subject. This report examines what has worked and what is likely to work in the future in this regard and provides policymakers with a practical roadmap to a low-carbon future and the steps needed to achieve it. I am sure that this report will be a major contribution to policy actions to deal with the real dilemma between energy for human development and induced climate change and I am pleased to commend it to you.

In addition to thanking all the Study Group members for the enthusiasm and expertise they brought to this work, we all owe sincere thanks to Kurt Yeager as Study Chair and Malcolm Keay as Director for the high quality of the report and its findings. I am also most grateful to the Member Committees from India, Japan and the United States for their generous support of this work.

C.P. Jain
Chairman, WEC Studies Committee
June 2007

Prologue

Throughout history, mankind's ability to live in harmony with its environment has been dependent upon the availability of energy. In this regard, civilisations can be seen as thermodynamic systems that grow in proportion to their energy access and are subject to decline when they become unable to sustain productivity and quality of life from their available energy. Today the world is an unprecedented period of growth in its human population, made possible by a technology revolution over the past 200 years that has dramatically increased mankind's ability to harness energy from nature. By 2050, this revolution, based primarily on fossil fuels, will have enabled a ten-fold increase in global population since 1800.

This dramatic growth has, however, also left the world precariously perched on an increasingly unstable global energy access structure which is producing diminishing returns at ever greater economic, environmental and security costs. Just as our ancestors had to progress beyond a hunter/gatherer, biomass-based energy system in order to meet their relatively elementary needs, so must we also transform our energy system to keep pace with the much greater and more complex demands of today's world. The overarching global energy goal must therefore be to provide all people with sufficient sustainable energy access to achieve and maintain their well-being in a world approaching 10 billion inhabitants.

The WEC's 3A's (Accessibility, Availability and Acceptability) are very effective criteria for defining and achieving a sustainable energy future because they reflect the critical issues which global sustainability must resolve – i.e., population, poverty and pollution. In effect, any energy strategy, policy or measure which fails to meet these 3A's will not be sustainable, and may actually prove to be counterproductive to the very goals it seeks. As this report will show, meeting the 3A's is proving to be a significant challenge for climate-related policies, strategies and measures worldwide. None the less, it will also be shown that a great deal has been learned over the past decade in this regard. As a result, a technology and policy framework for global collaboration and sustainable progress on greenhouse gas emissions is beginning to emerge.

The 20th Century was characterized by the international success of a development model based on the mass production of relatively low-cost, short lifetime products. This model has enabled rapid economic expansion but has also required more and more resources from the environment, including energy. The real challenge this century is to achieve a global development model where producers of less resource intensive products and services will prosper as consumers learn to embrace and use these sustainable products and services. The issue of climate change may also ultimately serve as a unique catalyst for broadly achieving this sustainable production and consumption model.

Kurt Yeager
Study Chairman

Executive Summary

The world needs to develop a coherent and practical approach to climate change. The Intergovernmental Panel on Climate Change has recently confirmed that the evidence for global warming is unequivocal; meanwhile, an effort is under way to develop a successor to the Kyoto Protocol and provide a roadmap towards the lower carbon world of the future.

Getting there will not be easy and it will depend on whether the policies and measures in place are viable and effective in reducing emissions, particularly from the energy sector, which accounts for around two thirds of total greenhouse emissions. The World Energy Council (WEC) has therefore undertaken a Study of Energy and Climate Change, drawing on the collective experience and resources of energy professionals worldwide. It has looked in detail at the impact of existing climate change measures, and how effective they have been in promoting sustainable development, using the criteria of the "3A's" – accessibility (to affordable energy); acceptability (of the energy sources used, particularly in environmental terms); and availability (how secure and reliable are those sources?).

The Study looks at what drives greenhouse emissions from the energy sector; what policies have been introduced to restrain those emissions; and how effective those policies have been. It concludes that, so far, the response from governments and others has not been up to the challenge; policies have been too narrowly focused and short-term, failing to provide the right signals for cleaner and more sustainable investment.

In particular, policies have often ignored the human and social needs which energy fulfils, reducing their credibility and viability, and have failed to respond to the complexity of energy systems, so that the measures have often not had their intended effect.

In developing a successor regime to Kyoto, policy makers will have to learn from these lessons and assess the effectiveness of the measures they introduce much more effectively than in the past. They will need to draw up a global regime which encourages a coherent, comprehensive and sustainable approach, focused on long-term, steady reductions in the carbon intensity of the energy system, while ensuring that those systems can still perform the vital task of powering human development worldwide.

There is no single policy or measure which can provide the whole solution, or even the main part of the solution. All the measures available have their advantages and drawbacks, as detailed in the WEC analysis. Strong efforts will be needed in all countries, based on a portfolio of measures appropriate to the country concerned, so no single prescription can be given. However, some central elements emerge from the analysis which will be important on a global basis:

- effective, consistent and predictable government policies will be needed to set a stable framework for long-term investment in cleaner technologies.
- reducing the carbon intensity of power generation (for which a range of alternatives already exist, such as nuclear and renewables; the range may well be significantly boosted in the medium term when carbon capture and storage becomes viable).
- restraining the growth in transport emissions in the short-term; stabilising them in the medium-term; and reducing them in the long-term. In the near term, a number of options are available for reducing the carbon intensity of transport, though a steep change is unlikely to take place until viable carbon free alternatives are developed and deployed.
- technology development, deployment and transfer need to be accelerated. Technologies are available already or under development that could make an enormous difference to future emissions trajectories. They need to be made accessible on a worldwide basis, or we risk getting locked into unnecessarily high carbon pathways.

The sooner society acts against climate change by stabilising and reducing CO_2 emissions, the better. Action is needed now on a global basis to take forward such measures and WEC members are ready to take their part in this process. They firmly believe that the energy sector can make a positive contribution to solving the problem.

Introduction

Climate change is recognised as one of the key challenges facing the world in the 21st Century. It engages the energy sector particularly closely because energy is central both to the problem and to its resolution. Energy-related emissions (including energy used in transportation) account for over two thirds of anthropogenic greenhouse gas (ghg) emissions[i] and contribute well over 80% of worldwide emissions of CO_2, the main ghg, as a direct result of fossil fuel combustion. Energy also accounts for around one third of the global emissions of methane, the second largest source of ghgs, in fugitive emissions, mainly from natural gas production; transportation; and coal production. In addition, energy contributes a small share of global emissions of N_2O, the third largest source, principally from biomass burning.

But energy is also a key driver of social and economic development. A world without energy is inconceivable and would be incapable of development, sustainable or otherwise. Energy systems are therefore a necessity, and to be compatible with sustainable development they should be designed to meet the WEC criteria, encapsulated in the three "3A's" – acceptability; availability; and accessibility (see Box). Unbalanced energy policies undermine sustainable development, whether the problem is that they give too little emphasis to the environment, or that they give too much emphasis to this issue, so compromising social and economic development.

Extensive experience has been gained of policies and measures to combat climate change, especially since the late 1980s, when the issue first started to be recognised at global level. This led, in 1990, to the First Assessment Report of the Intergovernmental Panel on Climate Change, and in 1992 to the adoption of the United Nations Framework Convention on Climate Change. The Kyoto Protocol of 1997 was another major step, setting emissions reduction targets for most developed countries. However, it is not the sole motivating force for climate change measures. Many countries have taken measures independent of any Kyoto obligations – some have not ratified the Protocol; some have no specific targets under the Protocol; some wish to go beyond those targets. Overall, it has been estimated by the International Energy Agency (IEA) that since 1990, over 1,000 policies have been introduced to combat climate change, whether under the umbrella of the Protocol or otherwise.

It is clear that significant action is being taken. What is less clear is how effective this action has been – whether the policies and measures are meeting all their goals, and whether they are meeting them in a balanced way; what their cost has been and what benefits have resulted. This is the focus of the present Study. The Study does not try to cover the whole field of climate change; its terms of Reference (Appendix 1) deliberately restrict its scope to those matters falling within the expertise of the World Energy Council and its members. Thus the study will not attempt to judge the underlying climate science. Its concern is only with energy-related emissions (including energy used in transport) and it does not attempt to assess response measures in areas outside the energy sector, such as agriculture and forestry. Nor is it concerned to recommend particular ghg targets or regimes – the starting point is simply that it is desirable to reduce ghg emissions from energy production and use.

The Study aims to look at three main areas: the facts as regards energy-related emissions; the policies and measures introduced and planned in the energy sector; and the effectiveness of these measures against the criteria of the 3A's. Building on this analysis, it makes recommendations about the course of future policies – whatever the future of specific climate regimes, we can be sure that concern about this issue will continue and that policies to meet the challenge will be introduced and developed.

Recent years have, of course, seen many studies on climate change, some of which are discussed below. However, the World Energy Council (WEC) believes that this new study can make a distinctive contribution to the debate for three main reasons:

- **first:** it is not a theoretical academic study, but a practical document, looking at what actually works.
- **second:** it brings to bear a unique expertise – the knowledge and experience of energy professionals from all parts of the world.
- **third:** it has a distinctive perspective, looking in an integrated way at all aspects of sustainable development, not just the environment in isolation.

The study is in four parts:

- **Part 1** looks at trends in ghg emissions in different regions across the world, and analyses the major drivers.
- **Part 2** provides an overview of the policies, strategies and measures being adopted and planned worldwide to combat climate change. It compares the different approaches adopted in different regions and the reasons for differences in emphasis.
- **Part 3** assesses the measures in terms of their expected impacts on the key WEC objectives of energy accessibility, availability and acceptability.
- **Part 4** draws broad conclusions as to the effectiveness and focus of existing measures and makes recommendations about the future direction of climate change strategies.

The Study was prepared by a Study Group under the Chairmanship of Kurt Yeager, President Emeritus of the Electrical Power Research Institute (EPRI). Membership of the Study Group is detailed in Appendix 3. The Director of the Study was Malcolm Keay, Senior Research Fellow at the Oxford Institute of Energy Studies. The Study also includes eight Appendices containing national assessments of the policies adopted in particular countries. These were prepared by individual Study Group members and can be downloaded from the WEC website www.worldenergy.org.

The Three Energy Goals:
Accessibility, Availability, Acceptability.

In 2000, the World Energy Council published a Statement "Energy for Tomorrow's World – Acting Now" which looked at the challenges the world faced in meeting its energy needs in the 21st Century. The following description of the three WEC energy goals is extracted from that document.

WEC considers economic growth, together with national and international institutional reforms, essential to energy accessibility for everyone, including the poorest two billion people in the world. When only some individuals or regions of the world benefit from energy development and others are left behind, the ensuing political and social instability can pose a significant threat to world peace and, in turn, to energy availability through supply disruptions. In addition to the impact of accessibility on energy availability, it is also linked closely to energy acceptability. Investment partnerships to achieve energy accessibility and availability could also address social and environmental issues.

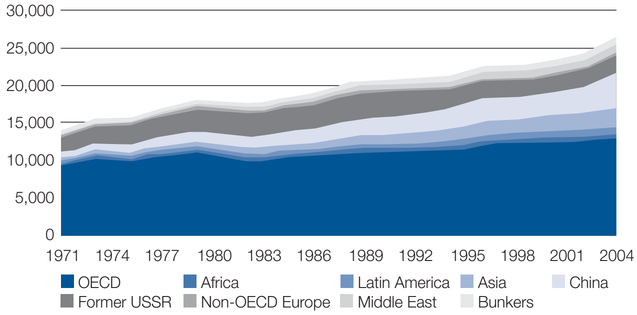
- ***Accessibility*** is the provision of reliable and affordable modern energy services for which a payment is made. It depends on policies specifically targeted to meeting the needs of the poor, in the context of increasing reliance on market signals. The best way to ensure that a growing number of people will be able to afford commercial energy in line with their needs is to accelerate economic growth and pursue more equitable income distribution. This requires increasing reliance on the market, while addressing cases of market "failure" with special policies. An energy tariff reflecting all costs, including external costs such as emissions or waste management, is necessary to secure adequate investment and encourage energy efficiency and environmentally preferred technologies, but such a tariff would be unaffordable for many people. At the same time, a tariff subsidised down to a socially affordable price would not attract sufficient investment, consequently, in the long run, working against the interests of those who are in need of commercial energy infrastructure. There may be a need, in some cases, to subsidise energy technology and delivery for a period of time without creating price distortions, or at least by keeping them to a minimum. Variable, maintenance and extension costs need to be reflected in the price paid for energy, but sunk costs might be handled differently in some circumstances.

- ***Availability*** covers both quality and reliability of delivered energy. The continuity of energy supply, particularly electricity, is essential in the 21st Century. While short-term interruptible supply may be feasible in certain circumstances, as long as the conditions are known and understood by customers, unexpected power cuts bear a high cost for society that cannot be ignored. The world's growing reliance on information technologies makes reliability even more critical… Energy availability requires a diversified energy portfolio consistent with particular national circumstances together with the means to harness potential new energy sources. Most WEC Member Committees agree that all energy resources will be needed over the next fifty years and there is no case for the arbitrary exclusion of any source of energy.

- ***Acceptability*** addresses environmental goals and public attitudes. Local pollution is a cause of harm to billions of people, especially in developing countries. Global climate change has become an important concern. Mindful of these two facts, developing countries are concerned about both the potential impact of climate change-related response measures on their economies, and the rising levels of consumer-based household emissions which create local (urban) and regional pollution (e.g. such as acid rain's impact on crops and forests). The energy sector is one area in which new and readily available technologies have already reduced emissions and hold prospects for future improvement. Of course, environmentally friendly technologies have to be developed, diffused, maintained and expanded in all parts of the world. Hence, there is a need to foster adequate local capacity to ensure that the technologies can be used and maintained by local people. Energy resources must be produced and used in a manner that protects and preserves the local and global environment now and in the future.

Part 1: Greenhouse Gas Emissions Trends

Figure 1-1
Evolution from 1971 to 2004 of world CO_2 emissions by region (Mt of CO_2)



Note: "Bunkers" refers to oil used for marine transportation, which cannot readily be allocated to particular regions.
Source: Key world energy statistics 2006, IEA Paris.

Steady rise in energy-related CO_2 emissions worldwide over recent decades.

Introduction

This part of the Study looks at the facts on energy-related greenhouse gas emissions:

- Section **1.1** deals with trends in energy-related CO_2 emissions and the differences between different regions and countries.
- Section **1.2** looks at sectoral trends in emissions and the significance of electricity generation.
- Section **1.3** analyses the trends, identifying the main emissions drivers.
- Section **1.4** looks at non CO_2 greenhouse gases associated with the energy cycle.

1.1 CO_2 emissions since 1970: Overall trends and country differences

The broad picture is well known: there has been a steady rise in energy-related CO_2 emissions worldwide over recent decades – by over 75% since 1971, and 20% since 1990, a rate of a little under 2% a year.

However, this broad picture conceals many striking differences between different parts of the world and different country groupings. These differences, not all visible in Figure 1 above, are discussed in more detail below. Table 1 below summarises emissions data for key countries, regions and country groupings, along with some key indicators.

OECD Europe

(i.e. Western and Central Europe, except those formerly centrally planned economies which have not yet joined the EU).

Key trend: slow rise in emissions from a relatively high base.

Note on Data Sources

Concern about ghg emissions is a relatively new phenomenon, and they have not traditionally formed part of a company's or country's energy statistical reporting base; indeed, in many instances this remains the case today. Even where emissions are reported, it is often on the basis of fairly broad assumptions; the accuracy is generally less than with physical quantities such as tonnes of coal or barrels of oil. Nonetheless, in relative terms, measurement of energy-related ghg emissions is good. Because the underlying physical energy quantities are themselves regularly and accurately measured, energy-related emissions, which can be derived from the physical energy quantities, are generally known to a higher level of accuracy than other sorts of ghg emissions, such as those associated with agriculture or forestry.

There are various sources of data about energy-related ghg emissions, each of which have their advantages and drawbacks. The sources include:

OECD Europe

Key trend: slow rise in emissions from a relatively high base.

- ***National energy and emissions data:*** these obviously tend to provide the most detailed information and the most analysis. However, they are not always readily available and available data may not always be on a comparable basis.
- ***UNFCCC:*** Article 12 of the UNFCCC requires Parties to report on the steps they are taking to implement the Convention. Various sorts of reports have been developed, differentiated as between the different classes of Party. For Annex 1 countries (developed countries), there is an obligation, among other things, to make annual submissions on ghg emissions. Non-Annex 1 countries have to make periodic reports, which generally include information on emissions. The advantage of the UNFCCC data is that they are collected on a consistent basis across a wide range of countries. The disadvantage (from the point of view of this Study) is that they relate to the UNFCCC's provisions – i.e. they generally go back only to 1990, the start date for the obligations; are mainly concerned with overall emissions (some of which of course come from outside the energy sector); and do not deal with wider aspects of the energy sector.
- ***International Energy Agency:*** Since 1997, the IEA has published annually a volume entitled "*CO_2 Emissions from Fuel Combustion*". This covers the period since 1971 (though with more detailed data for the period post 1990) and includes both IEA members and others – some 130 individual countries in all. Its figures are reconciled with those of the UNFCCC and include analysis and breakdown of interest to energy analysts. Furthermore, its energy figures are consistent with other IEA energy data, so making consistent comparisons possible.
- ***Carbon Dioxide Information Analysis Center:*** The CDIAC, part of the Oak Ridge National Laboratory, provides data on carbon dioxide for the US Government, including global, regional and national CO_2 emissions from fossil fuel burning. They use national energy data to estimate CO_2 emissions as far back as 1751, making this source particularly useful for long-term trends. However, the data are not produced specifically for UNFCCC purposes and do not always correspond with their definitions, or with IEA energy data.

All these sources have been used for the present study, but the main source has been the IEA energy data, because the concern of the Study is with the interactions between energy production and consumption and ghg emissions, and the impact of major energy developments and policy decisions. In general, the IEA provides the most comprehensive and consistent data base for this analysis.

This region has shown only a relatively small increase in emissions since 1971. Total emissions of CO_2 in 1971 amounted to 3.7 Gigatonnes (Gt) of CO_2; in 2004 they had risen to 4.1Gt, an increase of about 12%. The increase since 1990 has been a little over 4%. This compares with world figures of a 90% increase since 1971 and 28% since 1990, so Europe's share of world emissions has fallen considerably (from 26% to 16% over the period).

On the other hand, Europe's emissions per head remain high in international terms – nearly 8 tonnes

North America and Pacific OECD

Key trend: a steady rise in emissions and a high level of emissions per head.

of CO_2 per capita against a world average of about 4t. But emissions intensity is relatively low (0.35 kg CO_2 per US dollar of Gross Domestic Product (GDP) on a purchasing power parity (PPP) basis, well below the world average of 0.51) and has improved more quickly. Intensity has nearly halved since 1971 and has gone down over 20% since 1990.

In broad terms these trends are easy to explain. Europe has seen relatively slow economic growth by global standards, and a relative decline of the industrial sector. It has also seen significant changes in its fuel mix since 1970. There was a major shift out of oil in the power generation and industrial sectors after the price shocks of the 1970s, and a growth in the share of natural gas and nuclear power. Coal use in the residential and industrial sectors has also declined. In addition, the region experiences relatively high fuel prices and taxes and since 1990 has been active in developing climate change policies. The overall effect of these trends has been not only to improve energy intensity (as noted above), but also to lower the carbon intensity of energy (CO_2 emissions/terajoule). This has declined by 29% since 1971 and by 9% since 1990 (as compared with figures for the world as a whole of 6% and less than 1% respectively).

Despite these broad trends, which apply across the region, there remain significant differences between countries, reflecting such factors as their different stages of economic development and different industrial structures. For instance, in Germany, CO_2 emissions have declined by 15% since 1971; in Spain they have increased by over 150%.

Many countries have also seen changes in the trend of emissions. For instance in France, emissions increased from 1970 to 1980, then declined substantially during the 1980s as a result of the French nuclear programme, only to start rising gradually again thereafter. The United Kingdom also experienced a fall in emissions during the 1970s and 1980s as a result of declines in coal consumption and the relative importance of energy intensive heavy industry.

North America and Pacific OECD

(Canada, Mexico and the US; Japan and Korea; Australia and New Zealand).

Key trend: a steady rise in emissions and a high level of emissions per head.

The overall increase in CO_2 emissions since 1971 in this group of countries has been around 50%. Even the period since 1990 has seen significant increases of about 20%. The region also has high emissions per capita (around 14 tonnes). Emissions intensity across the region as a whole (about 0.5kg/$) is in line with world averages, though in some countries it is much lower (e.g. Japan – 0.25 kg CO_2 per $). The US has very high levels of per capita emissions but the emissions intensity of its economy is around the world average, as shown in Table 1.

The grouping really breaks down into various sub-groups.

- Three countries (Canada, Australia and the US) are very large geographically, with corresponding high requirements of energy for transport. All are also significant energy producers, and Australia and the US in particular are major coal producers and consumers of coal.

Economies in transition

Key trend: a rapid fall in emissions after the fall of the Berlin Wall, though from a very high initial base.

These countries have relatively low energy prices and tend to have high energy needs for heating and cooling as well as transport. The US is in many ways a region in itself – accounting for a significant proportion of global energy use and global emissions, stemming from its significant role in the global economy. Data for the US are shown separately in Table 1.

- Mexico is also a relatively large country with significant energy resources, though at a somewhat lower level of development.
- Japan and Korea are much smaller countries, lack significant energy resources, and have generally high energy prices. However, both have seen very rapid periods of growth (Japan in the period 1970-1990; Korea more recently) particularly in their industrial production, and very fast increases in car use.
- New Zealand is a much smaller economy, though it has indigenous resources of hydro power, natural gas (now declining) and some coal. Its emissions have, in fact, been rising rapidly, as in the rest of the region (nearly 50% since 1990) but they do not have a major impact on the overall figures. Unusually, New Zealand is a country where non-energy related emissions (from its large agricultural sector) may be higher than those from energy (which are relatively low because of the extensive use of hydro power).

Economies in transition

(i.e. the formerly centrally planned economies of Eastern Europe and Asia, excluding those now in the OECD).

Key trend: a rapid fall in emissions after the fall of the Berlin Wall, though from a very high initial base.

CO_2 emissions rose by 66% between 1971 and 1990, only to fall by 31% between then and 2004. Nonetheless emissions per head remain relatively high by international standards, at about 8 tonnes, while emissions per unit of GDP are very high indeed at 1.2 kg CO_2/$ – over twice the world average.

These trends are due to a number of factors: the harsh climate and huge distances in many countries of the former Soviet Union and the availability of indigenous energy resources, particularly Russian gas. But the main factor (shown by the sharp trend change in 1990) is political: the influence of central planning, with its emphasis on heavy industrial production, poor price signals and inefficient allocation of resources. Unlike some of the other regions discussed, there is a broadly similar pattern across the entire region, at least for those countries for which separate figures are available.

Developing countries

Key trend: rapid rise, especially in East Asia, but significant national and regional differences. Still very low emissions per capita.

Very different trends occurred in different regions within this group of countries, which are looked at separately below.

Asia: has seen rapid growth in emissions accompanying its generally rapid economic growth. Emissions nearly tripled between 1970 and 1990, and doubled again between 1990 and 2004. China is clearly a key driver and its emissions have risen broadly in line with this trend (though it should be noted that there are some difficulties with Chinese energy data,

Developing countries

Key trend: rapid rise especially in East Asia, but significant national and regional differences. Still very low emissions per capita.

for instance on coal production and consumption, which apparently fell in the late 1990s only to rise sharply in the early 21st Century. Since China's coal consumption is the largest such aggregate energy quantity in the world – larger for instance than US oil consumption – it has a significant impact on the world emissions total). It is also notable that since 2000 energy use in China has been increasing much more rapidly than the growth in GDP. For example, China is currently installing the equivalent of a 1,000 MW coal-fired power plant each week and generating capacity comparable to the entire UK electricity system each year.

India is also a key economy, both because of its large population and its fast rate of growth. It is still experiencing a shift from non-commercial to commercial energy – many rural consumers lack access to electricity, though the Government has an ambitious electrification programme. Increasing access to commercial energy and electricity, with the many social and development benefits that entails, will undoubtedly be a major welfare gain. However, it is also likely to be associated with rapid increases in energy use.

Factors common to most of the region include: rapid economic growth associated with a significant increase in industrial production and industry's share of GDP; heavy dependence on coal in the major economies in the region, China and India, for both power generation and industrial production; relatively low use of natural gas and nuclear; and a rapid growth in energy-consuming modes of personal transport in some countries.

There are of course a number of differences in so large a region, for instance the DPR of Korea has shown a rapid fall in emissions since 1990, but the differences are less pronounced than in many other regions, and most countries have followed the broad trend described above.

Africa: By contrast, Africa has shown a range of different experiences, with many countries experiencing economic problems and slow growth, and some being affected by conflict. There is also a wide variation in industrial and energy structures. It is therefore difficult to provide any clear generalisations except that, by and large, emissions per head are very low, though they have been increasing fast. Emissions roughly doubled between 1971 and 1990, and have grown a further 50% since then. However, this is not true of all countries. For instance emissions in Zambia, Zimbabwe and the DR Congo have fallen since 1990, while emissions in Ghana, Ethiopia and Togo have risen rapidly – more than doubling in each case. Emissions per head are very low overall (0.9t compared with the world average of around 4t and the OECD's 11t). But even on this measure there are large differences. South Africa, for instance, with its healthy economy and large coal reserves, has a figure of over 7t, in line with many OECD countries.

The low emissions reflect low energy use in the region arising from the low level of economic development in most countries, lack of industrialisation and low living standards. There is also a high use of non-commercial energy forms (see below) which are generally omitted from traditional energy and emissions data.

Middle East: The general picture across the region is of rapidly rising CO_2 emissions – they quadrupled between 1971 and 1990 and have doubled again

Table 1-1
Development of global CO_2 emissions per region

Region	% Increase in CO_2 emissions 1971-2004	Emissions per head 2004 (tonnes CO_2/capita)	Emissions intensity (kgCO_2/US$GDP using PPPs)
Europe	12	7.7	0.35
Other OECD	55	13.7	0.49
US	35	19.7	0.54
EITs	15	8.1	1.16
Asia	481	1.2	0.37
India	416	1.0	0.35
China	489	2.9	0.61
Africa	205	0.9	0.41
Latin America	147	2.0	0.29
Middle East	836	6.5	0.92
World	88	4.2	0.51

Source: CO_2 emissions from Fossil Fuel Combustion 2006. IEA Paris.

since then. However, there are a few exceptions, some due to war or conflict (e.g. in Kuwait, emissions fell substantially in 1990 only to more than double again since then; Lebanon also experienced a low point in emissions in 1990). Emissions in some countries have been directly influenced by the level of oil production.

Emissions intensity is also high and the region shows relatively high (in some cases extremely high) emissions per head. These figures are linked closely to the levels of gas and oil production and consumption. Thus there are large differences in emissions per head between those countries with significant hydrocarbons production but a low population (e.g. Kuwait or UAE at 25t/head or over) and those with larger populations but small or no oil and gas production (e.g. Syria and Jordan at around 2.5-3t/head).

Latin America: In many ways this region comes somewhere between the OECD and Asian developing countries. The general picture is of steady, rather than rapid, emissions growth – a little over 60% between 1971 and 1990, a further 50% between 1990 and 2004. Most countries have seen a similar overall pattern across time, but with many short-term variations, for instance Argentina's emissions fell in the opening years of the 21st Century due to its economic problems. Cuba has also seen a fall in emissions since 1990.

Emissions per head are fairly low in international terms at around 2t, though some oil-producing Caribbean countries have very high levels of emissions. As well as the relatively slow pace of economic development and low heating needs in buildings, this reflects the region's significant resources of hydro power. The carbon intensity of energy, particularly of electricity, is low. For instance, Latin America emits about 200g of CO_2 per kWh, which is the lowest of any region in the world – much lower, for instance, than the OECD (450g) or Asia (730g). Even the Former Soviet Union, which, with its significant use of gas and nuclear, is the next lowest region in terms of the carbon intensity of generation, produces about two-thirds more (340g) per kWh. A number of countries in the region (e.g. Brazil) have also developed active strategies for combating climate change and the use of alternative fuels, such as ethanol produced from biomass.

Buildings – 35% of emissions

Steady rise in energy use and CO_2 emissions with population growth.

1.2 CO_2 emissions: Sectoral emissions trends

As with the regional trends discussed above, the rise in overall emissions conceals large variations in the trends in sectoral emissions worldwide. However, comparative data are more difficult to obtain in this area, and it is not always easy to be sure that the figures are calculated on the same basis: there are differences of definition and classification and some data are estimated rather than collected directly. There are also differences in the treatment of electricity and heat from central heat stations (sometimes treated as a sector in itself, but more usually allocated to final use sectors such as buildings and industry). In addition a full breakdown of the data by individual sectors is not generally available on the same basis from different sources The IEA in its aggregate data, for instance, shows final industry and transport use but includes the (very large) remainder in one classification under “other sectors”. Other sources, such as the IPCC tend to give a fuller breakdown but be less up to date. The discussion below is therefore more qualitative than in the previous section, though the broad picture should be robust; it draws on a variety of sources (principally the IEA study referenced above) and individual analyses to produce an overview of the global sectoral breakdown.

Buildings – 35% of emissions

The picture here is of a generally steady rise in energy use and CO_2 emissions with population growth, the rise of the service sector and increasing prosperity, offset to some extent by increasing efficiency. In developed countries, for instance, emissions have risen at less than 1% per year since 1971 – somewhat faster in the commercial sector, somewhat slower in the residential sector. In the economies in transition, (for the reasons given above) buildings use increased rapidly between 1971 and 1990, and fell sharply, especially in commercial buildings, thereafter. Developing countries have generally seen fast growth in both residential and commercial buildings emissions (5% pa or more from both). The overall effect, given the predominance of the OECD in this particular area, is of relatively slow overall growth (2% or less per year) so that the buildings share of the total has remained fairly steady.

However, there is a large **variation** in emissions between countries. This obviously depends to a large extent on the amount and type of energy used in buildings – in Africa, for instance, very little energy is used in buildings for climatic and economic reasons. The energy efficiency of the building stock and appliances is another significant factor. The level of emissions also shows wide variations even between similar countries, depending on the energy source. In many countries, there has been a shift from coal or oil to natural gas and electricity for heating (and cooling). Nearly all countries have seen a significant growth in electricity’s share of the energy mix for appliance and other use within buildings – electricity accounts for half of total energy use in buildings. The CO_2 implications depend on the source of the electricity, a point discussed further below.

To give an indication of the potential size of these differences it may be noted that Sweden (a cold country by most people’s standards) emits about 1.5t/head from the buildings sector (and Norway, equally cold, about 1t). By comparison, more temperate countries like Ireland (5t), Germany (4.6t),

Industry – 35% of emissions
In many countries the largest single source of CO_2 emissions from final energy use.

Transport – 25% of emissions
Rapid growth in all regions and an increasing share of the emissions total.

the United States (7t) and even South Africa (2.3t) show much higher emissions. This reflects a number of factors but primarily the differences in the energy sources used for heating and electricity In Norway and Sweden the main source of heating, as well as for appliances, is electricity and the electricity in both cases is virtually emissions free, being produced from nuclear (in the case of Sweden) and hydro. In Germany, Ireland and South Africa by contrast, fossil fuels are the main sources of both electricity and heat.

Industry – 35% of emissions

Industry is, in many countries, the largest single source of CO_2 emissions from final energy use, but the picture varies sharply between regions. One key driver is the size and rate of growth of the industrial sector – fast growing in many developing countries, growing more slowly in developed countries. At the same time there has been a strong improvement in emissions intensity in industry in many countries, as technical efficiency increases and industry becomes more knowledge intensive.

The balance between these trends varies between countries, but the overall tendency is for emissions coming from the industrial sector to increase rapidly during the initial stages of industrialisation.
As economic development progresses and the service sector takes an increasing share of the economy, the rate of growth from industry tends to slow down. In many developed countries the slow growth of industrial output is offset by a decrease in energy intensity (due to a combination of increasing efficiency, fuel and process changes and a shift to more knowledge intensive output). This has resulted in some cases in a decline in the absolute level of emissions from industry.

In developed countries industrial emissions have been falling slowly but steadily (at under 1% a year), economies in transition saw rapid falls (over 6% a year) after 1990 and developing countries have seen a rapid increase (around 6% pa since 1971). The overall effect has been a steady increase in industrial emissions, but a slightly declining share of the emissions total.
As with the buildings sector, emissions depend strongly on fuel use, with coal still a significant industrial fuel in China and India, oil common elsewhere in developing countries, and natural gas very important in the OECD.

Transport – 25% of emissions

Transport shows a significantly different story – of rapid growth in all regions and an increasing share of the emissions total. Transport emissions have more than doubled since 1971 and about 80% of these emissions are associated with road transport, mainly car use. Increases have taken place worldwide (apart from a fall in the Economies in Transition in the 1990s), in poor and rich regions alike.

In developed countries the emissions increase has been about 2% per annum (pa) since 1971, in developing countries over 5% pa – and the figure may be accelerating. Recently, the increase has been around 7% pa. Many countries go through a process of take-off in transport emissions as GDP per head reaches about $5,000. CO_2 emissions from road transport doubled or more between 1990 and 2003 in countries like Korea, Thailand, Indonesia and Malaysia. Emissions are also increasing rapidly in China, though from a very low relative base. Even in countries which have not seen such fast economic growth, transport emissions have also been rising – in Africa and Latin America by 3% pa or more; in the Middle East by some 8% pa.

Table 1-2
2003 CO_2 emissions by sector

Sector	2003 emissions (Gt CO_2) and % of total	
Electricity	9.9	(41%)
Fuel Conversion	1.7	(7%)
Industry	4.5	(18%)
Transport	5.1	(21%)
Buildings	3.2	(13%)

Source: Energy Technology Perspectives 2006 IEA Paris. "Fuel conversion" includes refinery and other energy use in processing energy for retailing.

This fairly uniform trend reflects above all the dominance of transport by a single fuel – oil, which accounts for 95% of transport energy use. Whereas in other sectors there have been significant opportunities for fuel switching and thus lowering carbon intensity, with transport – till now at any rate – there have been few alternatives. Such alternatives as have existed (e.g. electricity or coal for trains), have tended to be expensive in terms of infrastructure or (in the case of coal or coal-generated electricity) themselves highly carbon intensive.

International aviation and shipping: This sector is not a huge proportion of the total (only 3%) but it is significant. First, because it is fast growing, and second, because at present it falls outside the UNFCCC framework, partly because of the difficulty of allocating emissions to national inventories.

Emissions from this sector are, however, growing rapidly: since 1990 they have grown by 43% for international marine bunkers and 36% for international aviation, as compared with 28% for the total level of emissions. Most commentators would expect emissions to continue to grow fast; like other parts of the transport sector, these subsectors are heavily dependent on oil.

The importance of electricity generation

Electricity generation is not an end-use sector and emissions from electricity generation are included in the relevant end-use sector in the data above.

Electricity at the point of use does not, of course, lead to CO_2 emissions. However, significant emissions do arise in most countries from electricity generation. Indeed, if the figures for electricity-related emissions were extracted from the above data and presented as a sector in its own right, the recorded emissions from other sectors would go down and electricity would then become far and away the largest single source of CO_2 emissions, accounting for around 40% of the total, or twice as much as any other sector's (non-electricity related) emissions – see below. The process of electricity generation involves upgrading of the energy inputs, but also entails losses. Typically, only around one third of the primary energy in the fuel input for electricity generation is actually delivered to the electricity consumer.

Electricity is worth a separate discussion in its own right. It is particularly important in the context of climate change for the following reasons:

- Electricity shows not only a steady and continuing **growth in demand**, in both the developed and developing world, but also an increase in its **share** of the energy market. For instance, over the past thirty years, the global economy grew by 3.3% a year on average, electricity demand by 3.6% (2.8% in the OECD, 4.7% outside). By contrast, energy demand overall has risen at a slower rate than the economy as a whole (around 2% pa).
- Electricity's share of the energy market is also **projected to increase** in all areas. It has the **potential to substitute** for other forms of energy: in heating and process use, for instance, but also, in the long-term, in transport, via hybrid vehicles or in the production of hydrogen for fuel cells.
- On the other hand, there are **no substitutes** for electricity in many uses (such as electrical appliances). Electricity is therefore a necessity for development in a way which is not true of other fuels, apart from oil in transport (i.e. a country

can do without natural gas or coal or hydro or other specific energy sources, but cannot develop without electricity).
- Electricity can be made from almost any primary energy source and is often the only practical route for distribution of such sources as nuclear and renewable energy.
- As a result of this flexibility, there are **huge variations** in the emissions intensity of electricity between countries. The example of Latin America has been quoted above, where emissions per kWh at around 200g per kWh are less than half the world average. Individual countries show even larger variations. Iceland, for instance omits only 1g per kWh – one five-hundredth of the world average. Obviously, in this case, the low figure depends on Iceland's natural resources of hydro and geothermal power, advantages which not all countries enjoy. However, in other countries policy decisions have had a big impact on the carbon intensity of generation, as discussed below.

The result of the above factors is that in principle electricity opens up more effective opportunities for **policy intervention** than other sectors – that is, it is quite possible, by regulation or other policy measures, to reduce the carbon intensity of electricity generation. Overall, because of the rapid increase in electricity demand and production, increases in electricity-related CO_2 emissions have also been considerable over the past thirty years. However, the position varies very markedly between countries because of the factors listed above e.g.:

- Globally, electricity-related CO_2 emissions increased by around 80% between 1971 and 2004 and increased their share of energy related emissions from about 25% to about 35%.
- However, the picture varies between regions. In North America and the Pacific region, electricity related emissions more or less doubled between 1971 and 2004; in Europe they rose much more slowly, by less than one quarter.
- Over shorter periods of time in individual countries the picture varies even more markedly. For instance, in France, electricity associated emissions fell significantly between 1979 and 1987 and remain low, as a result of the French nuclear programme. Overall emissions in France fell by 100 Mt CO_2 during that period, mainly for this reason. In the UK in the period from 1990-1995, emissions fell by about 35 Mt, mainly as a result of the switch from coal to gas in power generation.

In short, compared with the other sectors which show an overall pattern of steady increase or, in a few cases, slow decline, the electricity sector shows much more variation. Furthermore, it is the only area where it is possible to identify within the historical data significant short and long-term reductions in emissions which are not in some sense problematic. Any significant declines in emissions in other sectors and regions have been the result of major shifts in economic and industrial structures; sudden economic and political shocks; or civil conflict and war.

The overall trend of a steady increase in emissions conceals a wide variety of regional and national differences.

1.3 Analysis

As the discussion above has indicated, the overall trend of a steady increase in emissions conceals a wide variety of regional and national differences, for which some underlying reasons can be advanced. To gain a better understanding of the trends, it is helpful to analyse the data in more detail, and this analysis can be performed in various ways.

One common breakdown is via the following equation:

Emissions = population x output per head x energy intensity of output x carbon intensity of energy

or

E = (pop* GDP/pop* toe/GDP* ghg/toe)

where E is the level of national CO_2 emissions; pop is the size of the national population; GDP is the level of national output expressed either in terms of market exchange rates or in terms of purchasing power parities (PPPs); toe or tonnes of oil equivalent is a measure of energy consumption; ghg is the CO_2 emissions associated with each unit of energy consumption.

This equation (often know as the Kaya equation after the Japanese professor who pioneered its use as an analytical tool) does not necessarily identify the drivers as such – that requires further analysis[ii] – but it is helpful in describing emissions in terms which economists and energy policy makers can recognise, and in showing the indicators that need to improve if emissions are to be reduced. Clearly, as discussed below, more detailed analysis is necessary – the factors in the equation may vary significantly between countries for a variety of reasons – but the equation provides a useful starting point.

This study will take it for granted that the key indicators for policy attention are the last two items in the equation: the energy intensity of output and carbon intensity of energy. Reducing emissions by reducing population or GDP would be inconsistent with the 3A's criteria laid out above – and raise issues well outside the energy sector. Nonetheless, all the factors are worth looking at in order to develop an understanding of how emissions are linked with the various drivers, as a guide to policy making. It is important, for obvious reasons, for policy makers to focus on the key targets, i.e. those which are

- **important** to the outcome,
- **susceptible** to policy intervention, and
- offer **cost-effective** mitigation opportunities.

The various factors are therefore looked at in more detail below.

Population

At a global level, it is clear that population is one factor. Everyone needs to use energy, so the more people there are, the more energy will be used – other things being equal. Nonetheless, other things are generally not equal – what is most striking about the data is how emissions per head vary. The variations between countries are well known – CO_2 emissions per head in the US are about 200 times higher than in Tanzania; there are huge differences even between large regions – emissions in the OECD are over 10 times as high as in Africa, for instance.

Emissions per head vary.

Table 1-1 above illustrated the differences between country groupings; Table 1-3 below looks at selected countries at different stages of development to underline the scale of the variations.

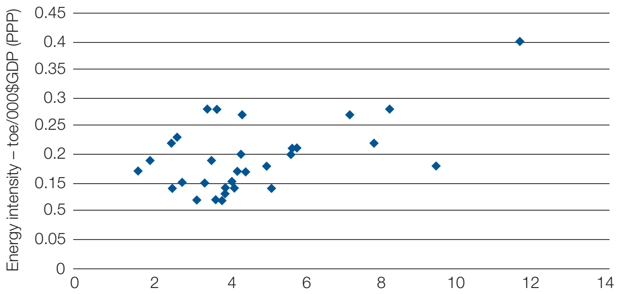
Table 1-3

CO_2 emissions, GDP and population of selected countries

Country	CO_2 emissions per head (tonnes)	GDP per head (PPP $ thousand)	Population (million)	Total CO_2 Emissions (Mt)
USA	19.73	36.4	294	5,800
Australia	17.53	29.6	20	354
Canada	17.24	29.6	32	551
Germany	10.29	26.2	82	848
France	6.22	26.9	62	387
UK	8.98	27.7	60	537
Sweden	5.80	29.2	9	52
Russia	10.63	9.1	144	1,528
Japan	9.52	26.9	128	1,214
Korea	9.61	19.1	48	462
Thailand	3.25	7.4	64	206
Brazil	1.76	7.5	184	323
Argentina	3.54	12.2	38	136
Mexico	3.59	9.2	104	374
Saudi Arabia	13.56	12.7	24	325
Iran	5.51	6.9	67	369
Syria	2.57	3.3	17	47
China	3.66	5.4	1,296	4,732
India	1.02	2.8	1,079	1,102
Bangla Desh	0.24	1.7	139	34
South Africa	7.55	10.3	45	343
Egypt	1.93	3.9	72	140
Tanzania	0.10	0.6	37	4

All data relate to 2004.

Figure 1-2
Energy use and energy intensity – OECD



Source: WEC study group

Much the same is true of developing countries, as illustrated in Figure 1-3, though there may be some complicating measurement issues here (see Box).

Economic output is clearly a major factor.

Economic output

As with population, economic output is clearly a major factor in the level of emissions; as a glance at Table 1-3 indicates, in general, the more developed the country the higher its emissions. But, once again, this is clearly not the only factor. While there is a relationship between emissions and wealth, there are also large differences between countries at a similar stage of development.

The basic position is clear: energy demand tends to grow with rising wealth, particularly in developing countries (though the figures are often complicated by a shift from non-commercial to commercial energies – see Box below). People who have more money can afford to buy more goods and services, and, since these generally have a direct energy component (e.g. heating and transport services), or an indirect "embodied" energy component (the energy used to create a product such as a newspaper), this leads to a higher overall level of energy use.

Nonetheless, the increase in energy use clearly depends on the amount of energy involved in the provision of the good or service involved. At a country level, this is represented by the third element in the Kaya equation, the energy intensity of GDP.

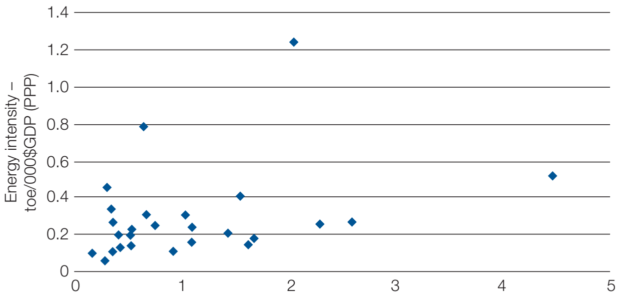
Energy intensity

All other things being equal (i.e. if the other elements of the equation are unchanged) improved (lower) energy intensity will lead to lower emissions, because it will be associated with a lower level of energy use for any given level of output. It is, therefore in principle a good indicator of progress towards a lower carbon economy.

In practice, however, matters are usually more complex. Other things may not be equal – in particular the level of output may not be independent of energy intensity. Countries which use energy (and other resources) more efficiently may, as a result, have a higher level of output and therefore a higher absolute level of emissions, even though their energy intensity is lower; on the other hand, richer countries may be able to invest in more efficient capital stock, so reducing energy use for a given level of output. The two factors can interact in complex ways.

The result is that **the relationship between energy use and the energy intensity of GDP is not very close**. Figure 1-2 looks at 30 OECD[iii] countries, plotting energy use per head against energy intensity. There is no clear relationship between the two factors (and it should be noted that the outlying example, in the top right hand of the graph, with very high energy intensity and use, is Iceland, which also has extremely low emissions per head. This odd combination is in fact the product of the same underlying cause – Iceland's high resources of hydro and geothermal power. This has both encouraged an energy intensive industry structure, such as aluminium smelting, and ensured a very low carbon intensity of energy).

Figure 1-3
Energy use and energy intensity – developing countries



Source: WEC study group

The importance of non-commercial energy in developing countries.

Analysing the growth in energy demand and its links with development is complicated by the fact that in many countries at an early stage of development there is significant reliance on non-commercial energies, usually in the form of renewable fuels gathered by individuals (usually women). These take various forms – firewood is obviously very common, but dried animal dung and other sources are also used. 2.4 billion people in developing countries are thought to depend on traditional biomass for cooking and heating.

A move away from these traditional sources towards modern commercial energy sources is closely correlated with increasing human and economic development, and is in nearly all cases highly desirable in itself. However, it can also create some data problems. Non-commercial energies are generally not measured, for obvious reasons: they never enter the market and exchange system, whereas the commercial energy forms which replace them are usually measured reasonably accurately. Thus, what looks from the recorded data like an increase in energy consumption may also contain elements of fuel-switching, from traditional to commercial forms.

It is difficult to say what this means in terms of CO_2 emissions – the CO_2 impacts of non-commercial energies are difficult to assess. This is not just because the energy input itself is difficult to measure, but also because the emissions impacts are complex and vary according to circumstances.

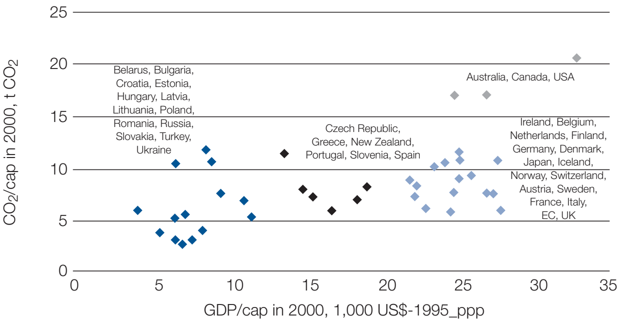
For instance, biomass in OECD countries is generally assumed to be carbon neutral. In developing countries, population pressures may mean that use of biomass involves extensive deforestation or loss of agricultural productivity (because of animal wastes that might otherwise be used as fertilisers, and the time taken, especially by women, in gathering firewood). These impacts may themselves have significant CO_2 and other environmental implications but are not measured in standard statistical sources.

In the countries shown above in Figure 1-3 (a selection of non-OECD countries across all regions[iv]), energy use per head is generally lower than in the OECD countries shown in Figure 1-2. Energy intensity is somewhat lower but shows even more considerable variation. The reasons for this variation are often country specific – for instance, of the two countries in Figure 1-3 showing the highest energy intensity, one (Uzbekistan) is part of the Former Soviet Union and displays the inefficiency in the use of resources characteristic of the region. However, the other (Zambia) qualifies primarily because, as a very low income country, its low GDP per head has a significant impact on all such ratios, while it also has a significant resources sector.

Carbon intensity

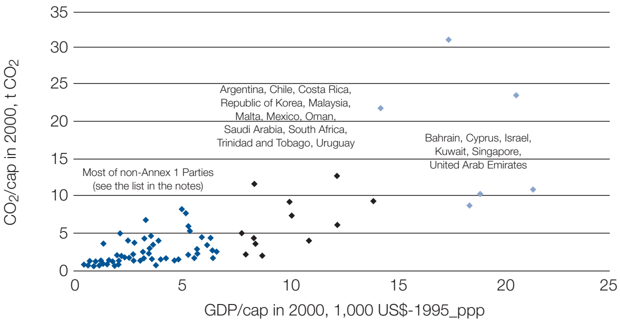
Just as energy intensity is only loosely related to energy demand, so **energy demand growth itself does not necessarily lead to an increase in emissions** – it depends on the final element in the equation, the carbon content of energy. Again, this varies very considerably between countries, as shown in Table 1-4 (see next page).

Figure 1-4
Annex 1 countries: comparing per capita emissions and per capita GDP, 2000



Source: UNFCCC Compilation and Synthesis Report of Annex 1 Communications, for Bonn 2003

Figure 1-5
Per capita emissions of non-Annex 1 countries compared with per capita GDP, 2000



Source: UNFCCC Compilation and Synthesis Report of Annex 1 Communications, for Bonn 2003

Table 1-4
Energy related CO_2 emissions of selected countries

Country	Carbon intensity of energy – CO_2 emissions/toe (tonnes)
USA	2.51
Australia	3.08
Canada	2.12
Germany	2.46
France	1.44
UK	2.33
Sweden	1.04
Russia	2.39
Japan	2.32
Korea	2.18
Thailand	2.12
Brazil	1.57
Argentina	2.06
Mexico	2.34
Saudi Arabia	2.34
Iran	2.56
Syria	2.56
China	2.64
India	1.90
Bangla Desh	1.52
South Africa	2.68
Egypt	2.33
Tanzania	0.19

Countries with substantial hydro or nuclear resources, like Brazil and France, have low carbon intensities; countries which use a lot of coal, like China and Australia, show high intensities.

Implications for CO_2 emissions

What does this all add up to in terms of CO_2 emissions? The discussion above suggests that many of the factors are only loosely correlated and show significant variations within and between regions and countries. It follows that **there is no simple key to understanding a given country's emissions levels**.

Nonetheless, in so-called non-Annex 1 countries there is a reasonably strong correlation between per capita emissions and per capita GDP. After a development threshold is passed emissions tend to increase with GDP, as perhaps one might expect, because energy demand tends to grow with increasing wealth, while the other elements in the equation either remain broadly unchanged or at least do not change in a consistent way to offset the increase in energy demand.

However, the correlation largely breaks down with developed countries. At higher levels of GDP the correlation with emissions is very weak – indeed, if three outliers (Australia, Canada and the US) are omitted, the graph above (Figure 1.3) shows virtually no correlation between GDP and emissions.

The carbon intensity of energy: this obviously depends to a significant extent on a country's resource base.

Why does the relationship break down? A number of reasons have been put forward, in relation to both elements of the equation.

First, as regards the **energy intensity of GDP**:

- **Economic structure:** in the early stages of industrialisation, the industry sector grows rapidly as a share of GDP (and agriculture declines); energy demand therefore grows rapidly. In the later stages (probably better described as post-industrialisation) industry declines as a proportion of GDP and the services sector grows. This tends to reduce the rate of growth of energy demand. In developed countries the industry sector is, in fact, usually a relatively small part of the economy (often 25% or less), services typically account for 60-75% of GDP. In developing countries, the service sector's share is typically much lower – industry (and agriculture, pre-industrialisation) tends to be more important. For instance, China has a services sector share of 41%, and that is after a statistical revision which increased the share by nine percentage points.
- **Industrial structure:** even within the industry sector a change tends to take place, from more materials intensive to more knowledge intensive output, as wealth increases, which generally means lower energy intensity.
- **Demand saturation:** it is possible in principle that there is a natural limit to energy demand (i.e. that people only need so much heating and lighting, can only drive so far in a year etc) and that once this is satisfied their energy demands will stabilise. The evidence that we have reached such a limit is not strong, but it seems intuitively plausible.
- **Economic maturity vs technical progress:** technical progress tends to increase efficiency, including energy efficiency, and reduce per unit energy consumption. Energy projections often include an element known as "autonomous energy efficiency improvement" for this reason, which tends to run at a little over 1% a year. When economies are growing rapidly and industrialising fast, this element is not usually pronounced enough to offset the underlying increase in demand (though there is in principle, scope for increasing the rate of energy efficiency improvement through "leapfrogging" technologies – this may be an important policy tool, discussed below). However, there is a clear tendency for the rate of economic growth to slow down as economies grow beyond a certain point. If the rate of technical progress remains roughly constant, it can have a significant effect in offsetting the increase in demand arising from the rate of growth of output, thus slowing down or even eliminating growth in energy demand.

Second, as regards **the carbon intensity of energy**, this obviously depends to a significant extent on a country's resource base. Nonetheless, there are factors tending to lead to a decreased carbon intensity with GDP growth, some related to the items above:

- **Structural shifts:** The structural shifts noted above tend to lead to a reduced carbon intensity after a certain stage of development. This is partly due to the reduction in the proportion of demand taken by industry and the increasing share of transport and buildings. Industrial demand is normally driven by economic considerations: companies want to purchase the cheapest fuels, usually coal and heavy fuel oil, which are both relatively carbon intensive. Residential and commercial consumers,

Whereas many developing countries are dependent on carbon intensive coal and oil, developed countries tend to use electricity and gas.

especially once incomes have grown sufficiently, often have other priorities – convenience and cleanliness for instance, which may point to the use of fuels such as gas and electricity.

- **Energy supply:** Allied to this is a change in the energy supply structure. As economies develop, the share of the energy mix taken by "network" industries, natural gas and electricity, tends to increase. These forms of energy tend to be relatively expensive per unit and to require the construction of capital intensive infrastructure. So they tend not to be so widely available in the first stages of industrialisation. The combination of this and the previous factor means that whereas many developing countries are dependent on carbon intensive coal and oil, developed countries tend to use electricity and gas. While the carbon intensity of electricity can vary, as discussed elsewhere, the introduction of natural gas into a fossil fuel system generally results in a lowering of carbon intensity. As an example, the carbon intensity of electricity generation in the UK is expected to halve in the period from 1990-2010 as a result of the introduction of natural gas into the system.
- **Policy intervention:** richer countries can often afford to adopt stronger policies with regard to reducing emissions, and invest in more expensive or capital intensive sources (nuclear, renewables etc). They can also afford to remove energy subsidies and/or tax energy sources because the social impacts on their populations are less than with developing countries, or easier to offset. This generally works both to reduce energy intensity and to reduce the carbon intensity as energy taxes often (though certainly not in all cases) aim to encourage less polluting fuels. In general, very few subsidies for energy remain in OECD countries and many energy sources are highly taxed. In non-OECD countries, by contrast, subsidies and cross-subsidies are common.

These factors could tend to support the suggestion that the rate of emissions growth should slow down above a certain level of development (the so-called **carbon Kuznets hypothesis** – see Box).

The Kuznets hypotheses

- The **Kuznets hypothesis** itself relates to income inequality. It suggests that inequality increases during the early stages of economic development but, after a certain point, declines.
- The **environmental Kuznets hypothesis** applies a similar framework to environmental damage – it suggests that it first increases then decreases with rising income.
- The **carbon Kuznets hypothesis** takes the principle into the specific area of carbon dioxide emissions. It postulates that emissions growth will follow a roughly S shaped curve – that is, emissions will grow slowly in economies below a certain level of GDP, then increase rapidly once a threshold is passed, then flatten off again as economies reach a given level of wealth.

In fact, though this relationship holds in a rough and ready way, it does not stand up to statistical analysis[1].

The reason is probably that the picture is compounded by the factors listed below, as illustrated in Table 4 (p23).

All countries differ in their energy resource endowment.

Resource endowment: Clearly all countries differ in their energy resource endowment: some have coal or oil; some have extensive hydro power; some have few natural resources. The same is generally true of other mineral resources, and this affects the composition and structure of the economy.

There are therefore two separate factors:

- First, consumers in those countries with large energy resources, particularly resources with high transport costs such as coal and natural gas, often enjoy them at a lower price than consumers on the world market (who have to pay the transport costs). In most cases, they enjoy at least the advantage of avoiding international transport costs – which can be very considerable. In the case of coal and gas imported to Europe from outside, the total cost of transportation (including carriage within the country of origin; transportation or transmission from the country of origin to Europe; and delivery to the final consumer in Europe) can be well over half of the final cost of the fuel. In addition, in some cases countries may subsidise domestic use of indigenous fuels, or at least charge a lower price than for exports, as a way of helping their citizens to benefit directly from the country's own resources. Countries, therefore, tend to consume relatively more of the resources which they possess in abundance. (China, for instance, has an energy economy heavily dependent on coal; Saudi Arabia uses oil and natural gas; Norway is very hydro-intensive).
- Second, economies with a high resource endowment tend to be intrinsically energy intensive (resource extraction is an energy intensive activity). South Africa, for instance, stands out as a particularly energy intensive economy – energy costs amount to around 15% of GDP. Mining accounts for nearly one third of industrial energy use, and iron and steel, which are closely related, for another third.

These resource factors seem to apply regardless of the relative wealth of the country concerned – it is not only developing countries like China that make extensive use of indigenous coal or have significant mining sectors. Developed countries like Australia, Canada, and the US show similar characteristics.

Geographical factors: Australia, the US and Canada are also, of course, large countries with challenging climates. These factors tend to produce high intrinsic energy needs for transport and for heating and cooling (since cooling tends to be affordable only after a certain stage of economic development, it may work against the general "Kuznets" trend by leading to an increase in energy consumption in this particular area as incomes rise). They are also subject to more policy constraints, despite their wealth. For instance, given the huge distances, it can be difficult to develop effective public transport systems as an alternative to private car use. Furthermore, the sheer availability of space tends to lead to dispersed settlement patterns. These factors compound the political sensitivity of higher gasoline prices – the impacts are much greater than in a compact country with transport alternatives. Similarly, the social impacts of higher electricity prices are greater because of the greater need for heating/cooling than in a more temperate country.

These geographical factors therefore tend to mean that the scope for policy intervention do not apply

There are still genuine differences in the viability of particular policy approaches in different countries.

so strongly to such countries. Of course, many forms of intervention are still possible in principle, even in large countries – for instance, in urban planning. The more dispersed settlement patterns and lower reliance on public transport typical of countries like the US, leads to much higher transport energy use even within cities of comparable sizes. For instance, Atlanta Georgia in the US is around the same size in population terms as Barcelona in Spain but its transport energy emissions are an order of magnitude higher. In principle, US settlement patterns could be brought closer to European approaches, but in practice, this would be seen as an extremely intrusive approach, would be likely to be extremely unpopular, might be counter-productive (people could simply move to different places) and would take a very long time to have any significant impact. In short, there are still genuine differences in the viability of particular policy approaches in different countries.

Carbon intensity of energy: The overall effect of such factors is that there are large differences in both the energy intensity of economies and the carbon intensity of energy. However, the relationship between the energy intensity of an economy and its carbon intensity is not very strong. Countries at similar levels of GDP and energy consumption can vary quite widely in terms of the carbon intensity of their energy and hence in their per capita emissions, as illustrated in Table 1-5.

The differences depend partly on the geographical and resource factors mentioned above but also on policy decisions (bearing in mind that wealthy countries have more leeway to make these decisions than poorer countries). Electricity is particularly important in explaining national variations because of the flexibility of fuel inputs. The carbon intensity of transport does not differ greatly between countries, since all rely primarily on oil. Transport intensity does vary considerably, but it seems to follow geographical factors, at least in countries at similar stages of development – and of course geography cannot be changed. However, the carbon intensity of electricity and the electricity intensity of economies vary very significantly, and often as a result of deliberate choice. These policy decisions were not always made for climate change reasons but can have big impacts.

Table 1-5 shows CO_2 emissions per head, as in Table 1-3, but adds breakdowns of emissions in transport, electricity and industry sectors.

[1]The arguments are too complex to be explored in detail here; a recent overview can be found in “Exploring the Carbon Kuznets Hypothesis” by Müller-Fürstenberger, Wagner and Müller, available on the web-site of the Oxford Institute for Energy Studies.

Table 1-5
Emissions per head and sector

Country	GDP (,000$PPP) /capita	Energy use per head (toe/capita)	CO_2 emissions per head (tonnes)	Emissions per head from electricity	Emissions per head from transport	Emissions per head from industry (inc energy)
USA	36.4	7.91	19.73	8.25	6.09	3.20
Australia	29.6	6.08	17.53	9.95	3.87	2.83
Canada	29.6	8.42	17.24	3.99	4.92	4.99
Germany	26.2	4.22	10.29	4.29	1.96	1.85
France	26.9	4.43	6.22	0.80	2.18	1.55
UK	27.7	3.91	8.98	3.27	2.14	1.74
Sweden	29.2	6.00	5.80	1.15	2.50	1.53
Switzerland	30.2	3.63	5.95	0.22	2.17	1.19
Japan	26.9	4.17	9.52	3.58	2.17	2.50
Korea	19.1	4.43	9.61	3.85	2.04	2.36
Thailand	7.4	1.52	3.25	1.06	0.86	1.09
Russia	9.1	4.46	10.63	6.01	1.45	1.82
Brazil	7.5	1.11	1.76	0.18	0.74	0.65
Argentina	12.2	1.66	3.54	0.83	1.00	0.90
Mexico	9.2	1.59	3.59	1.12	1.19	0.96
Saudi Arabia	12.7	5.86	13.56	5.08	2.86	5.47
Iran	6.9	2.18	5.51	1.32	1.38	1.19
Syria	3.3	1.03	2.57	0.99	0.69	0.71
China	5.4	1.24	3.66	1.75	0.23	1.26
India	2.8	0.53	1.02	0.58	0.09	0.25
Bangla Desh	1.7	0.16	0.24	0.10	0.03	0.07
South Africa	10.3	2.88	7.55	4.61	0.91	1.48
Egypt	3.9	0.78	1.93	0.66	0.44	0.64
Tanzania	0.6	0.49	0.10	<0.01	0.06	0.01

All data relate to 2004.

There are significant differences between countries when the figures are broken down by sector.

As will be visible from the Table, there are significant differences **between** countries when the figures are broken down by sector. While the differences between the various groups are often driven by factors like overall levels of development, there are also differences **within** groups of broadly similar countries, reflecting the sectoral breakdown of energy use and the carbon intensity of energy:

- Taking first the **high emitters** – Canada, the US and Australia. Although they have similar overall levels of emissions, the underlying sectoral variations are considerable. Transport emissions are particularly high in the US; power sector emissions in Australia (reflecting its extensive use of brown coal); and industrial emissions in Canada (reflecting the importance of energy intensive industry). The differences in emissions do not reflect energy intensity very directly – Canada's energy use per head is about 40% higher than Australia's but its emissions are similar.
- The **European countries** (in this table, Sweden and Switzerland have been added) come in two broad groups. All have significantly lower emissions than the previous group, including lower transport emissions, despite being at a similar level of development. France, Sweden and Switzerland in particular have much lower per capita emissions than other temperate industrialised countries with broadly similar features such as the European group and Japan or Korea (despite the high heating needs and relatively high transport needs in Sweden). In all three cases, this is due to the fact that their power systems rely almost exclusively on non-fossil sources, namely nuclear and hydro. Transport emissions do not vary significantly between the various countries, and industrial emissions are somewhat lower in the low emitting countries, primarily because of electricity in industry. But there is no particular link between low emissions and low energy use – France and Sweden are the two highest energy users in the group.
- The **East Asian** trio chosen all show a much heavier relative share for industrial emissions in their totals (in all cases greater than transport emissions, which is true only of Canada among the previous groups of countries). Thailand is, of course, at an earlier stage of development than the others in the group, but shows the same pattern across sectors as the rest.
- **Russia** has very high energy use and emissions for its GDP/capita level. This reflects both its climate (the electricity figure includes a significant amount of heat used in district heating systems) as well as the Communist legacy.
- Among the **Latin-American** countries, Brazil has particularly low emissions because of its hydro-based power structure and its significant use of ethanol in transport.
- The **Middle Eastern** countries have relatively high emissions for their stage of economic development, and this is most marked for those with high oil and gas resources but relatively small populations.
- The **developing Asian** countries have emissions which vary according to their level of development, but the low transport emissions are particularly noticeable. Industrial emissions are, in all cases, some three or four times greater than transport emissions. China and India also have high electricity emissions as a proportion of the total (roughly 50%) because of the extensive use of coal in power generation. In this, they are more like Australia or the US rather than Brazil or Argentina.

There is no single driver of emissions.

- The **African** countries again show significant differences. South Africa has relatively high emissions for its GDP/head figure – compare it, for instance, with Mexico or Thailand. Tanzania, and many other sub-Saharan African countries, have very low emissions in all sectors because of their low level of development. Egypt is more similar to its Mediterranean neighbour, Syria.

Conclusion – the drivers of CO_2 emissions

The broad conclusion that can be drawn from the above analysis is that the issue is multi-factorial – there is no single driver of emissions and no single area for policy to focus on. There is a broad correlation between increasing wealth and increasing energy consumption, but the implications for CO_2 emissions depend on a number of other factors: geography, industrial structure, indigenous resources, climate, policy stance and the like. In a way this is good news, there is no absolute link between economic development and emissions, so it is in principle possible to grow in a more sustainable manner. Nonetheless, the same opportunities are not necessarily available to all countries. While some of the factors are susceptible to policy intervention, others – like geography and resources – are not. Policy needs to take account of such differences.

Methane is also a significant greenhouse gas.

1.4 Non-CO_2 greenhouse gases

This study focuses mainly on carbon dioxide; as noted above, this is the greenhouse gas most closely interlinked with energy use. Over 80% of man-made emissions of CO_2 come from energy (industry and agriculture account for most of the rest). CO_2 in turn accounts for about three quarters of total global ghg emissions, so CO_2 from energy accounts for about 60% of man-made ghg emissions. (Other significant gases include methane and N_2O – see below – and fluorinated gases). In total energy accounts for about two thirds of anthropogenic ghg emissions (about 60% of this is from energy-related CO_2; about 5% from energy-related methane).

Methane

Methane is a significant greenhouse gas (it accounts for around one sixth of total ghg emissions) and energy is a significant source of methane (energy produces a bit over one-third of global methane emissions – the rest coming mainly from agriculture and waste). Energy-related methane emissions occur in coal and hydrocarbon production and natural gas transportation.

Recent trends Methane emissions are generally less accurately measured than CO_2 emissions but the broad trend seems to be of a slower overall rate of growth (e.g. energy related CO_2 increased about 28% between 1990 and 2004, total methane emissions increased by around 11%), and of considerable variation between sectors.

Methane emissions from coal production seem to be declining for two reasons:

- increases in methane recovery from coal mines, for safety and environmental reasons
- a shift towards surface mining, which produces lower levels of emissions.

Emissions from gas production (in particular in the Middle East and North Africa) have been increasing with the growth in gas demand. Emissions from gas transmission and distribution may also be increasing, but the data are not clear. On the one hand, more gas is being transported as demand and international trade increase; on the other hand, newer pipelines tend to suffer from lower leakage than older facilities.

In general terms: methane raises broadly similar issues to carbon dioxide – measures which decrease the energy intensity of output or the carbon intensity of energy will also tend to reduce methane emissions, and thereby secure an extra benefit. There may also be specific and cost-effective methane control measures, additional to those for CO_2, which arise from the following characteristics:

- methane emissions are often easier to control than CO_2 emissions – CO_2 is a direct product of fossil fuel use, whereas methane is normally an accidental by-product, in the form of leakages from, for example, gas pipelines and coal mines. This leakage can, in many cases, be reduced (for instance by replacing old gas mains with newer pipes) or captured.

- methane is itself a useful source of energy. Natural gas itself is virtually pure methane. Methane leaked from coal mines is normally less pure, but can often still be combusted to produce electricity, or purified to be introduced into natural gas pipelines.

This gives rise to some complications in relation to the general pattern discussed above:

- First, methane emissions from landfill (though not strictly energy related emissions) are significant in some countries. These emissions can be harnessed, like mine gas, for energy production. Although this is not in itself a particularly efficient form of energy, the impact of harnessing these emissions is usually very positive in greenhouse gas terms because methane is a particularly powerful greenhouse gas: it has a high greenhouse forcing effect – global warming potential or GWP – per molecule. In this situation, a deterioration (i.e. an increase) in energy intensity could nonetheless be associated with a reduction in overall ghg emissions.
- Second, it is normally the case that if coal is displaced by natural gas the result is a decline in the carbon intensity of energy, because natural gas has a lower carbon content than coal. However, if the gas comes from a source which involves high methane leakage (e.g. through long, old or ill-maintained pipelines) the net impact could be a reduction in overall ghg emissions could be negative, because of the high GWP of methane. So in this instance a deterioration in the carbon intensity of energy consumption could nonetheless be associated with an improvement in overall ghg impacts. Life cycle analysis of different mitigation options can help illustrate where the most effective reductions are achievable (see, for instance, the WEC study “Comparison of Energy Systems Using Life Cycle Assessment”).

For reasons such as these, while in general policy measures aimed at CO_2 will also tend to reduce methane emissions, there are also specific policy options of interest in relation to methane.

N_2O

N_2O is a relatively minor, though not negligible, ghg (about 10% of total emissions). Energy contributes to this source principally via wood-burning. However, this is estimated to account for only around 4% of global N_2O emissions – most of the rest comes from agriculture and industry (where large reductions are often relatively easy to make). Given the limited significance of the energy sector in this context, no detailed consideration will be given to N_2O as such in this study.

The energy sector is where the greatest reductions will have to be sought.

1.5 Conclusions

The following preliminary conclusions can be drawn from the above analysis:

- Energy use is the most important source of anthropogenic greenhouse gas emissions; the energy sector is where the greatest reductions will have to be sought. However, energy systems also have to meet a number of social and developmental needs and policies, and measures have to take account of this.
- Energy-related ghg emissions have been growing steadily; however, there are very considerable variations between regions and countries. In particular, developing countries show rapid energy and emissions growth, but from a very low relative base of energy use per capita. Their energy and development needs are still high.
- The differences between countries underline the need for differentiated policy approaches.
- Even at similar levels of development, there can be significant differences in per capita emissions between countries. **There is no automatic link between economic growth and energy use or between energy use and emissions**; decoupling emissions from economic development is at least conceivable, though it does not seem to be automatic.
- There is some evidence that emissions growth tends to slow down as economies mature; however, there are also a number of other important factors involved, some of which are more susceptible than others to policy intervention.
- The areas deserving particular focus are energy intensity and the carbon intensity of energy. The two factors are not, however, strongly correlated, nor is energy intensity strongly correlated with levels of energy use.
- The evidence suggests that, to date, the most significant impact on emissions has been made by reducing carbon intensity rather than energy intensity.
- As shown in Table 1, the CO_2 emissions intensity of GDP may offer the most practical baseline for reaching global policy agreement on sustainable carbon reduction commitments. The deviation around the world average is relatively small, and emissions intensity can be scaled by each country to reflect future global economic growth and technical progress as well as domestic development priorities.
- Currently, **the sector which gives most scope for reduced carbon intensity and emissions is electricity** because of the availability of low or zero carbon technologies.
- The transport sector is also very important but policy intervention may be more difficult – major technological or behavioural changes may be needed to show significant reductions.
- Particular policy approaches, and their success in achieving social and developmental as well as environmental objectives, will be examined against this background, in Parts 2 and 3.

[i] As explained in the Note on Sources, emissions data are based on the IEA publication *CO_2 Emissions from Fossil Fuel Combustion* 2006 edition.

[ii] See, for instance, the WEC publication *Drivers of the Energy Scene*.

[iii] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK, US.

[iv] Angola, Argentina, Bangladesh, Benin, Brazil, Chile, China, Costa Rica, Ethiopia, Georgia, Ghana, India, Indonesia, Jamaica, Malaysia, Morocco, Myanmar, Nepal, Philippines, Russia, Saudi Arabia, South Africa, Sri Lanka, Syria, Thailand, Ukraine, Uzbekistan, Zambia.

Part 2: Measures and Policies to Reduce ghg Emissions

1 Introduction

The aim of this part of the Study is to provide an overview of climate change policies, measures and strategies in place around the world. The task is not as straightforward as it might appear at first sight – the definition and categorisation of climate change measures raises a number of issues, some technical, some substantive.

The first requirement is simply to decide what constitutes a climate change policy. Because of the close interaction between energy consumption and greenhouse gas emissions, virtually any policy for energy or transport has implications for emissions, whether positive or negative.

Many such policies do in practice reduce emissions – but often the policies preceded concern about climate change and were not, at least initially, motivated by environmental considerations. Examples include:

- fuel taxes have been imposed in many countries for decades, usually originating as simple revenue raising measures. Nonetheless, such taxes remain one of the key measures in combating climate change, especially when recalibrated to reflect emissions more closely.
- similarly, the promotion of public transport has long been central to transport policy in many countries. Although the motivation was often originally to promote social welfare – by improving access to mobility and reducing congestion – in most cases the policy also has significant emissions benefits and remains central to climate change strategies.
- the development of nuclear power in many countries was driven by concerns about energy security and the need for self-sufficiency, but also has significant benefits in reducing emissions. Until recently, few countries were promoting nuclear as a climate change measure as such, but this may be changing.

It is not necessarily mere opportunism to introduce policies for one purpose and then use them for another. Indeed, the fact that many policies have multiple benefits is one indication that it is possible to meet all three of the WEC objectives (the 3A's) at once. Carefully directed climate change policies may have wider social benefits, and need not be a burden. Furthermore, the impacts of such policies can be considerable. For instance, the Netherlands estimates that of its total avoided emissions in 2010 due to domestic efforts, less than one third is related to policies instituted after the signing of the Kyoto Protocol; two thirds relates to policies which preceded Kyoto and therefore also had other motivations than meeting an emissions target.

Of course, not all policies have these double benefits. Nearly all energy-related measures have an impact on CO_2 emissions, and sometimes the impact can be significant. The impact is sometimes clearly positive (i.e. to reduce emissions), sometimes negative. But what complicates the analysis, and policy-making generally, is that there are many examples of measures which can have a significant but uncertain impact – i.e. in directions which may be either positive or negative. For instance:

In many cases it is that companies are ahead of governments in their emissions reduction efforts.

- measures to reduce sulphur emissions may increase or decrease CO_2 emissions – use of flue gas desulphurisation equipment on coal-fired power stations increases the output of CO_2, while a switch from coal to natural gas (an alternative sulphur reduction measure) reduces CO_2 emissions. There is also some evidence, paradoxically, that sulphur particulate emissions have acted in such a way as to slow down the rate of warming by reducing the amount of incoming solar radiation that reaches the ground.
- liberalisation of energy markets are likely to have a significant impact on greenhouse emissions, but this is not always possible to predict with certainty. On the one hand, it may lead to lower prices and a switch to cheaper fuels (often coal) thus increasing emissions; on the other hand, in many countries, such as the UK, Italy, Spain, and the US, liberalisation has prompted a "dash for gas" with associated emissions reductions. (Of course, fuel-switching between fossil fuels is not a long-term solution and may entail other problems in relation to availability as discussed below).

Such measures can well have a much larger impact on ghg emissions than the policies which are explicitly concerned with climate change but, by their nature, those impacts can be difficult to predict. In such cases, it makes sense to consider the climate change implications in advance so that either the specific measure concerned, or the wider range of energy policies, can be adapted to promote a positive result.

Another complication arises with some federal countries, such as the US and Australia (neither of which has ratified the Kyoto Protocol). In such countries in particular, the policy initiative on climate change may not be taken by the federal government but by state governments. For instance, in the US California is planning the implementation of mandated ghg emissions limits and may link up with seven states in the North East which are elaborating a regional greenhouse gas plan. This state-level initiative can also be a precursor to broader national action as indicated by the recent US Supreme Court decision that forces the nation's Environmental Protection Agency to treat ghgs as pollutants under the Clean Air Act. Other federal countries, like Switzerland, have found it easier to establish policy consensus covering both national and federal level.

In all countries, of course, there are many actors involved. Action on climate change may also therefore be taken at company level – a number of companies have voluntarily adopted their own ghg limits or targets, or are otherwise introducing measures to reduce emissions. They may see it as an active expression of their social obligations (corporate social responsibility), or as an area of future profit growth, or both. But the end result in many cases is that companies are ahead of governments in their emissions reduction efforts.

Finally, of course, many individuals or other organisations in private or public sectors have also made similar efforts, quite irrespective of any wider policy or legal background. Official reporting systems, such as the UNFCCC reports or government climate change strategies, do not generally capture the full range and richness of all these activities.

Given all these uncertainties it is not always possible to define precisely what constitutes a climate change policy, though one obvious reference is a country's published climate change strategy. In general, the starting point of this study is to consider those energy policies which have a significant impact on ghg emissions, along with other policies (e.g. in the area of transport and the environment) which operate mainly through their impacts on energy and are designed to achieve climate change objectives – i.e. wider transport and environment policies are excluded, even though some may have indirect energy or emissions implications (e.g. land use and spatial planning policies).

Just as the initial identification of climate change policies can be difficult, the subsequent categorisation of these measures is also complex. There are a number of different ways of cutting the pie. For instance, policies can apply at different stages of the energy system (e.g. supply vs demand side) or take different forms (e.g. command and control vs economic incentives) and could be categorised accordingly. Another way of looking at it is to consider policies designed to affect a particular area (e.g. renewables), though these can take different forms in different countries, or even within a single country (e.g. subsidies, tax breaks, and portfolio standards, or a combination of such measures might be used). Alternatively, measures can be looked at in terms of the equation discussed in Part 1 – according to whether their objective is to reduce energy intensity, carbon intensity, or both, or in sectoral terms – policies directed at industrial use, buildings, transport etc.

There is no single correct way of analysing the measures and this part therefore looks at the issue from various perspectives.

Section 2.1 considers the measures according to the **type of policy instrument** employed, following the categorisation used by the UNFCCC. This involves distinguishing between:

- Economic and fiscal instruments.
- Regulations and standards.
- Voluntary agreements.
- Information and awareness.
- Research and development.

Section 2.2 discusses the various measures according to the **particular policy areas** they affect (e.g. renewables, energy efficiency, transport). The aim in both cases is to investigate the sorts of measures which are used in different circumstances and regions and why; in many cases, the choice of policy is made by taking account of the implications for the objectives of accessibility, acceptability and availability, as discussed below. Finally, as in Part 1, it looks briefly at non CO_2 greenhouse gases (**section 2.3**), before drawing initial conclusions.

Note on sources

A range of sources has been used for the analysis in this part. The starting point was a set of **responses to questionnaires** issued by the WEC. Responses were received from 30 countries at various levels of detail, listing current and planned policies.

In many cases, the responses also referred to source documents, such as national **climate change strategies**, which have also been consulted.

In addition, a range of **UNFCCC** sources has been used, including national communications and UNFCCC synthesis reports.

Other sources have included **IEA** and **EU** reports on their members' policies and various national progress reports on climate change policies.

Finally, as part of the assessment exercise for Part 3 of this study, a number of countries participating in the study have assessed their **national policies** in more detail and the analysis in this part, as well as Part 3, also draws on this material.

The aim has been to cover as wide a range as possible of countries, many in some detail, others via the synthesis reports. Specific coverage (i.e. in the form of questionnaire responses, national reports consulted etc) includes the following countries: Australia, Austria, Brazil, Canada, China, Cote d'Ivoire, Croatia, Czech Republic, Denmark, Egypt, Finland, France, Germany, Greece, Hong Kong, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Kenya, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Poland, Portugal, Russia, Saudi Arabia, Serbia and Montenegro, South Africa, Spain, Switzerland, Taiwan, Thailand, UK, Ukraine and USA. Together, these countries account for around 90% of global CO_2 emissions and over 90% of climate change policies.

The majority of the subsidies for the energy sector in many countries are now devoted to renewables.

2.1 Analysis of measures according to the policy instruments employed

Economic and fiscal instruments

The first category in the UNFCCC classification is that of economic and fiscal instruments; in turn this covers three main classes of instrument: subsidies, taxes and emissions trading. These instruments are the most commonly used (along with regulation) in Annex 1 countries and are found in all sectors, accounting for over one third of the reported policy instruments in the energy and transport sectors. They are less commonly reported by developing countries, although, as discussed below, subsidy removal is an important tool in some countries.

Subsidies

As the previous comment suggests, subsidies are important in both a negative and a positive sense. In many ways, the first and most effective step in reducing greenhouse gas emissions in a cost-effective manner is the **removal of subsidies** on fossil fuels. In principle, this should improve economic efficiency (by removing price distortions) and the environment (by reducing demand for fossil fuels) at the same time, and many international organisations and others (e.g. the IEA and World Bank) have advocated this measure as a key first step in an emissions reduction strategy.

Most OECD countries are already a long way down this road, having removed most direct subsidies for fossil fuels. This does not mean that the energy sector is free of subsidies – quite the contrary. The sector is still one of the most subsidy prone areas of the economy. However, by and large the subsidies have been converted to a less damaging form in environmental terms. For instance, support for coal in countries like Germany now comes out of general taxation and should not have a significant effect on the market for coal (or consumption decisions). The majority of the subsidy for the energy sector in many countries is now devoted to renewables (and in some cases nuclear) and can be regarded as a form of compensation for the failure of fossil fuels to internalise the cost of environmental externalities. Overall – especially given the high level of taxation discussed below, particularly on motor fuel – there is no doubt that the effect of government intervention has been to raise fossil fuel prices to the consumer, not reduce them, in OECD countries, and to lower the effective price of renewable sources. The net impact of energy subsidies in the OECD is therefore positive in climate change terms.

This approach is made possible by the advanced level of economic development of OECD countries. Most have achieved 100% access to modern energy services and consumers are generally wealthy enough to absorb higher prices (though not always without complaint). Most also have well-developed welfare systems. Help for those suffering from fuel poverty can be offered through the welfare system (or, for instance, in special help with energy efficiency measures) rather than in the form of fuel subsidies, so avoiding distortion to fuel choice decisions.

There are, of course, variations in this overall picture. As noted above, in geographically large countries with low population densities, high levels of vehicle fuel

Removing subsidies, therefore, often involves real social costs.

taxation may be unacceptable (though in general fuel is not subsidised); in many countries there are also tax breaks of various sorts which have a similar effect to subsidies and encourage domestic fuel production; however, like the coal subsidies referred to, they do not normally affect consumer prices.

Social issues arise much more acutely in many developing countries. In many, because of the low level of economic development, access to modern energy forms would not be possible without some form of subsidisation, or cross-subsidisation between different groups of consumer. Fuel prices are often politically sensitive and may be held down for social reasons. Many developing countries either subsidise particular fuels or sell indigenous fuels to domestic consumers at below world prices, so incurring an opportunity cost. In many cases, utilities incur continuing losses by selling below cost to some or all consumers. For instance, a study of electricity prices in Tanzania in the 1990s showed that most tariff groups were subsidised, sometimes paying only one quarter of the true cost; on the other hand, some groups paid above the marginal cost of supply and the large industrial consumer group in particular was thought to be overcharged by about 40%. In general, subsidies are most common on sources used for domestic heating and lighting, such as electricity and kerosene, though they often extend to vehicle fuels because of the political sensitivity.

Subsidies should certainly not be condemned outright; they have proved a key policy tool, and not just in developing countries, for promoting major social objectives such as electrification. Although OECD countries, having achieved 100% electrification, are now moving on to competition and liberalisation, we should not forget that in all cases the process of extending power supply to rural and outlying areas involved significant elements of direct subsidy (for electricity connections) and cross-subsidy (e.g. by monopoly utilities accepting uniform tariffs which failed to reflect the higher costs of supply to rural areas). In no case was a fully competitive approach to electrification adopted within the OECD and it is likely that the process of extending electricity supply in developing countries will continue, quite properly, to rely on these proven methods.

Removing subsidies, therefore, often involves real social costs. Nonetheless, because of the strong economic and environmental arguments for doing so, a number of developing countries have made subsidy removal central to their climate change strategies. Indonesia, for instance, in its First National Communication to the UNFCCC, lists the phasing out of fuel and electricity subsidies as the primary energy market measure in relation to climate change, the aim being to remove market distortions and allow energy users to realise the true costs of energy. Many of the economies in transition have also been moving to bring their energy prices into line with world levels as part of the wider restructuring of their economies. Such aspirations are, however, not always easy to translate into reality. In practice, the social problems have often outweighed political will and progress has often been halting, but this continues to be an important area for further policy development.

In many cases, it is possible to refine the implementation of subsidies in such a way as to meet environmental objectives while mitigating any social impacts. Some examples are examined in the WEC publication "*Energy Market Reform: Lessons Learned and Next Steps with Special Emphasis on the Energy Access Problems of Developing Countries*." They include such approaches as confining subsidy to the fixed costs of connections; limiting subsidy to "lifeline tariffs" only; and providing subsidy from the public purse instead of distorting utility tariffs. In other cases, environmental benefits can be achieved by promoting cleaner fuels even where they are fossil in origin – for instance, the promotion of LPG for domestic use or CNG for vehicle use in order to lower emissions of ghgs and other pollutants. This happens, for example, with taxis and other public transport vehicles in Delhi, India. The policy was applied to some 84,000 public vehicles, mainly through regulation and direct control, though there is an element of effective subsidy: for instance, regulated taxi fares are adjusted to reflect the higher costs.

But the main forms of subsidy used in a climate change context are those directly designed either to lower energy intensity or to reduce carbon intensity. Thus many measures aim directly at **subsidising non-fossil fuels**, particularly renewables (to reduce carbon intensity), or **energy efficiency** measures (to reduce energy intensity). In some countries, subsidies or other forms of support are available for nuclear power (e.g. the US).

There are many examples of subsidies designed to reduce emissions, particularly in developed countries, nearly all of which provide support for renewables and energy efficiency. In developing countries there is also support for energy efficiency and renewables as climate change measures, though, because of the lack of resources, subsidies are less common and other instruments such as regulation are often chosen. These two policy areas are discussed in their own right in the second section of Part 2.

Subsidies for these purposes have a number of attractions as a policy tool: they are often an effective way of overcoming barriers to the adoption of more expensive but cleaner technologies and thus improving the accessibility of those technologies. They may also offer significant co-benefits, as in the case of energy efficiency, which has the potential to improve economic and environmental performance at the same time. However, it is not always clear whether subsidies are cost-effective. They inevitably involve a degree of market distortion – even when they are designed to compensate for the failure of energy prices to incorporate externalities. In practice, it is impossible to calculate the precise monetary scale of these externalities accurately, so a degree of judgement is inevitably involved.

Furthermore, unlike carbon taxes, subsidies have to be applied to particular activities or projects; there is often a tendency to "pick winners", such as particular forms of renewable energy, which may not necessarily be the most cost-effective or sensible form of carbon mitigation. With energy efficiency there is the additional problem of "free-riding". Since many energy efficiency measures are fully cost-effective in their own right, subsidies may not really be necessary to encourage people to invest in energy efficiency. Energy efficiency also raises the issue of environmental effectiveness, as discussed below.

Finally, of course, subsidies involve an opportunity cost. For many developing countries in particular it can be difficult to justify the use of scarce public resources in this manner when there are many other pressing claims on the public purse – and there may be limited administrative capacity to ensure that the subsidies can be implemented and monitored effectively. For all these reasons, subsidies for low carbon sources tend to be more common in developed countries. There is scope, however, for international instruments, such as the Clean Development Mechanism and the Global

Fuel taxes have always been common in OECD countries. As yet, however, there are very few "pure" carbon taxes.

Environment Facility, to help level the playing field in this respect, as discussed below.

Taxes

Energy taxes are in many ways the mirror image of subsidies, indeed the two categories may overlap, since many tax breaks have the same effective impact as subsidies. Fuel taxes have always been common in OECD countries, as noted above, particularly in relation to motor fuels. In Europe and Japan in particular, motor fuel taxes are very high indeed, amounting in many cases to around 70-80% of the final consumer price. Increasingly, OECD countries are also introducing wider fuel or carbon taxes – for instance, Japan has imposed an energy tax and is exploring carbon tax options. The European Union has set a framework for the taxation of energy products which sets out minimum levels of taxation for energy products and electricity but allows for exemptions or reductions to promote renewable sources. In practice, many EU countries have gone beyond this and have imposed higher levels of taxation, or specific carbon taxes.

As yet, however, there are very few "pure" carbon taxes – where all fuel taxes are based solely on the carbon content of the different fuels. For instance, Sweden has a carbon tax which it has raised over time, but industrial users pay at reduced or zero rates – the concern here is international competitiveness. The UK has a version of the carbon tax (the Climate Change Levy) which applies to industrial users, but it can be relieved for those who sign up to negotiated agreements. Furthermore, it applies to the energy content of electricity, rather than its carbon content, so does not directly encourage fuel-switching in electricity which, as discussed in the previous part of this study, offers some of the best carbon mitigation opportunities. In Denmark, fuel used for electricity generation is also exempt and there are special arrangements to protect the competitiveness of energy-intensive industries.

As these examples indicate, carbon taxes raise difficult social and economic (competitiveness) issues which can severely limit their political viability. These apply particularly in countries with high energy needs and energy and carbon intensive economies. This group includes not just many developing countries, but also the group of large resource rich OECD countries discussed in Part 1. Some OECD countries (such as the US) therefore make more extensive use of tax breaks (e.g. for investment in renewable energy sources), than of taxes as such, in promoting greenhouse gas reducing activities. For developing countries, the social issues are, of course, even more acute. It was pointed out above that for social reasons subsidies for energy use are a feature in many developing countries; fuel taxation would, in such cases, have such clear disadvantages in inhibiting accessibility and human development that they are often completely unrealistic.

Nonetheless, fuel taxes have many advantages: they raise revenue (unlike subsidies), and they also have the potential to improve price signals and avoid the need to "pick winners", leaving it to the working of markets to produce flexible and cost-effective responses – though, given the rarity of "pure" carbon taxes this may not always be achieved in practice. However, one of the possible advantages of carbon taxes – revenue-raising – can also be a problem. One of the attractions of motor fuel taxation to many

While fuel taxes have an important part to play in climate change responses, they are not an appropriate instrument in all circumstances.

OECD countries has been that it is close to being a "Ramsay" tax (see Box). This increases its attraction as a fiscal instrument but, by the same token, reduces its effectiveness as an environmental measure.

For all these reasons, while fuel taxes have an important part to play in climate change responses, they are not an appropriate instrument in all circumstances and need to be supplemented by other policy measures to ensure that social and other objectives are achieved. One way of doing so is to focus on sustainable use of the tax proceeds, for instance to support energy efficiency or other climate-friendly policies, or to introduce energy taxes as part of an overall restructuring of the tax burden from "goods" to "bads".

Price elasticity

The price elasticity of a particular good – that is, how much demand for the good changes in response to a change in price – is an important factor in assessing the impact of economic instruments. Demand for goods with a low price elasticity will not decline very much even if prices increase significantly. In policy terms, this means that economic instruments applied to low elasticity goods will have comparatively little impact on use of the relevant goods, so may be of limited effect.

This creates conflicting incentives for governments, if, as is often the case, they want to use economic instruments both to change consumer behaviour and to raise revenue. Traditionally, economists have favoured so-called "Ramsay taxes" as means of raising revenue with minimum economic distortion. This has in the past meant that energy taxes have been concentrated on motor fuel – probably the form of energy use with the lowest price elasticity, but also that where taxes are likely to achieve the least environmental impact.

Ramsay taxes are those applied to goods and services with very low price elasticity – that is, where an increase in the price makes very little difference to consumption levels. This is very attractive in economic terms: it permits revenue to be raised without distorting consumers' decisions (and hence economic activity). Ramsay taxes are therefore a recommended fiscal option. However, the fact that they have little effect on consumers' decisions reduces their attraction in environmental terms – the aim of carbon taxes is precisely to influence consumer decisions towards less carbon intensive behaviour.

There is some debate about the price elasticity of demand for motor fuels, and how much long-term impact price increases have. Nonetheless, as discussed in Part 1, transport fuel use has been increasing steadily in all parts of the world, and the trend is much more uniform than in other sectors, despite the huge differences in motor fuel prices and taxation between countries. There are significant differences in transport fuel intensity between countries, and some of the variation can be attributed to differences in price; nonetheless, there are no examples of sharp and sustained reductions in greenhouse emissions from this sector, as there are in other areas. The primary cause is a combination of the absence of substitutes for oil in transport and the low price elasticity. This is another reason why alternative measures such as voluntary

It is not entirely clear who has gained most benefit to date from the EU scheme – studies show different results – but it has certainly been accompanied by a significant increase in electricity prices.

agreements are used (see below), even by those countries with high levels of motor fuel taxation.

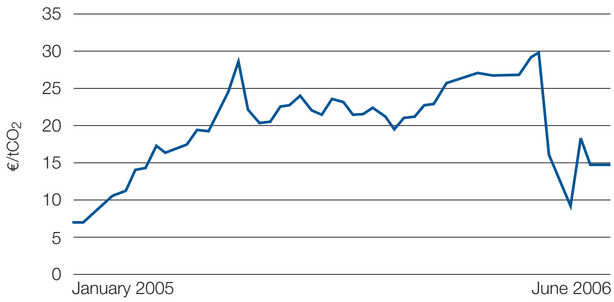
Emissions trading

Emissions trading is best regarded not as a way of reducing ghg emissions, but as a way of ensuring that a desired level of ghg emissions reduction is met efficiently. (The main current examples such as the EU scheme – see Box – are of "cap and trade" systems, under which participants are distributed a set amount of allowances up front and can meet their obligations either by managing their emissions to match the level of allowances, or by buying in allowances from other participants. In other words, the level of allowances is set administratively, rather than through the operation of the scheme itself.).

In principle, emissions trading should ensure that a given level of emissions reduction is met in a way which ensures flexibility and reduces the costs of compliance because participants have an incentive to identify and implement the least cost solutions. Because they are based on defined levels of emissions, they provide additional certainty – unlike fuel taxes and subsidies, which also influence behaviour through economic signals but whose impact can be difficult to predict and may (as with motor fuels) be relatively limited. However, as the EU experience shows, there may be a downside in terms of the price impacts, which are themselves unpredictable; also, unlike taxes, the benefits do not go to the public purse. It is not entirely clear who has gained most benefit to date from the EU scheme, studies show different results, but it has certainly been accompanied by a significant increase both in electricity prices (which is to be expected), but also in the price of input fuels for power generation (which in principle need not be the case). It is therefore arguable that the main benefits have flowed to fuel and electricity producers and that the costs have been borne by consumers.

Furthermore, it is difficult to draw long-term conclusions from the EU scheme, not only because it has been in operation for a short time, but also because its first phase operates over a limited period, and prices have proved very volatile. Its impacts have therefore primarily been on short-term switching between different forms of power generation (which is severely constrained by the existing capital stock) and on prices. To have a real impact on long-term emissions, the price signals given by an emissions trading scheme would themselves have to be long-term and credible, in a manner which ensured that they could influence investment in power generation and primary fuel production. There is no evidence that the EU scheme is yet having such an impact, unsurprising given the volatility of allowance prices (see charts on following pages), and the fact that the present stage of the scheme only runs until 2008. Discussions are currently underway about the next phase of the scheme, which runs until 2012. However, to give longer-term price signals a scheme would have to run for decades rather than years; this would require a settled international framework over such a period and political arrangements for setting allowances which would have credibility over that period. Given the uncertainties of political life and the short lifetimes of many governments, this is a very high hurdle to overcome, though the EU is attempting to do so by setting its own targets for emissions reductions up to 2020.

Figure 2-1
The EU emissions trading scheme allowance price – January 2005-June 2006



Source: DTI, 2006.

It is also not clear whether the scheme has produced a level playing field. There are major discrepancies both inside Europe and with the outside world. Companies inside Europe have to pay the cost of permits inside Europe but not those outside, which may distort the terms of trade without necessarily leading to any reduction in emissions (for instance it might lead to emissions producing activities locating outside Europe). There are also anomalies within Europe, where some countries appear to have set significantly stricter limits than others.

In addition, emissions trading is inevitably administratively complex: it requires sophisticated accounting and monitoring. This may make the approach more suitable in the foreseeable future for developed countries. Furthermore, for practical reasons it is difficult to expand emissions trading to smaller emitters: the transaction costs are too high. The first successful large-scale emissions trading scheme was with sulphur emissions in the US. The scheme had a few hundred of participants, each of them individually monitored. The EU CO_2 scheme has some thousands of participants and is still in many ways experimental. Extending such a scheme to the millions of smaller consumers and transport users is not an immediate prospect (though it is proposed to include aviation in the trading scheme). If economic instruments are to be aimed at individual users, practical arguments suggest that taxation is the main option.

In short, while emissions trading has many attractions, it is too early to say how large a place it is likely to play in climate change strategies: there is still much learning to be done about such schemes.

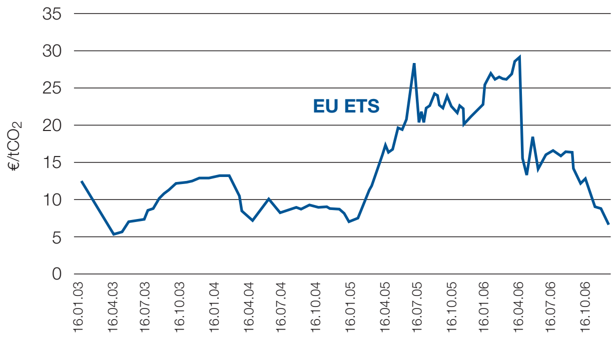
The charts below indicate the volatility of prices under the EU scheme. Prices rose at first from well under 10 euros, hitting 30 euros on occasion, only to decline somewhat during the first eighteen months of the scheme.

This relatively strong, though volatile, performance was followed by a price collapse, shown in the chart below. At the time of writing, current permit prices were around 1 euro, though forward prices for 2008 on were trading at above 15 euros, reflecting the Commission's much tighter approach on permit allocations under the second phase of the scheme.

The EU Emissions Trading Scheme (ETS)

A number of CO_2 emissions trading schemes have been introduced by individual countries (such as the UK and Denmark) and even companies (such as BP). However, the world's first and biggest international trading system is the EU-wide Emissions Trading Scheme, introduced in January 2005. It applies to around 12,000 installations including industrial consumers and electricity generators, but also a few larger publicly owned combustion plants such as those in hospitals and educational institutions. In total it covers around half of the EU's total emissions of CO_2.

Figure 2-2
Market price of EU allowances in €/t, 2003-2006



Source: Point Carbon.

The scheme is a cap and trade system. Participants are distributed allowances up front and are required to surrender a quantity of allowances each year which matches the level of their emissions in that year. The level of allowances is set by member states, via National Allocation Plans approved by the Commission; in principle, the totals should both be consistent with Kyoto targets and be less than what the sector would have emitted in the absence of emissions trading – this ensures that there is a scarcity of allowances, thus creating a market for them (in practice, some of the allocations have been controversial). There are penalties for non-compliance designed to be severe enough to create a clear incentive for participants to comply.

The scheme is being implemented in stages, with periodic reviews. The first stage lasts up to the end of 2007 and is designed, among other things, to allow experience to be gained and learned from; allowances for the subsequent period of 2008-2012 remain to be set but should be lower than the initial allocations (and so may give rise to even more controversy). The scheme itself covers the EU but is designed to allow trading with other parts of the world via the Kyoto mechanisms. Under a so-called “linking directive” the ETS can also accept CDM and JI credits (see below), subject to conditions on the technologies and the number of credits involved.

Average trading volumes have been around 1.5 million allowances per day, so the market has been reasonably liquid (though tiny compared with currency and equity markets). However, prices have been surprisingly volatile. They were initially expected by many to settle below €10 per tonne but since the Scheme started they have risen from around €6 to a high of above €30 and then fell sharply again to below €20, finally to collapse to around 1 euro (though forward prices for the second phase of the scheme have been more robust – see Figure 2-2).

Clean Development Mechanism (CDM) and Joint Implementation (JI)

Emissions trading is one of the flexible mechanisms envisaged as part of the Kyoto system. There are also two further mechanisms designed to extend the benefits of flexibility, particularly to developing countries which do not directly come within trading schemes such as the EU’s, partly because of the practical issues discussed above, partly because of the fact that schemes such as the EU’s rely on emissions caps. Non-Annex 1 countries do not, of course, have emissions caps under the Kyoto system – see Box.

Clean Development Mechanism (CDM) and Joint Implementation (JI)

CDM and JI are two of the flexible mechanisms allowed under the Kyoto Protocol and, unlike the third mechanism – emissions trading, their form reflects the specific structure of the Kyoto arrangements. They therefore need to be described briefly.

There are two main country groupings under Kyoto: Annex 1 countries are the 36 industrialised countries and economies in transition listed in Appendix 1 of the UNFCCC, which have various responsibilities and commitments under the Convention. The term is also used more loosely to describe the 39 countries listed in Appendix B of the Kyoto Protocol which have emissions reduction obligations – the categories largely, but not entirely, overlap. The key point is to distinguish this group of countries from the so-called non-Annex 1 countries, which do not have formal emissions caps under the Protocol.

Under the terms of the Protocol, Annex 1 countries can invest in either JI or CDM Projects and can also host JI projects. They cannot, however, host CDM projects, which must be implemented in non-Annex 1 countries. JI is a relatively straightforward way of transferring the credits from emissions reducing projects between countries which are subject to caps. CDM is more complicated, both conceptually and administratively. First, it has two objectives: not just to enable one party to meet its emissions reduction objectives, but also to promote sustainable development in the other (non-Annex 1) country. Second, because the non-Annex 1 country by definition has no emissions cap, strict criteria are needed to ensure that the emissions reductions are additional – i.e. that they would not have occurred in the absence of the CDM measure concerned.

The key difference, as compared with the ETS, is that these mechanisms are project-based. This gives some key advantages – for instance, it gives positive signals for investment; it also allows social and other factors to be taken specifically into account (as indeed is a requirement of the CDM). Furthermore, like all economic instruments, these mechanisms should offer the opportunity for lower compliance costs. In principle they could provide cheaper mitigation options than a more restricted scheme like the ETS. This is because they offer a wider market in which there should be many low cost options that developing countries have been unable to exploit because of a lack of resources or capacity, or an absence of incentives outside the schemes.

On the other hand, the advantages of economic instruments are normally seen in terms of simplification and flexibility, and an ability to take advantage of the responsiveness of markets to reduce costs. These advantages are less clear cut with project-based approaches. The various conditions attached to the CDM increase transaction costs and create some definitional problems (in ascertaining the degree to which emissions reductions are incremental to what might otherwise have taken place). There is also a self-imposed but significant restriction on the sorts of project which can be eligible – large scale hydro and nuclear being excluded. These issues are currently being grappled with and it may be possible to develop more streamlined and effective procedures in future.

For many countries, the Kyoto mechanisms also raise political issues – some Annex 1 countries believe that they need to show a lead and should not rely on efforts by others (especially so-called

There is very considerable variation in the planned use of the Kyoto mechanisms, in both the developed and developing world.

"hot air" in some formerly centrally planned economies, where, as discussed in Part 1, emissions have fallen for reasons other than climate change concerns). Some non-Annex 1 countries are also suspicious of the mechanisms, either because of the administrative complications or because they see it as a way for Annex 1 countries to evade direct responsibility for a problem of their own creation. Finally, of course, the Kyoto mechanisms are not directly relevant to those countries which have decided not to ratify the Kyoto Protocol.

There is therefore very considerable variation in the planned use of the Kyoto mechanisms, in both developed and developing world – and in practice they have not really taken off in the same way as, say, emissions trading. In practice also, more agreements have been made in relation to JI than CDM, though in terms of the WEC goal of accessibility CDM (or analogous schemes) would clearly be of much greater potential significance.

In the EU, according to the European Environment Agency[i], twelve member states have decided to use the Kyoto mechanisms. They project that about one third of the total required emission reduction will be met in this way (about 110 mt CO_2 per year during the first commitment period of the Kyoto Protocol from 2008 to 2012). Other EU countries have no plans to make use of the mechanisms and want to meet their targets by domestic action alone. But from the allocations of those countries which have identified an interest in these measures, the market is likely to reach at least €3 billion; the European Commission expects it to rise over time to €20 billion or more, which would make it one of the most significant sources of international capital for developing countries.

In developing countries themselves there is a similar variation of approach. South Africa, for instance, is taking a strong centrally coordinated approach to CDM, with a CDM secretariat which would act as a single point of entry for all information relating to CDM, a central registry for projects, and a vehicle for securing project approval – though it has relatively little in the way of actual results to date. Other countries are unsure about CDM or positively intend not to participate in the scheme.

The differences of approach are visible in the breakdown of projects under the scheme. Of the 565 registered at the time of writing, over 90% came from two regions: Asia Pacific and Latin America, and within that total, three countries were particularly significant: Brazil, India and Mexico, Africa hardly featured. This pattern can, however, be expected to change. China, for instance, was initially slow to get involved in the mechanisms but has recently shown itself much keener to host CDM projects. Many more schemes are in the pipeline in many parts of the world; the UNFCCC expects the total to reach about 1,600 projects, delivering some 2 billion tonnes of greenhouse gas emissions reduction. About half the projects are in the energy sector, principally renewable sources. Energy efficiency accounts for a very small proportion, probably reflecting the high transaction costs involved. The concentration on renewables also reflects the severe restrictions put on such alternative technologies as nuclear, large hydro or clean fossil systems – the system is designed in such a way that it gives priority to renewable sources.

In addition to the formal Kyoto mechanisms, the possibility of "Green Investment Schemes" has been put forward, with the aim of ensuring that revenue

Regulatory approaches are widespread in OECD countries, all of which report a range of measures.

from the sale of CDM or JI allowances should itself be used for emission reducing projects. There is also a range of more general investment funds, not necessarily directly linked with the Kyoto mechanisms, under which subsidies are available (often on a competitive basis) for projects offering the most cost-effective environmental improvements. Such funds can be based on government support or operate on a market basis, allowing investors to place their funds in projects which may at the same time produce a return and benefit the environment.

Regulations and standards

Regulations and standards are a very common approach, particularly in the OECD where they account for about one quarter of the policy instruments reported. It is difficult to generalise about regulatory approaches since they apply across so many sectors and in such a variety of ways.

However, common approaches include:

- **Buildings standards** Nearly all countries in the OECD, and many outside, have building regulations of one sort or another. While originally designed mainly to promote safe construction, many now specify insulation or other relevant standards, such as the overall energy performance of buildings (an approach increasingly being adopted in the EU).
- **Appliance standards** Again, it is becoming increasingly common to specify minimum efficiency standards for appliances, or for particular functions (such as standby operation). As with buildings, the emphasis in the OECD is increasingly on a more holistic approach to "eco-design" and focusing on products with high potential for cost-effective reduction of ghg emissions.
- **Vehicle regulations** and standards of various sorts (see discussion below) have been very widely used in the transport sector with the direct intention of improving fuel efficiency. Many wider transport measures also have an impact on emissions (e.g. speed limits, congestion charges etc) but are not examined in detail in this study for the reasons discussed above.
- **Other environmental regulations,** such as the EU's Integrated Pollution Prevention and Control system which mandates the use of state of the art technologies, may also be aimed, at least in part, at reducing CO_2 emissions. What is virtually unknown (as compared with, say, emissions such as sulphur) is direct controls on CO_2 as a pollutant. That is, specific CO_2 emissions limits for particular plants or products (other than the sort of overall limit imposed via trading schemes, or via voluntary agreements). This is partly because CO_2 is not always regarded as a pollutant as such (though the issue is largely a question of semantics); partly because CO_2 is distinct from many other emissions: CO_2 is a direct result of fossil fuel combustion not a by-product or the results of impurities in the fuel source.

Regulatory approaches are widespread in OECD countries, all of which report a range of such measures. They undoubtedly have an important place in promoting efficiency and in overcoming market failures – not only the failure to internalise environmental costs but also some of the well recognised barriers to greater energy efficiency, such as consumer indifference and incomplete incentives in landlord/tenant relationships etc.

Regulatory approaches have been widely adopted in developed countries, they therefore tend to be less common in developing countries.

Nonetheless, because they generally operate indirectly on energy efficiency rather than directly on CO_2 emissions, it is often difficult to identify the precise results of such regulatory approaches – for instance, higher levels of insulation may lead to higher levels of comfort (higher internal temperatures) with little impact on fuel use. Vehicle standards in particular may have complex impacts. There is considerable evidence, for instance, that the vehicle fuel efficiency standards applied in the US after the oil price rises of the 1970s (the so-called CAFE standards) had a significant initial impact in increasing fuel efficiency and thus reducing emissions per vehicle, though it is difficult to separate out the impact of the standards and that of the higher oil prices which prompted them. Furthermore, over time the impacts were much less clear cut, for a number of reasons:

- While the efficiency of individual vehicles improved, people's vehicle preferences changed. In particular, the popularity of so-called SUVs (Sports Utility Vehicles) soared – at one point they were accounting for over 50% of the new car market (though preferences may be changing in response to higher oil prices). They are classified as light trucks under the regulations and subject to laxer efficiency standards, so fuel use per vehicle rose as they formed a greater proportion of the car fleet.
- Fuel use depends on a number of factors in addition to vehicle efficiency – most obviously the number of vehicles in use and the average distance travelled per vehicle, which may vary for reasons unconnected with the vehicle standard itself.
- Finally, the increase in measured efficiency per vehicle may not adequately reflect fuel use in practice. Other factors include driving habits, increasing congestion and the change in vehicle equipment. For instance, cars with a larger range of appliances generally result in increasingly higher specifications electric windows, air conditioning etc. Standard driving modules for efficiency tests do not pick up all these changes, which can add considerably to fuel use in practice.

For all these reasons, while higher regulations and standards undoubtedly have a place, monitoring and measuring their impact is extremely difficult; it is not possible to rely on simple pro rata calculation (such as that a 10% increase in vehicle efficiency or in a house's insulation standards leads to a 10% reduction in emissions). Indeed, because of the difficulty of measuring what might have happened in the absence of such standards, it is often difficult to know whether they are having any impact at all.

It is also difficult to measure their cost-effectiveness and to know what particular level of regulation is justifiable, so there is a risk of market distortions. The higher cost of appliances, vehicles etc, which may result from higher standards of regulation, may therefore act as an economic barrier, while having unclear environmental impacts. Regulations may effectively create trade barriers or a loss of competitiveness if national standards are set above world levels; they may also raise administrative or other complications and problems of enforcement and monitoring.

While regulatory approaches have been widely adopted in developed countries, they therefore tend to be less common in developing countries. In many cases, they are able to accept the de facto international standards and the incentives to efficiency

Voluntary measures are often more effective when combined with other measures.

created by the standards set by OECD countries; in other cases, they are able to set their own standards, taking account of national circumstances. In some cases, however, the problem is mainly one of enforcement – high standards are set, but in practice ignored because of a lack of administrative capacity for enforcement.

Voluntary agreements

In principle, voluntary agreements should get round some of the problems of regulation. Because they are negotiated directly with those affected (usually industrialists and manufacturers), they should have the benefit of flexibility of response and cost-effectiveness. However, the simple fact of being voluntary creates obvious problems of enforcement; it also offers scope for gaming. There is usually a degree of information asymmetry – the industry generally has better information than the government side about its true costs and may therefore be in a stronger negotiating position.

Voluntary agreements are often more effective when combined with other measures (e.g. taxes) or backed up by sanctions. Examples include the UK Climate Change Agreements, which are voluntary agreements but offer the carrot of relief from the Climate Change Levy. Voluntary agreements have also been used extensively in the Netherlands for many years. These agreements are long-term and integrated into the environmental permit-setting process. They are backed up by sanctions – those who do not join up to the agreements incur direct obligations to undertake cost-effective voluntary measures. However they do not apply directly to energy intensive industrial sectors.

A major example of a voluntary agreement, designed to improve vehicle standards, is the agreement the EU has reached with a number of car manufacturing associations in Europe, Japan and Korea. This aims to achieve average CO_2 emissions across the new passenger fleet of 140g CO_2 per kilometre by 2012 (a 25% reduction compared with the mid-1990s), on the way to a longer-term objective of 120g. New car emissions have indeed fallen across the EU – for instance, in 2003 they were 12% lower in the EU-15 than in 1995 – but they are not on track to meet the target. Such schemes incur similar problems to those of the CAFE standards discussed above, i.e. whether an improvement in new car efficiency leads to reduced overall vehicle emissions. In addition, they raise further issues (manufacturers from non-participating countries remain outside the agreement), as well as potential difficulties of enforcement (ultimately it is for consumers to decide what vehicles to buy). As noted in Part 1, transport related emissions across the EU, as in other areas, continue to rise, so it is clear that the agreements are not a solution in themselves.

Another model is the overall agreement with a representative industry association, such as the Keidanren Voluntary Action Plan in Japan, under which the Japanese industry association, the Keidanren, is endeavouring to reduce CO_2 emissions from industry and energy conversion to below 1990 levels by 2010. About 35 sectors, representing over 80% of industrial emissions, are participating, and the Plan is on track to meeting its target.

Voluntary agreements appear to be relatively rare outside the OECD, partly because of problems of monitoring and enforcement, but also because

Voluntary agreements appear to be relatively rare outside the OECD.

of the possible implications for competitiveness and growth. The imperative of development is often so overriding that it is simply unreasonable to ask national manufacturers, whose outlook is often export-focused, to take on what appear to be competitive burdens on a voluntary basis. Nonetheless, a number of countries are considering the use of voluntary agreements – for instance Cote d'Ivoire.

There also wider sectoral discussions – about how a given sector can make a global contribution to emissions reduction by voluntarily taking on particular targets or objectives. Clearly the global scope of such approaches can significantly increase the potential impact; on the other hand, the problems of monitoring and enforcement are also multiplied considerably.

Information and awareness

Many studies have identified a huge range of cost-effective opportunities available across the economy but which are not currently being implemented. One of the barriers to exploiting these opportunities is often seen to be a lack of consumer information and awareness. If this can be overcome by the provision of better information, it may be possible for consumers to make their own decisions in a way which promotes improved energy efficiency and lower emissions without the need for further intervention. Consumer choice could also lead to the deliberate use of lower carbon intensity fuels (e.g. renewable electricity) even where it is higher cost, helping overcome the failure to incorporate environmental externalities.

Measures in this area are relatively low cost and have considerable attractions for their ability to promote sustainable development without the risk of significant market distortions; indeed the provision of better information is one way of making markets work better. Most governments, in both the developed and developing world, have therefore introduced information measures, education and awareness campaigns and the promotion of consumer-relevant energy efficiency information are particularly common. Measures such as energy labelling of appliances or buildings are also fairly widespread. Sometimes such measures are combined with subsidies (for instance, subsidies for energy efficiency surveys in industry or for the installation of energy monitoring and targeting systems) or regulation (as with some labelling schemes, or the requirement in some countries for the documentation for a house sale to include an energy audit).

The problem with such measures is not that they are in any way objectionable in themselves but in there are question marks over their ultimate impact and effectiveness. It is noteworthy that, despite their cheapness and flexibility, they account for only a small proportion (less than 10%) of reported measures. Governments have in many cases been running information programmes of this sort for many years (often since the 1970s, when they were introduced because of the pressure to reduce energy consumption for resource reasons); while recognising their value, they also recognise that they are not on their own enough to deliver significant emissions reductions. While they form part of most programmes, they are essentially supporting measures, not the centrepiece of any government's programme.

Technology is central to nearly all governments' approaches in both the developed and developing worlds.

Research and development

Research and development is the fifth of the UNFCCC's categories. In principle, it is probably better to take the category widely to include research, development, demonstration, technology choice and deployment and technology transfer, because of the importance of all these aspects of the technology issue to the longer-term emissions picture. In this wider sense, technology is central to nearly all governments' approaches in both developed and developing worlds, though of course there are considerable differences of emphasis. Technology is important because it holds out the prospect of reducing both energy and carbon intensity, while potentially also reducing costs. In other words, it can in principle make a major contribution to all the pillars of sustainable development. It therefore forms the heart of nearly all long-term visions of a low carbon future, whether based on improved energy efficiencies, a hydrogen /fuel cell economy, carbon capture and storage, nuclear, or the significant development of renewable energy (or some combination of these technologies). Such long-term aims have featured in a number of international agreements. Some are specific and focused on a particular technology, such as the Carbon Sequestration Leadership Forum, which is a focus for international collaboration on various aspects of carbon capture and storage technology. Some are wider in their aims, e.g. AP6 – see Box.

AP6 – a technology based approach

The Asia-Pacific Partnership on Clean Development and Climate Change (AP 6) was set up in early 2006 by six Asia Pacific nations – the US, China, India, Japan, South Korea and Australia. These countries account for around half of global ghg emissions. They come from both developed and developing worlds; some have ratified the Kyoto Protocol, some have not.

The AP6 Charter is designed to be consistent with the principles of the UNFCCC and to pursue development, energy, environment and climate change objectives in an integrated fashion through technology cooperation. This is defined in a broad fashion to include development, diffusion, deployment and transfer of technologies and practices for both the short and long-term. A list of existing and emerging technologies is included in the AP6 Vision statement, ranging from energy efficiency, clean coal, nuclear, renewables, carbon capture and storage and advanced transportation, so the scope is very wide. It also refers to longer-term "transformational" technologies such as hydrogen and nuclear fusion.

The governance of the Partnership is much looser than the Kyoto arrangements – decisions are made by consensus, no sanctions or funding obligations are involved, and no formal commitments have to be made, though some countries have announced voluntary allocations of funding.

Carbon capture and storage – one of the most promising technologies.

Eight Task Forces have been set up, in such areas as cleaner fossil energy or for particular sectors such as steel or buildings, and they are currently developing action plans for technology development in their areas.

Carbon capture and storage

One of the most promising technologies currently under discussion is carbon capture and storage. This is a process whereby CO_2 from the combustion of fossil fuels is first captured then transported to a safe permanent site and stored indefinitely. The CO_2 can be extracted either before combustion – e.g. in the process of coal gasification – or after combustion (though post-combustion capture can raise practical problems, since the exhaust stream normally includes large amounts of other gases, principally nitrogen). One option is therefore to burn coal in a pure stream of oxygen (oxyfuel) so that the product of combustion consists mainly of CO_2. Carbon capture and storage is the subject of an international agreement – the CSLF – and has also recently been examined in an IPCC special report (to which the reader is referred for a detailed discussion).

It is, of course, in many ways still at an experimental stage – there are major questions about the economics and feasibility of the approach, as well as its long-term environmental acceptability. Nonetheless, it is not a purely academic exercise. There are a number of active projects already under way, which are much more than laboratory experiments – the three largest projects (at Weyburn in Canada, Sleipner in the North Sea and In Salah in Algeria) each sequester around 1m tonnes of CO_2 annually. Many more proposals are under active discussion or development, both from companies, such as Vattenfall and RWE, and from governments, such as the US's Futuregen project.

One advantage of the approach is that the economics of some such projects can be improved by using the CO_2 produced to enhance oil recovery (the CO_2 is pumped down an oil well, forcing more oil to the surface). A recent proposal in Norway, for instance, involves a combination of different elements. The Norwegian oil company Statoil would construct an 860-megawatt gas-fired power plant at its Tjeldbergodden methanol complex in mid-Norway. The CO_2 produced by the plant would then be piped to Shell's Draugen oilfield off Norway – and later also to Statoil's Heidrun field – and injected into subsea reservoirs to increase the rate of oil recovery. Some 2-2.5m tonnes of CO_2 a year could be captured in this way. The economics are improved by the oil recovery element; nonetheless, the companies have made it clear that substantial government funding and involvement would also be needed. The cost of the CO_2 capture and storage element would roughly double the capital costs of the power plant while operationally also reducing the plant's energy efficiency.

Enhanced oil recovery is not, of course, the only possible incentive for carbon capture, and in the long run the potential for storage in other geological formations, such as saline aquifers, is huge. In the case of the Sleipner project mentioned above, an incentive for storage of CO_2 is given by the Norwegian carbon tax.

It is also difficult to imagine that the problem of reducing emissions can be solved without a major programme of technology development and deployment.

A problem with such approaches is that technology development is inevitably long-term in nature and uncertain in results. Most of the technologies described above would have to achieve significant cost reduction to be deployed on a scale wide enough to deliver significant emissions reductions, without compromising sustainable development. Such cost reductions cannot, of course be guaranteed on any particular timescale, if ever – there are examples of promising technologies, such as nuclear fusion, which have been explored for many decades without yet reaching the stage of commercial application. On the other hand, it is also difficult to imagine that the problem of reducing emissions can be solved without a major programme of technology development and deployment.

Many countries, while recognising the importance of technology development for the longer-term, put great emphasis on the shorter-term need for the deployment of existing state of the art technology – very considerable emissions reductions could be achieved on the basis of these technologies alone. This technology forcing can, however, be achieved in a range of ways, many of which are discussed above – e.g. via regulations, taxes or other incentives. In many developing countries, there is also considerable emphasis on direct command-and-control measures. In these countries (as was the case until recently in the OECD) technology choice is often mandated by the government. For instance, the capital investment programme of state owned utilities is usually agreed with governments, so that power generation technologies are effectively determined by government. Furthermore, because of the rapid growth of transport and power demand in many developing countries, the scope for effective fuel-switching is often much greater than in developed countries (which are more constrained by their existing and slowly changing capital stock).

Many developing countries therefore report as their main climate change measures, the direct technology choices made by governments and utilities (e.g. switching to gas and renewables in power generation).

So technology can be important both in long- and short-term and in both developed and developing countries. However, it covers such a broad range of different types of measure (as discussed in this section) and of policy area (as discussed in the next section), that it is difficult to give any single overview here – the different aspects are discussed separately in the relevant sections.

Just as there is a wide range of different forms of renewable energy, so there is a range of different policy approaches to support for renewables.

2.2 Analysis of policies according to policy areas affected

2.2.i Energy sector

Renewables

The majority of climate change measures internationally fall in the energy sector, and most countries have included support for renewable sources within their policy portfolio, in both the developed and developing worlds. The potential benefits of renewable energies are clear: first, that they directly reduce the carbon intensity of energy use; second, that they are likely to be more sustainable than fossil fuel sources (though this is not always the case – traditional biomass, for instance, is often harvested unsustainably). Furthermore, they are generally available indigenously and can thus reduce the risks of disruption or price rises in internationally traded fuels. The sources of renewable energy are very varied and a huge range of different natural resources can be used (sun, wind, tides, photosynthesis in plants, rain etc) so nearly all countries have at least one significant renewable source available. In principle, therefore, renewables can contribute to all aspects of energy policy and sustainable development and they are likely to continue to form a centrepiece of climate change strategies across the world. That is not to say that they are without problems – some of which are discussed below – but, given their importance, the message is that policies need to be directed, among other things, at overcoming these problems in order to enable renewables to play a larger part in the world energy mix.

Just as there is a wide range of different forms of renewable energy, so there is a range of different policy approaches to support for renewables.
The main types are economic instruments, regulation, and R&D, and examples of such policies are found in all parts of the world. Common approaches in the developed world include renewables portfolio standards (requiring electricity suppliers to source a certain proportion of their supply from renewables); subsidies (or cross-subsidies via electricity prices), which increase the income of renewables generators or subsidise investment costs; tax breaks, (with similar objectives to investment subsidies); tradable certificates (on the lines of emissions trading, so-called "green certificates" can be traded between companies to meet their portfolio obligations); and research and development support for new renewable sources.

In developing countries, support for renewables is also widespread and a similar range of measures is used; though economic instruments are rather less common than in the OECD, for reasons discussed in the previous section, while direct technology prescription for state-owned utilities is more common. In general, most developing countries (and economies in transition) are at an earlier stage in their support for renewables than countries in the industrialised world, most of which have well developed programmes, but there are some major exceptions, discussed below. Because renewables are generally indigenous sources, national circumstances are a critical factor; many developing countries have a comparative advantage in one area or another, so in some cases they are significantly ahead of the OECD.

Large scale hydro is regarded as more or less fully exploited in many OECD countries.

However, because of the great difference between sources, the different types of renewable are best discussed separately.

Large scale hydro – Apart from traditional biomass, large-scale hydro is far and away the most important renewable source. It accounts for about 15% of electricity generation worldwide and the generating process itself emits no CO_2. In the right circumstances, hydropower is very economic and it reduces the requirement for fossil fuel sources. Countries like Norway, New Zealand, Costa Rica, Brazil and Iceland have high proportions of hydro resources in their electricity supply, low power prices and low CO_2 emissions.

However, large scale hydro projects have very significant environmental impacts of other sorts (including emissions of greenhouse gases, e.g. from forest clearance or rotting sedimentation), and assessing their overall sustainability is a complex matter – discussed in some detail by the World Commission on Dams.

The availability of hydro resources also obviously varies from country to country – wet, mountainous countries will have significant resources (e.g. Norway, where 99% of power comes from hydro), while dry flat countries will have none (less than 1% of electricity across the whole Middle East comes from hydropower).

Large scale hydro is regarded as more or less fully exploited in many OECD countries. The position in developing countries varies. Latin America as a region has already exploited a good deal of its hydro potential (it accounts for over 80% of power generation in Brazil and Paraguay for instance) but there is probably room for further expansion. Africa makes relatively low use of hydro at present but there is thought to be very significant potential for growth; the so-called Greater Inga project alone, which potentially has a capacity of up to 40GW, is so large in relation to the continent's power demand that it has been seen as a possible source for exports of power outside Africa. China's Three Gorges project, when completed, will be the largest hydro project in the world with a capacity of around 18GW.

Such projects are, however, often highly controversial and it is not clear whether hydro power will be able to increase its share of the energy mix substantially (as opposed to achieving an increase in absolute volumes) while remaining sustainable.

Small scale hydro – is generally regarded as more acceptable and receives support in many countries in both developed and developing worlds. For instance, nearly half of low income non Annex 1 countries are either implementing or considering small hydropower applications, and interest in these measures is particularly strong in Africa. There is significant scope for expansion in many countries but – given the small scale of the individual projects – they are unlikely to make major inroads into the overall global energy mix, though they may help in increasing accessibility and availability in remote communities. The replacement of older turbines with more efficient models can also increase the capacity of existing small hydro installations.

There are often, however, cost issues (costs are site-dependent but often higher per unit than for larger plants) as well as connection problems (integrating smaller remote sites onto a national grid). In any event, the distinction between small and large scale hydro is often simply a matter of definition (in the

Wind power is one of the fastest growing forms of power generation, but there are almost certainly practical limits to the process.

UK, for instance, there have been examples of hydro plants being downrated in capacity in order to qualify for support as small scale) and it would be wrong to take an oversimplified position to the effect that small scale hydro is good; large scale hydro bad.

Wind – Wind power is one of the fastest growing forms of power generation and is dominant among new renewables in developed countries in particular, although it is also significant in some developing countries. Growth has been particularly fast in Europe, where it has been running at 15% pa or more for some years, although the US also has significant installed capacity. Many of the countries with the highest total installed wind power capacity are in the OECD – Germany (18.4GW), Spain (10GW), the United States (9.1GW), and Denmark (3.1 GW). But support is not confined to developed countries; another country with significant capacity is India (over 4.4GW and rapidly growing – it has recently overtaken Denmark). China is also emerging as a significant wind power market – one of the world top ten – with a capacity of over 1.3GW some experts are forecasting that this could grow to 30GW by 2020.

This robust growth has been supported by two main factors:

- the relatively good economics of wind. As with other renewable sources, the cost of wind power is site-dependent, but the technology has advanced significantly in recent years and costs have come down fast.
- strong support in many countries. For instance, Germany has operated a so-called "feed-in" law, giving wind producers a price linked to the retail price of electricity and well above that of fossil producers; China has a broadly similar (though smaller scale) system of support. Countries as diverse as the US and India offer an array of tax incentives. Other countries (and some US states) operate quota (portfolio) systems and other forms of support for renewables in general, a large proportion of which in practice goes to wind power (there is a useful overview in the publication "Wind Force 12" available from the European Wind Energy Association).

There are, of course, many barriers to the greater penetration of wind – including the intermittency and unpredictability of supply, and the availability of suitable sites. As with hydro, there is a tendency for the most environmentally and economically acceptable sites to be exploited first so that incremental expansion gets increasingly difficult. New sites may need to be offshore (adding to costs of construction), or remote (adding to costs of transmission), or both. After a certain point, as in Germany currently, there may be increasing worries about the problems of integrating large quantities of intermittent power into a stable grid – generally these difficulties are regarded as increasingly serious when the proportion of wind power reaches above 20% or so. Integrating wind power is often easier when it can be combined with flexible sources (such as hydro) or within larger systems (e.g. Denmark is able to export significant amounts of power to neighbouring systems, with which it is strongly interconnected).

In developing countries, there may be straightforward economic problems – although wind is generally more economic than other renewables, it is still often more expensive than fossil power from local resources. China, for instance, has therefore

Emphasis should be put on the need for the right circumstances to be present.

introduced the support mechanisms described above, and has a number of CDM-supported wind projects. In other cases, specific international funding sources may help overcome the cost barrier. Mexico, for instance, currently has very limited capacity of new renewable energy but is planning a new wind project of 101 MW at La Venta with support from the Global Environment Facility.

Policy should therefore, as suggested above, be directed partly at helping overcome such barriers. Nonetheless, while there is enormous potential for the expansion of wind capacity, as with hydro, there are almost certainly practical limits to the process.

Biomass – is also important in many countries, and particularly in the developing world. It is important to distinguish between traditional biomass (firewood, animal dung etc) and more sustainable modern forms of biomass. Traditional biomass is currently a very significant form of energy in many developing countries, but there will almost certainly need to be a move to more commercial and modern energy forms, because of the environmental impacts as well as accessibility and availability issues. Modern forms of biomass are most common in developed countries but by no means confined to that region. They are also important in many developing countries, which offer not only significant opportunities for exploiting this resource, but also some of the world's best developed programmes.

Biofuels are discussed below, under transport, but raise many of the same issues as other forms of biomass. Two of the key problems with biomass are developing the market and creating appropriate technology. Developing a biomass market often involves a sort of chicken-and-egg problem.

Farmers do not want to grow crops for biomass, as opposed to food, unless they are confident there will be a market (which will normally need to be local, because of the relatively high transport costs of fuel crops). On the other hand, developers of biofuel facilities also need to know whether there will be an input available for their facilities, given that there is not a world market (as for most fuels) to draw on.

One way of mitigating these problems is by blending, which allows the market to be developed gradually. Gasohol (an ethanol-gasoline blend – see below) is one example of an approach to using biomass which simplifies the technical problems by enabling existing fossil fuel technologies to be used. The same principle can be applied in power generation where co-firing of biomass with solid fuel is often possible up to a level of 15-20% or so of fuel input.

Other forms of power generation from biomass are also possible of course. In some circumstances they can be very effective – for instance use of timber waste by-products to power generating plants in Finland. Gasification can also be effective with animal wastes, and this approach is being implemented in developing countries such as China and India, which has some 3.8 million small biogas plants. However, gasification of energy crops in developed countries has not, so far, lived up to its theoretical potential.

As these examples show, emphasis should be put on the need for the right circumstances to be present. In general, this is more often the case with developing countries in the south because of their favourable climatic conditions. For instance Brazil, in its biofuel programmes, has a combination of hot

Longer-term development of solar technologies will probably depend on further decreases in costs.

weather; abundant rain; fast, low input plant growth: relatively simple process requirements: and the availability of a renewable energy source (sugar cane – bagasse) for process use. In other circumstances such benefits may not be available – Europe for instance has high input agriculture; North America tends to have high energy requirements (for transport and processing). These offset the environmental advantages from the use of a renewable source. Calculations of the net benefits are difficult and situation-dependent – there has recently been some controversy about the impacts of the US ethanol programme, for instance. As emphasised in the recent WEC Life Cycle Study, such impacts need to be take carefully into account in calculating the true benefits, in terms of acceptability, of such programmes.

There are also some general issues – for instance land-use: biomass risks encouraging an environmentally sterile monoculture and competes with other potential land uses – there have been accusations that in Brazil it has been associated with clearance of the Amazonian rain forest, in other cases it may compete with food production; but these only reinforce the need for careful assessment of the circumstances of individual cases. These issues are discussed further in Part 3.

Other renewables – although other renewable sources do not at present make a significant contribution to the global energy mix, many may well offer scope for expansion.

Solar power in particular is seen as promising by both developed and developing countries alike. It combines three key features:

- a universally available energy source (sunlight). Even temperate countries can often enjoy a surprisingly large solar potential, but this is one resource in which the Southern Hemisphere probably has a competitive advantage, for obvious reasons.
- a variety of technologies to capture the source. Photovoltaic cells convert solar power directly to electricity, but other technologies use the power to heat water directly; or to focus the sunlight with mirrors to generate high temperatures for steam-raising – concentrated solar power may be an important future technology. Sunlight could also (potentially) be used more directly to power turbines using a rising column of solar-heated air.
- flexible and modular applications. Photovoltaic cells can be arranged in huge arrays (e.g. the Bavaria Solarpark, which contains over 50,000 solar panels); but cells or solar heating elements can also be used on such small sites as rooftops, enabling them to be installed locally and with minimal environmental impact. In 1999, for instance, Germany launched a 100,000 roofs programme to install solar photovoltaic equipment on 100,000 roofs and walls across the country, to create some 300 MW of generating capacity.
- solar power is often also suitable for off-grid applications in many developing countries – around 20% of installations are currently off-grid.

Solar power, and solar photovoltaics in particular, have therefore been growing very fast in recent years, at a rate of around 40% a year. The global market is expected to increase to around 5 GW by 2010. Nonetheless, longer-term development will probably depend on further decreases in costs – photovoltaics and most other solar power sources still tend to be much more expensive than conventional power (though costs have been coming down fast). They also tend to be extensive rather than intensive sources (i.e. they require a large land area to produce significant amounts of power, though this is offset by the flexibility of siting mentioned above). They also often involve significant installation and maintenance costs, which can create problems in the remote locations for which they would otherwise be suitable. For these reasons, while many developed countries have extensive programmes, in developing countries there can be problems of cost and accessibility – the funding of solar power often requires the support of international aid programmes. Nonetheless, because of their natural advantage in terms of access to solar resources, many developing countries have significant solar programmes.

India, for instance, has a major photovoltaic programme and has installed over one million systems across the country – putting it fourth in the world after Japan, the US and Germany. Of the world's 94 million square metres of solar thermal installation capacity, China has around 55% (52 million square metres), other countries are trailing far behind – Turkey is next at 9.3 million, then Germany at 4.9 million. Capacity in India is also growing fast and the potential is estimate at some 140 million square metres.

There is not room in this Study to review all renewable sources – many other renewable sources are being developed, and may have longer-term potential. Marine technologies in particular (wave and tidal power) are expanding fast, both in terms of technology development and actual application, and may have a significant future role. In some countries geothermal power already makes a significant contribution and – where the resource exists – that contribution could also be expanded further. However, in terms of the overall energy balance, these alternative renewable sources do not currently make a significant contribution to ghg reduction. Whether they are eventually able to do so will depend on the extent of further technological development. Some (e.g. large-scale tidal plants) are also likely to raise major environmental issues, on the same lines as those raised by large dams (see Part 3).

Combined heat and power and distributed generation

Combined heat and power (chp) generation (cogeneration) has been at the centre of many countries' approaches to climate change – for instance it is one of the EU's core measures.

The principle is simple – traditional forms of power generation from fossil sources waste a lot of heat; typically, in an older plant only 35% or so (and in some cases considerably less) of the thermal content of the fossil fuel is converted to electricity. The remaining heat usually goes to waste, effectively heating the air via cooling towers or heating local rivers, lakes or the sea through hot water outflows. Putting the excess heat to effective use via cogeneration can increase efficiencies to 85-90% in the best-designed schemes, so potentially reducing energy intensity – and in many cases also reducing carbon intensity since chp plants are now normally powered by gas. But gas need not be the fuel source – chp is a broad principle rather than a specific technology, working with many different fuels, conversion technologies, sizes and applications.

Distributed generation is power generation on a small scale, close to the point of consumption. This closeness has a double benefit – it reduces

It is not surprising that chp has proved attractive to many governments in both developed and developing countries.

It is impossible to generalise, and therefore to predict, the emissions benefits of such programmes.

losses in electricity transmission, and it may well make possible the use of the waste heat from the power plant. Heat transmission over long distances is impractical, so a heat plant has to be situated close to the point of consumption (and conversely the problem with using the waste heat from a large conventional plant is usually simply that it is too far from any site where the large quantities of heat produced can be effectively used). Although chp is in principle distinct from distributed generation, the two approaches therefore often go together.

In principle, the ultimate form of distributed generation – so-called micro-chp – could be used in residential applications. Each house could then generate power as well as heat, trading any excess or deficit of power as necessary via the grid, Such applications offer very high efficiencies and, as the cost of the plant itself and the IT needed to perform the trading come down, may look an increasingly attractive prospect.

An additional benefit in many developing countries is that certain forms of agricultural waste lend themselves to chp generation so combining the benefits of various approaches.

With all these benefits, it is not surprising that chp has proved attractive to many governments in both developed and developing countries – the EU, for instance has the aim of increasing chp generation to 18% of total electricity production by 2010. Since the target for renewables is 22% of consumption, this would in theory lead to around 40% of electricity coming from these policy-preferred sources (though the targets have different status and definition, making them difficult to compare).

The main difficulty with chp is that, as noted above, it is impossible to generalise, and therefore to predict the emissions benefits of such programmes – schemes vary and may well not show such significant savings as the figures above imply.

There are many reasons why savings may not be as high as expected, for instance:

- New power plants can be much more efficient than the 35% figure quoted above, which is typical of existing plants. The best new CCGT plant can be up to 60% efficient. Meanwhile, a new heat plant is generally over 90% efficient. Since chp plant efficiencies reflect the production of both heat and power, the comparison must take both aspects into account.
- Savings in electricity transmission and distribution arising from distributed chp should be offset against any increase in losses in heat distribution and inefficiencies arising from a mismatch between heat and power demand. The best schemes will have a good balance of heat and power demand and a large and steady local heat demand, but this is not always possible. Indeed, since the best sites tend to be exploited first, overall efficiencies tend to go down over time and are often much lower than the 85-90% commonly quoted – in the UK for instance, chp plants have efficiencies of only around 70% on average.

For these reasons, blanket support for chp is unlikely to deliver such large emissions savings as might be expected from a simple comparison of technical efficiencies. Indeed, the region which traditionally made the most significant use of chp and district heating – the Former Soviet Union – did not perform well on energy or emissions intensity. Factors such

For those countries which find nuclear acceptable it offers the potential for very significant emissions reductions.

as inefficient pricing of heat and power, poorly insulated heat distribution systems and inflexible heat supplies offset any advantage which might have been gained from cogeneration. Some of the most cost-effective current emissions reductions programmes are based on improving the efficiency of district heating systems – for instance in Poland where there are a number of JI projects based on this concept.

Even in countries where these inefficiencies are absent, it is not obvious that significant penetration of cogeneration leads to a major impact on emissions – Denmark, Finland and the Netherlands, for instance, have the highest penetrations of chp in the EU-15 (30-50%)[ii], yet they do not stand out among other European countries with a much lower penetration of chp, such as the UK, as having low energy or carbon intensity – it is only in countries with high levels of hydro and/or nuclear power (such as France, Sweden, Norway and Iceland), that significantly lower carbon emissions can be associated with the structure of electricity generation.

While support for chp and decentralised generation will continue to be an important policy measure, policies need to be very carefully targeted to ensure that they actually deliver emissions reduction. Such targeting is a complex technical and administrative matter, which may create problems in developing countries – indeed, it is not clear how many OECD countries have grappled successfully with the problems. Blanket programmes of support are unlikely to be particularly effective in reducing emissions.

Nuclear

Nuclear is of course highly controversial – highly acceptable for some, but unacceptable for others because of worries about safety, waste management, decommissioning and links with military programmes. One thing that is clear is that, for those countries which find it acceptable in these other senses, it offers the potential for very significant emissions reductions. As discussed in Part 1, countries with a high dependence on nuclear have achieved levels of emissions some 40% lower than countries which are otherwise in a similar position but which have rejected the nuclear option or have a significantly lower penetration of nuclear.

Given the controversial nature of nuclear power, there are hugely variable approaches, in both the developing and developed worlds. Some countries (like Ireland and Austria) have rejected nuclear power entirely; some have existing nuclear plants but have plans to phase them out and do not intend to build any more (e.g. Sweden and Germany). Some have nuclear plants and would be happy to have more but do not want to dictate to the market (e.g. US, UK) – they are offering significant incentives for new nuclear but are nonetheless uncertain how much will be built; some have existing nuclear plants, intend to build more and have specific projects in hand (e.g. France, Finland).

The same general picture – of huge variations in approach – is valid for the developing world, but in general nuclear penetration there is lower. Nuclear is generally considered a complex technology with high capital cost compared with conventional fossil plants. The technology has also exhibited economies of scale, leading to relatively large plant sizes. It requires a developed infrastructure and skills for building, operating and maintaining the plant safely; usually a degree of government involvement is needed. Historically, therefore, the development

Nuclear, like other technologies, is undergoing continuing technical improvements.

of the technology has taken place in developed countries. However, a number of large countries with high and growing energy demand, such as India and China, are committed to developing the option further. Both countries have active nuclear programmes and ambitious plans for expansion – indeed, Asia in general is likely to be the focus of nuclear construction over coming decades. Some forecasters see world nuclear capacity doubling between now and 2030.

In view of its importance in a climate change context, the nuclear option is assessed further in Part 3. It is unlikely that the world will reach universal consensus on the acceptability of nuclear power in the near future; nuclear will probably develop on a case-by-case basis. Nonetheless, as discussed in Part 3, nuclear, like other technologies, is undergoing continuing technical improvements. Many of the existing objections to nuclear can at least be mitigated, and possibly removed, potentially enabling it to make a bigger contribution to meeting the climate change challenge.

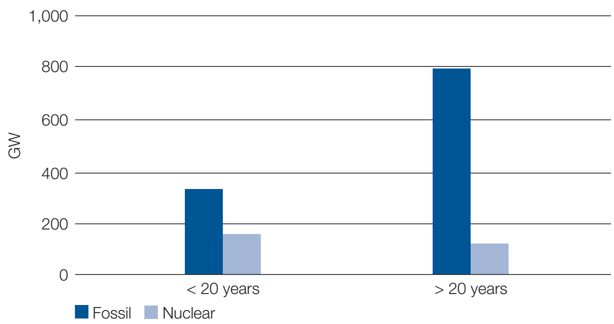
Other fuel-switching

As indicated in Part 1, fuel switching between fossil fuels (e.g. switching to natural gas in power generation) offers one of the easiest and most cost-effective ways of improving carbon intensity, and hence reducing emissions.

It has therefore been important in practice in both the developed and developing world. However, it is much less important in policy terms in developed countries, where there have been fewer specific programmes or targets designed to promote fuel-switching in power generation (such as those designed to promote chp and renewables), probably because these countries tend to rely on markets and market forces rather than central direction (i.e. specific programmes of support are seen as very much exceptions to a general rule). In developed countries, there is also often the feeling that fuel-switching is at best a transitional measure, which fails to address the fundamental problems of resource depletion and long-term emissions reduction. It may also raise wider energy policy issues – e.g. in the UK the "dash to gas" in the first half of the 1990s led to a significant drop in CO_2 emissions but also to concern about energy security and the loss of fuel diversity. The process was halted by a moratorium in 1997; by the time the government opened the way for further investment in gas, market circumstances had changed. This experience points to wider problems: encouraging a switch to a particular fuel like gas both tends to reduce diversity and (in most cases) increase import dependence and reliance on limited fossil sources.

In developing countries, however, governments often exercise more direct control of such factors as utility fuel and technology choices, and this may be a convenient route for enforcing policy objectives – particularly where economies are relatively unsophisticated and the administrative capacity for complex incentives programmes may be lacking. A significant number of countries in the developing world therefore list fuel switching by utilities as one of their main climate change measures. Mexico, for instance, intends to convert the bulk of its thermal power plants in environmentally sensitive areas from fuel oil to natural gas. Egypt is also promoting a switch to gas.

Figure 2-3
Average age of power plants in the OECD, 2003



Sources: Platts (2001) and IEA analysis.

Cleaner fossil fuel systems

One of the easiest ways of reducing emissions is simply by replacing old plant with new. Even with no basic change of technology or fuel, there are nearly always considerable efficiency gains and hence emissions reductions. The phenomenon is familiar from the transport sector, where new cars are consistently more fuel efficient than older models – at one point France had a programme of encouraging the scrapping of older cars and the purchase of new ones, with environmental improvement among the programme's aims.

Much the same applies to other energy using equipment and, particularly, power plants. While power demand in developing countries is growing fast and construction programmes find it hard to keep pace, many OECD countries suffer from almost the reverse problem – their existing fossil plants are aging and only being replaced at a slow rate. The chart below gives an indication of the scale of the problem.

Most fossil plant in the OECD are well over 20 years old – i.e. they were designed and constructed long before serious concerns about climate change started to emerge.

Typically, an older coal plant has an efficiency of around 35% or less – in many developing countries efficiencies can be much lower, 30% or less.
New plants, such as the supercritical plant now being built as standard in much of Europe and Japan, have efficiencies of 40-45%. Integrated Gasification Combined Cycle plants can also reach over 40% efficiency, and may have longer-term advantages in that the technology makes carbon capture and storage more feasible.

Natural gas plants have reached even higher levels of performance – new Combined Cycle Gas Turbines can reach efficiencies of 60%. Since emissions per unit decrease as efficiency increases, the scope for emissions reduction is enormous – just replacing older power plants with news, more efficient, plant could produce national emissions reductions of the same order as those aimed at by the Kyoto protocol.

Intelligent technology

Intelligent technology refers primarily to the transformation of electricity supply and end use from analogue, electromechanical control to digital control. (Digital control both requires and enables the functional integration of energy and real-time information – hence the term intelligent technology.)

This transformation, occurring to varying degrees worldwide, is opening up significant opportunities for improving the efficiency of energy consumption and the diversity of supply. In terms of efficiency, intelligent end use devices are able to adapt automatically and instantaneously to changing needs and conditions, thus minimizing energy losses and unnecessary consumption. In so doing, the energy consumption for lighting, heating, air conditioning, industrial processes, etc., can be significantly reduced without loss of functionality or productivity.

With respect to supply diversity, a primary limiting factor in the utilization of many renewable energy sources is their intermittency. This restricts the ability of an electromechanically controlled electricity grid to reliably dispatch such energy sources without equivalent conventional back-up power. Through the use of digital controls such as the Flexible AC

Along with renewables, energy efficiency is probably the most popular area for policy intervention in both the developed and developing worlds.

Transmission System (FACTS), these intermittent sources can be assimilated as power assets with greatly reduced need for fossil-fueled back-up power.

Such digital control capabilities are adaptable to both large centralised bulk electric power networks and localised microgrids in developed and developing economies alike. Cost has been the primary factor limiting the pace of commercial applications of intelligent electric technology. This is also changing as the cost and intensity of electricity consumption grows worldwide, and the cost of innovative technology declines for both new and retrofit applications. Just as electricity transformed the productivity and value of steam in the 20th Century, so is digital technology transforming the productivity and value of electricity in the 21st Century.

Energy efficiency

Along with renewables, energy efficiency is probably the most popular area for policy intervention in both developed and developing worlds. A range of measures of the sort listed above are used, and many countries have operated a number of programmes for many years. Over half of developing countries, as well as nearly all developed countries, list measures in this area. Some of these programmes have been quite large scale – for instance in 1996-1998 China implemented a Green Lighting programme during which it marketed 267 million high efficiency products. China has placed energy efficiency at the very centre of its energy policy, with resource conservation much in mind – with its rapidly growing energy demand, it wishes to make the best possible use of its indigenous energy resources. Many other developing countries have similar goals – India, for instance, set up a Bureau of Energy Efficiency under the Energy Conservation Act 2001 with the aim of reducing energy intensity across the economy. Thailand also puts great emphasis on energy efficiency, and its demand-side management programme aims to reduce emissions by over 50 million tonnes per year.

In principle, energy efficiency offers scope for meeting a wide range of energy policy objectives if implemented effectively. It can add to the global security of energy supplies by reducing the need for energy and hence the call on insecure energy sources; it can reduce emissions by improving energy intensity and reducing fuel use; and it can increase access to energy services, by reducing their effective cost. It is therefore not surprising that there is such wide reliance on this option.

However, similar considerations apply as with chp or vehicle standards – it can be very difficult to predict or monitor the impacts of end-use energy efficiency improvements. Energy systems and people's behaviour are both complex and dynamic processes and there are many feedbacks and interactions. In particular, it is not always clear whether energy efficiency leads to lower energy use: since it lowers the effective costs of energy it may also increase demand. The direct savings can be taken up by such factors as increased comfort, more extended use of a service, or willingness to use new services (e.g. air-conditioning did not take off as a technology until it had reached an adequate level of efficiency). As the analysis in Part 1 indicates, there is only a very loose correlation between energy intensity and energy use. For instance, China has a strong record on energy efficiency, aided by programmes such as those described above. During the 1990s, energy intensity halved in China and it is significantly lower than in many countries at a similar stage of development. Nonetheless, it is also the

The opportunities for enhanced energy efficiencies throughout the world are a reality… but… further gains will not be easily won and will vary across countries and components of the energy value chain.

Taken from the World Energy Council Statement 2006

case that, over the same period, energy use and CO_2 emissions grew by 40% – improved energy efficiency does not guarantee declining emissions. While the increase in emissions might have been higher in the absence of the energy efficiency gains, this is also by no means certain. A slower growing economy could have been associated with a slower rate of efficiency gain, as discussed in Part 1.

Because of these complications, it can be misleading to talk about the "reductions" in energy use or emissions achieved through energy efficiency. In nearly all cases, such references are not to actual reductions but to an outcome which is lower than it might otherwise have been (so that the calculation is very dependent on the assumptions about what would have happened in the absence of the energy efficiency programmes concerned). There is considerable academic debate about the issue, which this Study cannot explore in detail. However, there seem to be two broad conclusions. On the one hand, (at least with well-conducted energy efficiency programmes – many programmes are not well-conducted or assessed), the savings from individual programmes remain genuine, even after taking account of increased comfort and other effects discussed above. On the other hand, the savings are usually relative (to expectations or to a control group) – in very few cases have actual reductions in energy use been demonstrated to result from an energy efficiency programme. Furthermore, even where there are savings at the programme level, they do not flow through to an absolute reduction in energy use or emissions at the national level. For instance, a recent IEA information document on the subject notes that, "energy efficiency efforts alone have not been sufficient to halt growth in energy consumption or CO_2 emissions in the OECD countries,"[iii] (and the conclusion would also apply outside the OECD).

The distinction is critical in relation to climate change policies. Both the Kyoto system and most (though not all) national targets are based on absolute rather than relative targets (i.e. what matters is whether emissions are actually lower, rather than simply lower than they might otherwise have been). It is also, of course, the absolute level of emissions which has an impact on the environment, not the relative level.

Few countries have made a sustained attempt to unravel all these complications and produce a robust analysis of the impacts of energy efficiency. There is still considerable debate about the impact of "demand-side" measures undertaken by US utilities in the 1980s, and in a review of energy efficiency policies a recent report by the UK House of Lords commented that, "the Government appear to have no clear view on how to measure, and thereby manage energy efficiency".

A recent World Energy Council Statement "Energy Efficiencies: Pipe-dream or reality" summed up the position as follows:

"the opportunities for enhanced energy efficiencies throughout the world are a reality… but… further gains will not be easily won and will vary across countries and components of the energy value chain."

Energy efficiency will certainly continue to be a major Part of many countries' programmes but a realistic and well-targeted approach – more so than in the past – will be needed if such programmes are going to make a significant impact on ghg emissions.

There is huge potential in technology transfer – the problem is with developing appropriate mechanisms for delivering results.

Technology transfer

Another very important area will be that of technology transfer. This too can be a powerful tool in meeting global energy objectives – improving access to clean technology and energy services worldwide. Many countries in both the developed and developing worlds are therefore committed to this aim, as are many countries' aid programmes and international institutions (e.g. the Global Environmental Facility referred to above). The total amount of money involved in these programmes is considerable – bilateral aid alone provides around $2.5bn per year for climate change related activities and has supported over 5,000 individual projects, while the GEF runs at over $100 million per year and effectively leverages much larger amounts via co-financing. There is also huge potential for meeting the wider policy criteria set out above – technology transfer offers the prospect of hitting the biggest target (the growth in emissions in the developing world) in an effective way (making economic, environmental and social sense). For instance, bringing a coal-fired plant in China and India up to the level of efficiency of a new German plant would deliver emissions savings commensurate with those expected from the whole Kyoto process, while improving the efficiency of resource use and enabling increased access to modern energy.

Indeed, the benefits are not one way, even in technological terms. It is often the case, for instance, that developing countries offer opportunities to deploy emissions-reducing technologies more cheaply than in the OECD, because costs are lower while the mitigation potential is higher. In many cases too, there are economies of scale or learning effects which will lead to faster cost reduction if technologies are deployed more widely.

The problem is not so much agreeing with these propositions as with developing appropriate mechanisms for delivering results. Although mechanisms such as those discussed above – for example, the CDM, GEF and bilateral aid – provide significant aid, they remain small scale by comparison with the scale of the problem; total investment in new energy technology over the coming decades in developing countries is in the trillions, rather than the billions, of dollars.

In practice, therefore, like a number of the initially attractive approaches discussed in this section, achieving significant and measurable results can be difficult. There are often bureaucratic and political obstacles in agreeing to the terms of technology transfer: employment and capacity issues over its use; issues over maintenance and reliability in developing country conditions; difficulties in agreeing on the treatment of intellectual property; and so on. Technology transfer has always been an important feature of the UN approach – as far back as Agenda 21 of 1992, for instance, and it has set up a technology information clearing house called TT:CLEAR. The various obstacles to technology transfer are being looked at within the UN framework by an Expert Group on Technology Transfer, but it would be unrealistic to expect all the problems to be resolved in the short-term.

2.2.ii Transport measures

As indicated above, the concern of this Study is primarily with the energy sector. Nonetheless, transport and energy are so closely interlinked that the transport sector cannot be ignored. Indeed, it is a major focus for climate change policies aimed at reducing energy related emissions – nearly all developed countries and around two-thirds of developing countries report measures in the transport area.

The main ones of direct energy interest have been discussed above, i.e. fuel taxes and vehicle standards. Other wider measures include encouragement of intermodal shifting (e.g. from cars to public transport); integrated transport planning; and long-term spatial planning to reduce the need for long travel distances. Such measures are common in both developed and developing countries, but they serve wider social ends (improving access to mobility rather than access to energy services) and involve wide social and political issues (e.g. in adjusting consumer behaviour and settlement patterns) which go beyond the scope of this Study. As noted above, the differences between transport emissions in particular countries and cities arise from very deep-seated social and economic factors. While these can be addressed by policy measures, there is no single policy that approach that fits all circumstances. However, there is further discussion of some of the possible measures – particularly those relating to vehicle technology – in the context of the current WEC Scenarios study.

Of more direct relevance to the energy sector might be the promotion of **fuel switching** in transport. The scope for doing so is relatively limited in the short to medium-term, though there are some examples, discussed above, including encouragement of LPG, CNG and biofuels, as well as scope for electrification of train travel in many countries.

Biofuels in particular seem a promising area, and one in which developing countries may well have a comparative advantage, for the reasons discussed above. Brazil is a pioneer in this area, with a well-developed biofuels programme (see Box), and other developing countries may also be able to implement similar programmes, taking account of their natural resource base.

Brazil's Alcohol Programme

Brazil, in particular, has for many years operated a National Alcohol Programme aimed at stimulating ethanol production, mainly from sugar cane (though also in principle from manioc or other raw materials). The programme, which was initiated in the 1970s, was seen as a way of promoting energy availability and security, but it also has benefits in terms of acceptability and accessibility. Brazil's circumstances are particularly favourable for such a scheme. Production costs for sugar are among the lowest in the world and the production process for sugar and alcohol are very similar so it is very easy to adapt from one output to the other. Furthermore, a renewable energy source (bagasse – the crushed cane from which the sugar has been extracted) is available as a by-product to fuel the conversion process.

Ethanol has been used in two ways: to blend with traditional gasoline to form "gasohol" or as a direct fuel in ethanol only vehicles. Over 5 million ethanol-only cars have been produced, while gasohol has been used in more than 10 million vehicles.

Total CO_2 emissions are estimated at over 400 million tonnes over the life of the programme so far.

The Brazilian Government has supported the process in a variety of ways, for instance by maintaining the ethanol price lower than gasoline and imposing lower taxes on ethanol fuelled cars, and this enabled a large market to be built up,

Nonetheless, there have been some hiccups in the process. As a result of variations in world prices of sugar and oil and the varying levels of government support, the proportion of new cars fuelled by ethanol has varied over the period of the programme between virtually 0% and nearly 100%, largely responding to changes in the relative prices of gasoline and ethanol. The emphasis now is on flexi-fuel vehicles which can use either gasoline or ethanol or a combination, so providing protection against these movements in relative fuel prices.

The experience indicates: first, the considerable potential, in the right circumstances, of biomass, and second, the ability of developing countries to act as pioneers – Brazil is now exporting ethanol for use in gasohol mixtures in Europe.

In the longer-term, the scope for fuel switching will increase. Development efforts will be needed before it is possible to identify the precise form such fuel switching will take, but it appears that there is significant potential in electrification of the personal transport sector. In the medium-term, hybrid vehicles, combining petrol and battery power sources, seems the most attractive. Plug-in hybrids, allowing the use of mains electricity to charge the vehicle battery, may offer further opportunities for improving both the economic and environmental acceptability of hybrid technology. In the longer-term there is much interest in the option of using hydrogen in fuel cells in automotive use. A number of significant technological developments will have to take place before this can become a reality: in safe hydrogen distribution and storage; in bringing down the cost of fuel cells; and of course in producing hydrogen (which is an energy carrier rather than an energy source) cleanly, so this cannot be relied upon to provide short-term solutions. However, as the analysis in Part 1 indicated, there is no prospect of making serious long-term reductions in CO_2 emissions unless the problem of transport emissions is addressed, so this must be a key area for R&D effort.

Fewer measures have been reported to date in relation to **aviation and shipping** despite their growing importance. There are a number of reasons for this. Emissions from these sectors come outside the UNFCCC classifications, so a country cannot gain credits from reducing such emissions. Their international nature also makes it difficult to impose national measures of the sort discussed above – e.g. taxes, regulations etc – since such matters are usually covered by international agreement or impossible to police in practice. While there has been considerable technological advance in these sectors – greater operating and other efficiencies – it is clear that ways need to be found of bringing them into a framework for emissions reduction, for instance by the inclusion of aviation in the EU Emissions Trading Scheme, currently under discussion.

2.3 Non-CO_2 gases and flaring

As noted in the previous section, there is scope for specific measures in this area, in addition to the general CO_2 and energy oriented measures noted above. The main such areas are:

- **methane capture** from coal mines. Methane can be drained before mining and/or captured during the mining process. There can be economic advantages in doing so (the methane can be sold direct or converted to electricity), but usually some policy support is needed. The most common approaches are subsidies, taxes and regulation, mainly in developed countries. Capturing and burning mines gas, for instance, was one of the most significant early participants in the UK emissions trading scheme.
- **reduction in methane leakage** from gas production and transportation. Again there can be economic and safety advantages. However, leakage from gas transportation is difficult to measure and there are few policies aimed directly at this area. One approach is via JI or similar arrangements, whereby an OECD company can make leakage reduction in the FSU more economic by taking credit for the decrease in emissions.
- **reduction in gas flaring** Measures to reduce CO_2 emissions from flaring can produce significant reductions in ghg emissions. In many cases this amounts to a form of energy efficiency – the best alternative to flaring gas is often to capture it and distribute it to customers for energy or chemical use. This may well lead to a similar absolute level of CO_2 emissions from the gas itself, since the gas is still being burnt – the advantage comes in the reduction of the fuel which might otherwise have been used. In other cases it is similar to carbon capture, since an alternative to flaring is the re-injection of natural gas into an underground reservoir. So the ghg benefits of reduced gas flaring depend on the precise circumstances, and the destination of the gas which would have otherwise been flared. By and large, however, the main potential future savings are in developing countries. In most developed countries, regulation is already used to limit gas flaring to the minimum necessary for safety purposes (which generally leads to re-injection of the gas, or its commercialisation). There is scope for further such measures in many developing countries and there can be social as well as environmental benefits (from the development of a gas distribution system), though there may also be high upfront costs. Nonetheless, significant efforts to reduce gas flaring have been undertaken by such countries as Nigeria.
- **landfill gas capture** As with mines gas, there can be a range of benefits. This is an important measure in many OECD countries (using a range of measures, such as taxes, trading and regulation), and there is significant potential in developing countries. For instance, a Chinese official recently suggested that since China has 700 registered landfill sites but only 10 of them have installed gas recovery and utilisation systems, there is huge potential for CDM projects to tap this source. Indeed, one of the biggest carbon credits generated so far in the CDM system (of 1m tonnes) is from the Biogas project in Brazil which uses methane from Sao Paulo's waste to produce electricity.

Sustainable progress in reducing ghg emissions will depend on harnessing this global goal to the enlightened self interest of each country.

3 Conclusions

A large number of climate change measures have been introduced across the world, but as yet effective assessment is less well developed – the measures vary significantly in their overall impacts and it is not always clear that countries have given them full consideration and analysis. The UNFCCC, for instance, comments that "environmental effectiveness and cost-efficiency" appeared to be the most prominent criteria. It acknowledges that social and other issues are sometimes taken into account, but comments that Parties rarely elaborate on the ancillary benefits and provide only limited cost data. Similarly, the European Commission notes that the EU Climate Programme aims to identify the "most environmentally and cost effective" measures. Indeed, it rather avoids the social issues, commenting that "the Kyoto Protocol already has the tools for ensuring that effects on international trade and social, environmental and economic impacts on other Parties… are minimised", a statement which seems to take a lot for granted.

So in practice there is relatively little emphasis on social issues in the choice of policies and, as noted above, even environmental and cost effectiveness is often measured only perfunctorily. There is also significant potential for the identification and further development of measures which would have a positive impact in all three areas; these aspects are explored in the following part of this Study.

More detailed points to emerge from the analysis include the following:

- there are **significant differences** between countries in the measures introduced, depending to a large extent on their national circumstances.
- although developed countries have generally undertaken a wider range of climate change measures than developing countries, **in a number of cases developing countries are in the lead**.
- **economic instruments are more common in developed countries**; in developing countries they raise difficult social and development issues.
- **command and control type measures** (e.g. mandated fuel-switching) are more common in developing countries, where the government often has a more "hands-on" role in the energy sector.
- **renewables and energy efficiency are popular choices in both developed and developing countries**. Technology is also important in both regions, but there are significant differences of emphasis in the types of technology used and the overall approach.
- **technology transfer and deployment offers huge potential,** but more effective mechanisms need to be developed.
- there are very **significant differences in approach between countries in relation to use of the Kyoto mechanisms.**
- **renewables have significant potential** but there are practical and economic issues which need to be addressed.
- energy efficiency programmes need to be **more effectively designed and assessed** if they are to lead to actual emissions reductions.
- **international aviation and shipping** need to be brought within the ambit of climate change measures.

One clear message emerging from this policy overview is that sustainable progress in reducing ghg emissions will depend on harnessing this global goal to the enlightened self-interest of each country. The current diverse global portfolio of energy policies is neither designed to, nor capable of, achieving this essential precursor to worldwide sustainable greenhouse gas emissions reduction.

[i] *Greenhouse gas emissions trends and projections in Europe 2006* European Environment Agency, Copenhagen, 2006.

[ii] Ibid.

[iii] *The experience with energy efficiency policies and programmes in IEA countries* IEA August 2005. See also discussions of the relevant literature in special editions of Energy Policy (Vol 28, nos 6-7, June 2000) and *Energy and Environment* (Vol 11 no 5, 2000).

Part 3: Assessment of Measures

The assessments have been undertaken against the criteria of the WEC's 3A's (availability, acceptability and accessibility).

1 Introduction – the assessment process

As discussed in earlier parts, governments across the world have been introducing measures to combat climate change. Whatever the shape of any future global regime, the process of policy-making will continue. Yet the assessment of these measures is much less developed – many of the policies have not been assessed at all; in many cases the environmental and economic impacts have been measured only perfunctorily; and in very few cases has there been any serious assessment of the social impacts. In other words, almost none of this huge range of measures has been fully assessed against all the criteria of sustainable development as set out in the WEC's 3A's.

This part will attempt to make such an assessment, at least on an initial basis. Clearly, given the scope of the document, the judgements it contains cannot be definitive or universal. As emphasised in earlier parts, circumstances vary substantially between different regions; the impacts of particular policies, and their appropriateness for the different circumstances, will also vary. So, in the final analysis the assessment of individual measures will have to be done in the context of the particular country (or state or other body) introducing or considering them.

Nor can a study such as this undertake a full analysis of every single policy and policy variant introduced across the world. What it can do is draw some broad conclusions about particular types of policy – pointing out where necessary the factors which might change these conclusions and make the policies more effective in meeting the criteria of the 3A's. In this way, it is hoped that this study can give some pointers to policy makers and others about where they should be devoting their efforts, and how they might be changing their approaches if they wish to promote sustainable development and combat climate change effectively.

The assessments are founded on the global reach and expertise of the WEC and take advantage of its unrivalled experience of the energy sector in all parts of the world; they also draw on available national and international studies (see box on the assessment process). Inevitably, they will not be the last word on the subject; nonetheless, we believe that the methodology used to form the assessments means that they are more solidly based and wider ranging than most previous analyses, thus offering a unique insight into these complex issues.

The assessments have been undertaken against the criteria of the WEC's 3A's (availability, acceptability and accessibility) – described in more detail in the Introduction to this study. Clearly a number of elements are involved in each criterion and, so far as possible, the assessments take account of the full range of relevant factors. The justification for the particular judgements, and the considerations which led to them, are set out in more detail in this part in the discussion of key measures and summarised in the simple tables giving "star ratings" for different technologies and approaches. These simple "star ratings" award between one and five stars, indicating the contribution a particular measure makes to each of the 3A's ranging from one star (*) – little or no contribution, to five stars (*****) – a very significant contribution.

In making these assessments against the 3A's, the following questions have been particularly important:

- **Acceptability:** What evidence is there that this measure has a positive impact in reducing ghg emissions in practice (as opposed to theory)? Is the measure one which can be adopted widely across the world?
- **Availability:** What are the implications of this measure for energy security and diversity? Does it lead to increased dependence on unreliable sources? Does it add to pressure on scarce fossil fuel resources?
- **Accessibility:** Does the measure make it more difficult for people, particularly in developing countries, to access modern energy sources, for instance by slowing down the development of modern systems or raising energy costs for the poor?

There is also a significant question of assessing **actual** achievement versus future **potential**. Some measures may be making only a very small contribution at present but to have very significant potential for the future. In most cases this is dealt with by appropriate commentary in the text itself or in the remarks on the assessments. However, in looking at technological options, the discussion tries to distinguish between near term, mid-term and long-term options. This obviously involves some uncertainty but the discussion is informed, among other things, by the parallel WEC exercise on energy policy scenarios which looks at possible futures in much more depth. This Study does not attempt to repeat that exercise. It does, however, try to draw from it to give a feel for the timescales on which particular policy measures are likely to be most relevant.

Measures assessed

The main policy measures listed in the previous part are assessed, at least in summary table form, and a brief justification is given in all cases for the judgements made. In addition, fuller assessments are given in some key areas identified in the previous Part, because of their importance in current or potential future climate change programmes. These areas are: economic instruments; energy efficiency (drawing to a large extent on the WEC study referred to above); renewables (concentrating on four key technologies – wind; biomass; hydro and solar power); nuclear (a sensitive area on which views differ, but an issue which cannot be avoided in any serious consideration of climate change); and technology development and deployment where, as noted, an attempt is made to gauge future potential and the timescales.

In each case an assessment is made against each of the WEC criteria, drawing on the various sources listed in the Box, to lead to an overall judgement, whose basis is explained and justified in the text.

Note on Sources for Assessment Process

The assessments and star ratings draw on a number of sources, including the following:

- Previous WEC studies, such as those on Energy Efficiency, Life Cycle Assessment and End Use Technologies (see Bibliography). These studies include informed judgements about the technologies and measures concerned against the background of the WEC criteria – sometimes using a simple tabular approach to summarise the judgements (though not usually awarding a “star rating” as in this Study).

- Current WEC studies, including in particular the ongoing Scenarios Study. This is a major global Study looking at possible future developments in energy policy worldwide. As part of this exercise, groups in each of the world’s major regions have been looking at future energy scenarios and at some key issues – such as possible developments in particular technologies and sectors – and judging these trends against the WEC criteria, thus producing forward-looking assessments similar to those being undertaken for the present Study.
- A number of national assessments have been undertaken as part of this study, which look in detail at the impacts of particular measures in the context of particular countries. These national studies in turn draw on published government and independent analyses produced in the countries concerned. See list in Appendix 3. Although there are some differences between countries, as might be expected, a number of common themes also emerge clearly.
- Other independent studies, such as the IPCC report on Carbon Capture and Storage, or studies by the IEA and other organisations, look in detail at particular technologies or policies and produce evidence about their impacts in the economic, social and environmental areas. This evidence can be used to underpin assessments about the implications for the 3A’s.
- Finally, but importantly, the Study draws on the judgements of Study Group members, based on their many years experience of the energy sector in different parts of the world, and on discussion and debate within the Study Group, which has refined and improved the assessments and ensured that they were brought on to a common basis.

Taken together, these sources give the assessments a robust foundation, going beyond the subjective or individual approaches found in narrower studies.

As with the previous part, this part is divided into three main sections:

- Assessment according to types of policy instrument – economic instruments, regulation etc (**Section 2**).
- Assessment of policy measures relating to particular energy options (**Section 3**).
- Assessment of technology and technology potential (**Section 4**).

The theoretical advantages of fuel taxation are rarely fully realised in practice.

2 Assessment of policies by type of policy instrument

2.1 Economic instruments

2.1.i Taxation

Acceptability ****

At a theoretical level, energy or carbon taxes score relatively highly against the criterion of environmental acceptability, which is probably why they have been widely adopted in OECD countries. There are strong arguments of principle in their favour. Some economic activities lead to results which impose costs (or create benefits) for others who are not directly involved in the activity concerned (these costs and benefits for outsiders are called "externalities"). Burning fossil fuel is an example – it creates emissions of various sorts, which impose costs on the rest of society. Where activities involve externalities which cannot be traded in the market, the best way of reflecting these wider social costs is usually to incorporate them directly in the cost of the economic activity concerned – to "internalise" the costs, via taxes. In the present case, this can in principle be done via an energy or carbon tax. If this succeeds in internalising the environmental costs of energy use, it should lead to a socially optimum result, with minimum economic distortion. For instance, it should encourage greater energy efficiency and the choice of lower carbon fuels, without the need for additional subsidies or regulations.

But these theoretical advantages are very difficult to realise in practice. For a start, since the environmental damage of ghgs is very difficult to measure precisely, it is not possible to be sure that taxes have been set at the right level. In addition, the process sets governments conflicting objectives – measures which raise revenue most easily also produce the least environmental impact, as discussed in the previous part. Because governments always want to raise revenue, they may be tempted to load taxes on price-inelastic energy forms. In most countries, energy taxation falls heaviest on motor fuel, although it still makes only a moderate contribution to total ghg emissions.

In addition, although the WEC criterion of acceptability relates primarily to environmental acceptability, other aspects of public acceptability cannot be ignored. If a measure is unacceptable for wider reasons, it may simply be unrealistic to attempt to introduce it in the first place, or the inevitable policy trade-offs involved in making it acceptable may result in such distortions that, in practice, environmental acceptability is undermined. Taxes may simply be impractical in many developing countries because the social and other impacts are so great that they cannot be contemplated. Even in developed countries where these social aspects may be more manageable, they are still often very difficult. Taxes still raise issues such as competitiveness, encouraging governments to distort their application in various ways and undermine their theoretical economic attractions. For instance, in practice, there are very few pure "carbon" taxes which apply even-handedly across the whole energy balance. Exceptions are common – for instance: for larger users; for particular forms of power generation; or particular sectors such as residential use, as described in Part 2.

For all these reasons, the theoretical advantages of fuel taxation are rarely fully realised in practice, though they are part of most OECD countries' energy policy mix.

Energy taxation affects poorer consumers more than the wealthy.

Availability ***

The impact of taxes on availability is more complex. On the one hand, consumer taxes may serve to reduce demand and therefore relieve the tightness of the energy supply/demand balance worldwide. On the other hand, their effectiveness in reducing demand is uncertain – they may divert economic activity (from a high tax country to a low tax country) rather than curtailing it, or they may simply raise revenue, as discussed above. Furthermore, tax rates are not usually fixed for years in advance – both the taxes themselves and the relativities between taxes are normally treated as sovereign matters for governments to decide as they wish. Even if governments wish to give long-term signals, it is difficult for them to make credible commitments – history shows a consistent record of tax rates and systems being adapted to changing circumstances. This uncertainty about the long-term stability of tax regimes means that they are not generally seen as a firm basis for investment decisions – for instance, countries with carbon taxes rarely guarantee them for years ahead, so the taxes are not normally of themselves enough to justify investment in low carbon sources such as renewables, which in most cases receive additional forms of support.

Producer taxes, which provide an important stream of revenue for many governments may stimulate availability by providing states with incentives to promote energy exploration and extraction. On the other hand they may discourage investment if they seem to be too high or too unpredictable. As with consumer taxes, changes in upstream taxation are very common as producing countries respond to political changes and moves in energy prices – for instance, not only have tax rates for offshore oil in the UK changed a number of times, but the whole basis of taxation has changed. On the whole, however, producer taxes are designed to raise "rent" (i.e. to skim off excess profits) – they do not usually affect world market prices as such, so are less commonly used for climate change reasons.

Accessibility *

Energy taxes do not score well against this heading. They have a tendency to be regressive – i.e. to impose higher burdens on the poor than the rich. Clearly, this depends on the fuel and the country involved, and whether countervailing social measures are introduced. It applies particularly strongly to fuels used for home heating and cooking and (in some countries) home cooling. As regards motor fuel the position varies between countries – in many countries, private road transportation is a possibility for richer citizens only, so motor fuel taxation (especially if public transport is exempted) need not of itself be regressive (though it may still be highly controversial). In some countries much the same applies to electricity – poorer consumers either lack access to electricity or consume very small quantities.

Nonetheless, overall the general rule is that energy taxation affects poorer consumers more than the wealthy. This applies both within and between countries. Within countries, spending on fuel for home heating and cooking tends to be highly income-inelastic – i.e. the poor spend nearly as much on energy as the rich, so any proportional increase in prices hits them harder. The poor also often have higher energy needs, e.g. the unemployed or families with small children spend more time at home; senior citizens and disabled people are more vulnerable and have higher heating and cooling needs; poorer consumers are less able to afford investment in insulation or other forms of energy efficiency.

Energy and Carbon Taxes	Assessment	Remarks
Acceptability	***	Strong theoretical advantages, but many problems in practice, particularly for developing countries.
Availability	***	Impact varies a lot according to circumstances and there are often both positive and negative effects.
Accessibility	*	Taxes usually have adverse impacts on accessibility unless carefully designed and accompanied by offsetting measures.

Yet their energy usually costs them as much or more per unit as the rich (unlike food, say, where it is easy to trade down to cheaper sources), and so takes up a higher proportion of their spending.

Between countries a similar overall picture applies. Apart from those countries with indigenous sources discussed in part 1, most countries have to take a large proportion of their energy from world markets at world prices, leading to a much larger impact on poor countries than on rich ones. Many of the figures quoted in part 1 of this study use Purchasing Power Parity comparisons, which reflect the fact that the cost of living tends to be much lower in many developing countries than in the developed world. The effective purchasing power the citizens of these countries enjoy is therefore higher than exchange rate comparisons imply – indeed, it may be two or three times higher. However, when globally traded goods have to be used at world prices, this apparent boost to the relative standard of living disappears and it is the (often very much lower) money incomes which count.

Furthermore, many developing country consumers only have access to energy sources such as diesel oil and LPG which are relatively expensive unless subsidised, because their energy infrastructure is undeveloped. In many cases, they do not have access to gas (few developing countries have mature gas networks), or even electricity. For many (and there are nearly 2 billion people without access to commercial energy) it is not just a matter of expense, but also of time and effort in collecting traditional biomass. Consumer taxes on commercial energy prices – putting access yet further beyond the reach of these consumers – raise serious social and development problems.

Overall, therefore, while taxation has many theoretical benefits the practical problems are also considerable, which means that they are not suitable for all situations. In particular, because of the major social problems they involve, they are unlikely to promote accessibility and are therefore difficult to implement effectively in many developing countries. In addition, the evidence is that they do not always have a strong impact on demand and often add to uncertainty, and thus fail to encourage appropriate investment.

The message here is that if governments want taxation to be effective in relation to the 3A's, they should be properly justified in terms of externalities, stable and predictable, and imposed with due regard to the social consequences (which will often imply accompanying social measures). Tax measures meeting these criteria might score well against the WEC criteria but existing tax measures score only moderately.

More generally, it is possible to see energy taxes as part of a wider approach to tax reform. If tax reform succeeds in shifting the burden of tax from "goods" – sustainable economic activity – to "bads" such as ghg emissions, there may be a positive economic impact without a higher tax burden overall. This is easier said than done, of course, and raises issues which go beyond the scope of this Study. Nonetheless, it is an important message – energy and carbon taxes should not be considered in isolation but in a wider social context.

Removing subsidies on fossil fuels	Assessment	Remarks
Acceptability	*****	An important first step in combating climate change, though it may create difficulties for developing countries.
Availability	****	Removing market distortions should improve availability.
Accessibility	**	Provided consideration is given to meeting the social needs which the subsidy was designed to meet, it should be possible to offset any adverse impact from subsidy removal.

Subsidies encourage excessive energy use and also promote the wrong sort of investment.

2.1.ii Removal of subsidies on fossil fuels

Many of the remarks above on taxation apply (mutatis mutandis) to other economic instruments, so less detail will be given in this discussion.

Acceptability ***

Removal of subsidies on fossil fuels scores well, in nearly all cases, on the criterion of acceptability. Subsidies encourage excessive energy use and mean that consumers receive distorted price signals; they also promote the wrong sort of investment in energy using equipment (e.g. large cars), and thus create a new interest group with a reason to lobby for what is essentially unsustainable behaviour. Removing subsidies on fossil fuels may involve political problems, for instance in relation to employment or social impacts, but in nearly all cases it tends to promote environmental improvement (the few exceptions were discussed in Part 2 – for instance subsidies for clean, accessible, low carbon sources, such as CNG and LPG).

Availability ***

In the same way, subsidy removal will tend to promote availability, by reducing excess demand and (in some cases) increasing producer returns.

Accessibility **

Much the same considerations apply as with taxes – removal of subsidies tends to create social problems, in particular for developing countries. Subsidies are not simply anomalies – they have normally been introduced to meet a particular social objective. Nonetheless, the continuation of subsidies is often itself highly distortive and may indeed be unsustainable. In some cases it diverts money from socially more useful expenditure – which could include expenditure to promote access to energy. For instance, in countries where electricity is subsidised, it would often be more effective to subsidise the electricity connection (thus promoting access), rather than electricity itself (which may help only those already privileged to have access to power, and encourage them to over-consume, as well as reducing the funds available within the electricity system for expanding the network). So, while it should be recognised that subsidy removal may create social problems, there may be relatively straightforward means of reducing any impact on accessibility.

The overall message here is that, while there may be problems, subsidy removal has such strong benefits that it is a key measure for consideration in any country where significant subsidies currently exist on fossil fuel use. Where the subsidy has been meeting an important social need, alternative means of dealing with the problem should (and generally can) be identified.

Emissions trading is not so much an emissions reduction measure, as a way of ensuring that a given level of emissions reduction is met efficiently.

2.1.iii Trading

Acceptability ****

Trading can, of course, take various forms – for instance, "green" trading of renewables obligations, or "white" trading of energy efficiency obligations. The same general arguments apply to all forms of trading, however, and this section focuses on emissions trading, which has the most fully developed and large scale market in the form of the EU ETS, discussed in Part 2. As noted there, emissions trading is not so much an emissions reduction measure, as it is a way of ensuring that a given level of emissions reduction is met efficiently. It is similar to taxation in using market forces. The big difference is that it operates more directly – instead of setting a price (via taxation) and letting the market sort out what quantities of emissions will result, it sets an emissions limit and allows the market to sort out the price consequences. In terms of high theory, this is the wrong way round – it may result in too high a price being paid. But in practice (given that, as noted, the externality cost is impossible to calculate precisely) it has many advantages, not least that it should enable a particular target to be met (which of course a tax cannot guarantee). But there are still problems – as the discussion of the ETS noted – in setting the initial allocations, i.e. in getting the target right. It is also a general rule that the more restricted the scheme, the less effective it will be in reducing costs – and conversely the more comprehensive the scheme (both in terms of geographical and sectoral coverage) the more likely it is that it will succeed in delivering the lowest possible mitigation costs. But extending the scope of trading schemes can be difficult for practical reasons – for example, including sectors such as transport, or extending the geographical scope of a scheme while still ensuring a well-regulated but liquid market, can raise very substantial problems. In its present experimental state the ETS cannot be said to have provided all the answers. So, while in principle a trading scheme should promote environmental acceptability, in practice the position may well be significantly more complex.

Availability ***

Emissions trading has the same general problems as taxation in relation to availability, with the additional difficulty, at least at the present stage in the development of such schemes, of uncertainty. Existing schemes, such as the ETS, have not been very successful in encouraging investment in clean technology. Because of their short-term nature, they tend instead to encourage short-term fuel switching, and in general (especially when this increases demand for gas) this is unlikely to promote availability – it adds to short-term demand pressures without creating a predictable long-term market to encourage new investment in upstream or downstream capacity.

Trading schemes could have a stronger impact on investment if they were long-term in nature and global in scope, but such a wide-ranging scheme would depend on a global consensus on a long-term climate change regime.

Accessibility ***

As previously pointed out, trading schemes suffer from some of the same problems as taxation – they tend to increase consumer prices and may thus be regressive in their impact. In principle, however, many of these problems could be mitigated by a global trading scheme, or even a more effective and responsive version of the present Kyoto mechanisms. Despite the recent fall in prices under the ETS, the cost of carbon remains much higher than for credits under the

Emissions trading	Assessment	Remarks
Acceptability	****	Very useful in principle, but complicated in practice.
Availability	***	It may take time for trading schemes to become credible enough to promote appropriate investment.
Accessibility	***	Trading schemes at present do little for accessibility. In principle, they could be a powerful tool, but there are formidable practical difficulties.

CDM or JI arrangements. More liquid trading could lead to larger transfers to developing countries, without imposing extra costs on developed country consumers. If combined with Green Investment Schemes, the revenues could be used to improve access, so providing further benefits to the developing countries involved.

Thus, in principle, trading schemes could make a strong contribution to accessibility worldwide. However, the contribution at present is limited, and there are some inherent problems. Trading schemes are complex and require a capacity for effective monitoring and enforcement; if they are to meet all the criteria of sustainable development, this almost certainly adds to the necessary administrative complexity, as has happened with the CDM. To enable trading to make its full potential contribution to climate change, reduction of trading would require not only a global consensus on a longer-term regime, as discussed above, but also simpler and more credible rules, enabling a liquid global market to develop. This is a major challenge and unlikely to be achieved in the shorter-term.

The overall message on taxes, subsidy removal and trading as economic instruments, is that to make a more balanced contribution to all 3A's, they have to be implemented with more consideration of the social impacts, or combined with measures to offset these impacts (e.g. help with energy efficiency). While many OECD countries may be able to afford such help, many developing countries cannot, and though there are a few international programmes which attempt to address this (e.g. on LPG), much more would be needed before economic instruments could play a major role.

2.1.iv Subsidies for low carbon options

Subsidies for low carbon energy forms come in so many varieties that it is impossible to give an overall assessment. Clearly, if well designed, they should improve the **acceptability** of the energy mix by reducing its carbon intensity. They may also improve **availability** by encouraging indigenous and non-fossil sources like renewables and nuclear – though, on the other hand, they may create market uncertainty and discourage other investment. In addition, by promoting policy driven rather than market driven investment, they may result in lower efficiency and less reliable supply overall. Subsidies can in principle improve **accessibility**, e.g. by supporting energy efficiency measures, though this may create conflicts. Energy efficiency support for low income consumers often results in higher comfort levels rather than lower consumption, a worthwhile result in itself but not significant in terms of emissions reduction. Subsidies for climate change supply measures may in some cases promote accessibility – e.g. by encouraging the development of off-grid applications – but this may not always be a consumer's desired choice (since off-grid supply is often of lower quantity or lower reliability than grid supply).

Impact of subsidies	Assessment	Remarks
Acceptability	****	Subsidies can be used to promote low carbon options directly, but can be an expensive option for developing countries.
Availability	****	Subsidies normally go to indigenous sources or to demand reduction, so should tend to promote availability. However, they reflect government, rather than market, choices which may not be efficient.
Accessibility	***	Subsidies for low carbon sources are not usually designed specifically to promote accessibility, though they can do so in some cases.

As even this brief discussion makes clear, it all depends on what precisely is being subsidised and how; the issues are looked at in more detail under the headings relating to the particular policy areas concerned.

There is an underlying problem – with subsidies, unlike most other economic instruments, government support usually involves picking winners, that is, supporting particular projects or technologies, rather than supporting carbon reductions as such (as with taxation or trading). This raises the risk of pressure from interest groups, loss of market efficiencies, or simply ill-informed decision-making undermining the ability to reach the objectives nominally being aimed at.

The assessments in the table above reflect an overview of subsidies as they exist today – for the reasons given, many are ill-designed to achieve the WEC criteria and few climate change subsidies have had accessibility as a clear goal.

Regulations and standards	Assessment	Remarks
Acceptability	****	Can be effective if well-judged, but often fail to achieve as much as expected.
Availability	***	By and large, these measures are not aimed at improving availability, though they may reduce demand pressures.
Accessibility	**	In some, but not all, cases, regulations tend to increase costs so they may create problems for accessibility unless carefully designed with offsetting measures.

2.2 Regulations and standards

The many different types of regulation were discussed in the previous part – for instance appliance and product standards, direct emissions limits etc. Similar considerations apply to this class of measure as to subsidies – it depends on what is being regulated and what standard is being aimed at. However, as the discussion in Part 2 underlined, there are major additional problems of monitoring and enforcement. It is very tempting to extrapolate simplistic results – that a 10% improvement in vehicle fuel efficiency will lead to a 10% reduction in vehicle fuel use – which rarely have much practical basis. While regulations and standards will form a major part of the policy armoury, they should not be relied on by themselves as a way of meeting emissions targets, unless extremely draconian approaches (which are unlikely to prove publicly acceptable) are adopted.

Voluntary agreements	Assessment	Remarks
Acceptability	****	VAs can improve acceptability, but in many cases only to a limited extent.
Availability	**	Most VAs are not primarily aimed at availability and probably have marginal impact in this area.
Accessibility	***	VAs should avoid the problem of excess cost and may have a generally positive effect on accessibility, but do not have a major impact on their own.

Information and awareness	Assessment	Remarks
Acceptability	***	Information and awareness measures are desirable and unobjectionable, but insufficient on their own to deliver major improvements in acceptability.
Availability	**	Unlikely to have much impact, though can be useful supporting measures.
Accessibility	**	Unlikely to have much impact.

2.3 Voluntary agreements

Voluntary agreements have generally operated in the same general area as regulations and standards – i.e. in improving energy efficiency and reducing emissions intensity – so similar considerations apply. The main difference is that, by their nature, voluntary agreements are not guaranteed to achieve results; on the other hand, they may be more efficient and lower cost in relation to the results they actually achieve. As discussed in Part 2, they are probably best seen as acting in complement with other measures.

2.4 Information and awareness

Information and awareness are an important part of any climate change strategy – they should, at the very least, help to gain public support for other policy measures and may of themselves have some impact in promoting lower carbon approaches. But, as with voluntary agreements, they are unlikely on their own to have a major effect. Their importance lies in the way they fit into a wider package of measures.

Energy efficiencies are achievable at all stages of the energy supply chain.

3 Assessment of measures according to the energy source affected

3.1 Energy efficiency

Only a relatively brief discussion will be given here. The WEC report *Energy Efficiency: A Worldwide Review,* produced in collaboration with the Agence de L'Environnement et de la Maîtrise de l'Energie and published in 2004, gives a full overview of energy efficiency measures and their impacts, on a global basis. The study provided the basis for the WEC Statement 2006 *Energy Efficiencies: Pipe-dream or reality?* which concluded that "while energy efficiency programmes are necessary for sustainable energy development, they are not sufficient on their own to address all energy accessibility, availability and acceptability goals." The reader is referred to these documents for a detailed examination of the issues. The following paragraphs provide a brief overview.

One important point stressed in the WEC document referred to is that energy efficiencies are achievable at all stages of the energy supply chain including, for instance, power generation, and in transmission and distribution as well as in energy use. Similarly, energy efficiency can be promoted in a variety of ways, from information and awareness campaigns such as energy labelling of appliances, to higher prices. In practice, however, most government programmes focus on end-uses of energy, with other stages of the supply chain being dealt with in other ways (e.g. in technology development), and the discussion below also focuses on end-use, with other forms of efficiency dealt with under the appropriate heading.

Acceptability ****

Clearly, insofar as they are effective, energy efficiency programmes are a very acceptable way of reducing emissions. The problems are that it is not always clear whether they are effective, and that governments are not good at monitoring the impacts. For instance, the WEC review pointed out that the best results on energy efficiency came from the industrial sector (where market forces are strong) and that passenger transport and households were not showing such achievements – for instance, none of the labelling or standards programmes had been able to stop or reverse the increase in appliance consumption, and the effectiveness of voluntary agreements was doubtful. It also stressed that more progress in data collection needed to be achieved. Overall, it judged that improving energy efficiency was a difficult challenge, not the easy option that many assume. These deficiencies stop energy efficiency from achieving the highest rating for acceptability.

Availability ***

The position here is somewhat analogous to that on economic instruments. On the one hand, effective energy efficiency programmes can help reduce demand and pressure on world markets. On the other hand, as pointed out in Part 1, there is no strong correlation between energy intensity and energy demand: the various interactions are extremely complex. So it is difficult to substantiate the claim that energy efficiency programmes have reduced emissions significantly; furthermore, they may introduce some uncertainty into the investment climate.

Energy efficiency	Assessment	Remarks
Acceptability	***	Important as part of any package of measures, but it is more difficult than usually recognised to achieve worthwhile emissions reduction.
Availability	***	Energy efficiency measures have not in practice had a significant impact on availability.
Accessibility	*****	Normally helps by lowering the costs of energy services.

Wind power	Assessment	Remarks
Acceptability	*** – ****	Environmental acceptability depends to a large extent on local circumstances.
Availability	****	Wind makes a significant contribution to availability, but as penetration increases, the practical problems become greater.
Accessibility	***	Wind is usually more expensive than conventional sources at present; costs may come down, but there are conflicting pressures.

Accessibility *****

On the other hand, energy efficiency generally scores very highly in terms of accessibility. Even if it does not lead to an absolute reduction in energy consumption in all cases, it clearly improves access to energy services by lowering their effective cost – and indeed may be justified on these grounds alone. There can be exceptions, of course – e.g. banning cheap but inefficient appliances like incandescent bulbs may create problems of access to the service (lighting in this case) for low income consumers. But it is relatively easy to avoid such problems – for example, by subsidising the more expensive, but more efficient, alternative.

Messages to be drawn from the above include the need for governments to monitor and assess their energy efficiency programmes more effectively and the scope for combining energy efficiency with other approaches – for instance to help overcome the disadvantages of economic instruments in terms of accessibility.

3.2 Renewables

Because these sources are all so different, four key technologies are discussed separately below, while other important renewable sources are looked at in less detail. In the long run, it is clear that renewables will have to play a greater part in the energy mix for reasons connected with all three pillars of sustainable development. In the shorter run, however, the position is more complex – there are economic and practical issues which limit the rate at which the contribution of renewables can grow without compromising development more widely.

3.2.i Wind

Acceptability *** – ****

Wind power has clear benefits as a non-fossil source in combating climate change. Nonetheless, it is not without its environmental impacts (noise, visual intrusion, impact on wildlife such as birds) which vary according to location (hence the range of markings set out above). One problem is that the best sites in economic and environmental terms tend to get exploited first, so with increasing penetrations wind tends to become either more expensive (e.g. offshore), or more intrusive, or both – for instance, distant sites often require the construction of extra transmission lines, with the significant environmental impacts that entails. Again, this limits the potential of wind in the longer run.

Availability ****

The advantages of wind are strong: it is renewable and widely available as an indigenous source, not just in OECD countries – developing countries like India and China also have major wind programmes. The global resource is huge – many times the current total global demand for electricity.

But the disadvantages are also clear – wind power is variable and intermittent. While the best sites may obtain high capacity factors (35% or so), the average in those countries with extensive wind penetration is much lower (less than 20%). Since, in addition, wind output does not correlate closely with electricity demand, a higher overall level of plant capacity in the system is required (e.g. in the UK, it is estimated that a wind component of 26GW would have a capacity credit of only about 5-6GW). While this extra plant would not solely act as back-up to the wind, it would inevitably operate at a lower load factor than would otherwise be the case, because

Biomass	Assessment	Remarks
Acceptability	***	Calculations of acceptability are complex and depend on the specific circumstances, but often biomass is significantly less acceptable than appears at first sight.
Availability	*****	Biomass can make a significant contribution in most parts of the world and can in particular be used for motor fuels.
Accessibility	****	The costs of biomass vary significantly but there is significant potential at relatively low cost.

of the wind component, so making investment less attractive. Alternatively, a system with significant quantities of wind power would also require large amounts of electricity storage – at present such storage is very expensive. The costs could come down with technology development, but this cannot be relied on.

For these reasons, it is generally recognised that wind power starts to cause serious practical problems once its penetration increases beyond 20% or so. This depends on the overall composition of the electricity system, of course. Wind may, for instance, provide a good match for controllable hydro power in systems with a good resource of this nature. In other words, while wind power may make a contribution to availability, that contribution is usually variable and limited. The rating given above reflects the present, relatively low, level of development of wind power – as penetration increases the contribution to availability is likely to decline.

Accessibility ***

In many countries today, wind is the cheapest source of renewable power. In the US, for instance, EPRI calculates generation costs at around 4.5 to 6.5 c/kWh. As wind power is also very widely available, it scores better than some renewables on accessibility – in many circumstances worldwide, wind will be the most effective way of providing access to clean modern energy. On the other hand, wind is rarely fully viable without some form of government support because, at all but a few sites, it is more expensive than conventional power. This site-dependence means that calculating likely future costs is difficult – on the one hand, capital costs have been coming down as the technology has developed; on the other hand, since the best sites are exploited first, future sites may be increasingly expensive (e.g. offshore or remote). Taking account also of the other limitations set out above, wind is likely to make only a moderate contribution to accessibility, except on the most favourable assumptions.

3.2.ii Biomass

Acceptability ***

There are question marks over the acceptability of biomass and biofuels. In some cases the results of life cycle analyses are ambiguous – it is not always clear whether there is a net decrease in ghg emissions, and even when a decrease is shown, it is usually much lower than the nominal reduction. For instance, a recent study by the University of Minnesota suggested that corn-based ethanol reduced greenhouse gas emissions by only around 12% compared with the use of gasoline. Biodiesel from soybeans produced a larger reduction – though, at 41%, emissions were still more than half the gasoline equivalent, and of course it is corn-based ethanol which is the main form of biofuel use in the US today. It is not, in any event, possible to generalise – the emissions reduction will depend very much on what crop is involved, where it is being grown, how it is processed etc.

In addition, biomass may create environmental and other problems, for instance in relation to land use, as discussed in Part 2. Some of these problems could be significant if biofuels develop further – for instance the OECD estimates that to power one in 10 of America's cars with home-grown corn-based ethanol would require almost one-third of US farmland. Already, there have been reports that US support for ethanol is putting upward pressure on

Calculations of acceptability are highly complex and situation dependent, yet in practice, government policies have not been very discriminating.

corn prices and leading to social problems of higher food costs.

A distinction can, in principle, be drawn between two sorts of biomass – food crop based and cellulosic (woody) material. Cellulosic biomass burns relatively easily, but is difficult to convert into liquid fuels, so is more commonly used for power generation at present; though in the longer run technological development should make it more viable to convert cellulosic material to biofuel. Food crop biomass is easier to convert to liquids, but obviously competes with agricultural uses. In practice, it is often the result of intense forms of agriculture with high inputs in terms of fertiliser and other resources. Cellulosic material tends to require fewer inputs, but also to be less "dense" in energy terms – it requires significant amounts of energy for transport and handling. In either case, of course, where the biomass in question is essentially waste – the by-product of forestry or agricultural activity – its use is likely to be much more environmentally acceptable. Where they are, and where biomass use is integrated into good forestry management programmes, there can be very positive results. However, in practice these high standards are rarely met.

In short, calculations of acceptability are highly complex and situation dependent, yet in practice, government policies have not been very discriminating in their support for biomass, as US experience indicates, because there are conflicting pressures – e.g. from the agricultural lobby.

Availability *****

Biomass scores high on availability – it is available in most countries and developing countries often have a comparative advantage, as illustrated in the Brazil case study discussed in Part 2. The global potential is enormous – estimated by the WEC at over 100 EJ a year, or over 20% of global energy consumption. Biomass is very flexible – it can be used as feedstock to produce solid fuels (e.g. briquettes or pellets), or gases (biogas, synthesis gas). Furthermore, unlike some of the other sources discussed, biomass in the form of biofuels (biodiesel, bioethanol) can be used not only for power generation, but also directly in road transport, so directly substituting for imported oil. It is also often relatively easy to co-fire coal or gas with biomass, or to produce "gasohol" type mixtures.

Accessibility ****

As with availability, biomass scores well on accessibility, at least in principle, because it is so widely available in developing countries in particular. However, it is difficult to give typical cost estimates, as these vary so much according to local circumstances. A typical range is 3-12c/kWh for electricity and $8-25/GJ for liquid fuel. At the low end of these ranges, biomass and biofuels are broadly competitive; at the top end they are not. However, because of the often distorted nature of agricultural prices, such calculations are themselves subject to a good deal of uncertainty. In addition, since developing countries may face some of the acceptability dilemmas (e.g. competition with agricultural uses) most acutely, in practice accessibility may be lower than appears at first sight.

The messages from the above discussion are that governments should be more discriminating about the sorts of biomass they support and the ways of doing so if they want to ensure that it contributes effectively to the achievement of the 3A's.

Solar power	Assessment	Remarks
Acceptability	****	Generally a very acceptable source, though at present there is little large-scale development. Often a good option for remote areas.
Availability	****	A huge and widespread resource, though availability differs between regions.
Accessibility	** – ***	At present still a high cost option, though costs might come down.

3.2.iii Solar power

Acceptability ****

Solar power scores high on acceptability. Because of the nature and variety of the technologies available, it can be used with due attention to environmental impacts in a variety of locations. The only significant question mark relates to its current early stage of development. Many energy sources which are perfectly acceptable when they are used only on a very small scale have much larger impacts as they develop more widely (wind and hydro might be examples – as their contribution has increased so has awareness of the environmental downside). Since solar power, like many other renewables, is a relatively low density form of energy, significant use of this resource would require the use of significant land areas. Whether this can be achieved in an environmentally acceptable way remains to be seen.

Availability ****

The technical potential of solar power is huge – 3,000 times current world energy use. Like a number of other renewable sources, solar power is widely available – and developing countries possess the bulk of the world's significant resources. Furthermore, solar power can be exploited in a variety of ways: in concentrated form, to raise heat for power generation; via photo-electric cells to generate power directly; and in passive designs, to take direct advantage of prevailing weather conditions. It can be developed at very small scale locally or in much larger centralised arrays.

What stops it from getting the highest rating is the simple fact that, like many other renewables, it depends on a natural source (sunlight) which is not uniformly available – e.g. at night, in cloudy conditions, near the Poles in winter etc. It therefore normally needs to be fitted into a flexible system, using other sources or backed up by storage (e.g. batteries), adding to the already high costs.

Accessibility ** – ***

In general, at the moment, solar power scores low on accessibility. Although costs have been coming down, it remains very much more expensive than alternative sources (an order of magnitude or more) so creating a major barrier in terms of accessibility. Photovoltaic power has been estimated to cost between 25 and 76c/kWh – well above the cost of conventional power. Concentrated solar power, at least in areas with high direct solar radiation, can be cheaper – EPRI estimates the cost from plants in California at around 18c/kWH, though this is still significantly above the cost of conventional power, and costs would be higher in less favoured regions. Passive solar power (e.g. good house design to capture the maximum potential amount of sunlight or shade) can be highly cost-effective but may be better thought of as a form of energy efficiency.

A range is given above, for two main reasons First, that there is scope for technological development to push down the costs significantly – the efficiency of solar modules and cells has increased rapidly in recent years while costs have come down, and this looks likely to continue. If this happens, a major objection to solar power would be removed. Second, there can be circumstances, particularly in developing countries where the costs compare favourably with the alternatives – e.g. where there is a large solar resource, but no grid connection. For instance, in Bangladesh, where two out of three households lack a grid connection, some 80,000 homes now own a basic solar panel that generates

Large Hydro	Assessment	Remarks
Acceptability	** – ****	Acceptability depends significantly on the circumstances
Availability	****	A widespread, but not unlimited, resource.
Accessibility	****	Generally a low cost source, though not an option for all countries.

about 50 watts of power. This is a limited form of accessibility (and not very cheap, given the need for batteries to complement the panels), but in some circumstances it constitutes a valuable option.

3.2.iv: Large scale hydro

Acceptability ** – ***

As with many other renewable sources, the acceptability of hydro depends a lot on the circumstances. In many OECD countries, the environmentally acceptable potential of large-scale hydro power has already been more or less fully exploited; there are major issues about the impact on aquatic life and in some cases question about the ghg impacts of rotting vegetation trapped behind dams. In developing countries, there is still significant potential for expansion of large scale hydro, though as well as the direct environmental issues there are also often major social issues connected with the displacement of population. In the view of many, large scale hydro has become regarded as increasingly less acceptable.

Availability ****

Hydro is far and away the most significant renewable electricity source at present, producing some 17% of global electricity. In absolute terms, output from hydro sources could potentially rise by two or three times (though this is likely to mean that the proportion of electricity from this source remains roughly stable, as demand itself rises). So it makes a major contribution to availability, though that contribution is not likely to increase significantly.

Another factor which limits hydro's contribution to availability is the risk of a dry year with low rainfall or snowfall. Countries as varied as Brazil, Portugal and Sweden, and states such as California, have all suffered from availability problems for this reason in recent years.

Accessibility ****

Hydro is generally a relatively low cost energy source (current schemes produce, at an average, costs estimated at around 2c/kWh, though there is a wide range depending, as with other renewables, on the site). However, given the constraints on acceptability and availability discussed above, and the fact that many countries do not have suitable geography for hydro development, **hydro will not be the main route to lower emissions**.

Small scale hydro	Assessment	Remarks
Acceptability	****	Usually a very acceptable source.
Availability	****	A relatively minor resource but where available can make a useful contribution.
Accessibility	****	Particularly helpful in improving accessibility in remote areas.

Wave power	Assessment	Remarks
Acceptability	****	Wave power should prove an acceptable source but it is difficult to give an overall judgement at the present stage of development.
Availability	***	A widespread resource but relatively difficult to exploit. Generally reasonably well correlated with the pattern of demand.
Accessibility	**	Costs can be high and there are still significant technical problems, which may be removed as the technology develops.

3.2.v Small-scale hydro

Acceptability ****

Unlike large scale hydro, small scale hydro is still generally acceptable, and indeed is part of the climate change programme of countries across the world, as Part 2 noted, and the range given above reflects this difference. This does not mean that small-scale hydro is without environmental impacts however – since the sites are often remote and are by definition small-scale, they may require significant amounts of transmission capacity in relation to their overall contribution to the energy mix.

Availability ****

Small scale hydro, despite its attractions, makes only a very small contribution to the present hydro total (under 5% of all hydro power); while it too may expand in absolute terms, its share of the total is unlikely to change significantly, so its contribution to availability will remain limited. However, it is often an economic and practical source for remote areas, given the widespread nature of the resource and the scalability of hydro systems.

Accessibility ****

For the same reason, small scale hydro, where available, can make an important contribution to accessibility.

3.2.vi Other renewables

Other renewable sources may make an important future contribution but are generally less well-developed at present, or (like geothermal power) are an option readily available in a few countries only. These sources are given only summary rankings below, though in all cases the same sort of consideration and analysis has been given as in the more extended discussion above.

Wave power

There are various ways of extracting power from waves – through floating modules, whose motion is used to generate power; through onshore cavities, where entering waves create pressure to drive turbines etc. The potential (especially in deep water waves) is significant, but the practical problems also remain significant – the devices and associated transmission lines have to be able to withstand extreme weather conditions and this has in the past created some problems, though the technology continues to improve.

Tidal power	Assessment	Remarks
Acceptability	***	There is only a limited number of suitable sites; each would require a specific assessment in relation to acceptability.
Availability	***	Not a very widespread resource but where it is available it is reliable and predictable.
Accessibility	***	At suitable sites costs should be acceptable, but in most countries the potential is limited.

Geothermal power	Assessment	Remarks
Acceptability	****	Generally very acceptable, though expansion might mean that less suitable sites are being used.
Availability	***	A useful resource but where it is available.
Accessibility	***	Costs are generally acceptable, but the resource is not available in all countries.

Tidal power

In the right circumstances (bays and estuaries with a large tidal flow) the potential can be significant, and tidal power has been used for many centuries (e.g. to power mills). However, large scale projects raise significant environmental issues – the bays and estuaries involved are usually major habitats for birds and aquatic life – and the number of suitable sites is relatively limited. So, while in the right circumstances tidal power may be a significant electricity source, the potential is relatively limited. Nor is it clear whether in general the costs will be acceptable – current costs are estimated to be in the range 8-15c/kWh.

Other ocean technologies

There are various other potential ocean technologies – e.g. exploiting the power of underwater currents such as the Agulhas current off the coast of southern Africa, and so-called Ocean Thermal Energy Conversion, which exploit temperature differences between different layers of the ocean. These technologies have significant potential in the sense that there is a large energy resource available to be tapped, but it is too early to say how far they will prove acceptable or contribute to accessibility.

Geothermal

Geothermal energy can be exploited in a variety of ways. The easiest (though this is only possible in suitable geological conditions) is to use hydrothermal resources (water from hot springs) directly, and this is a significant resource in countries like New Zealand and Iceland. Other approaches include “hot dry rocks” – finding a layer of hot rocks underground, pumping water down to the relevant strata and extracting steam from another well for use in power generation or heating. In the right conditions costs of geothermal power are relatively low (as little as 2c/kWh), though typical costs of electrical power in the US have been estimated at 5-6c/kWh. The ultimate potential is large (WEC estimates it at over 1,000 TWh per year), though not unlimited. There may also be environmental and other sustainability issues (e.g. if heat is extracted faster than it can be naturally replenished).

A further option is the use of heat pumps to transfer heat from the ground (or indeed any environmental source) for residential or industrial use. Heat pumps are better treated as a technology in their own right (and there is a substantive discussion in the technologies analysis produced for the current scenarios study to which the reader is referred), but they can also improve the efficiency of utilisation of geothermal sources.

Acceptability is obviously the key issue for nuclear.

3.3 Current nuclear (for potential see following section)

Acceptability * – *****

Acceptability is obviously the key issue for nuclear. There is no consensus globally on the issue, and this is reflected in the range above. Many would argue that as a non-fossil source, emitting no ghgs in operation but capable of meeting energy needs effectively, it is the world's most acceptable energy source. The analysis in Part 1 showed how countries with high proportions of nuclear in their systems (such as Sweden and France) had ghg emissions per head significantly lower (30-50%) than those of comparable nations, demonstrating the contribution nuclear could potentially make to dealing with climate change globally. Proponents also point out that most surveys show that only a minority of the public is actively opposed to nuclear power, and that much of the objection is based on a misunderstanding of the issues.

Others disagree, pointing to issues of economics, safety, radioactive waste management, decommissioning, proliferation and security, including vulnerability to terrorist attack. The list is a long one and this study cannot attempt to settle these questions finally.

In the end the message must be that **all governments should give serious consideration to the potential of nuclear power for reducing ghg emissions**. If they still wish to reject the option, for reasons of acceptability, then they must ensure that they take equally effective alternative measures in combating climate change. For those wishing to proceed with nuclear, they must work hard at the various areas listed above to improve acceptability and enable nuclear to make an effective contribution to sustainable development.

Availability ****

Nuclear scores high on availability – nuclear plants are reliable and not dependent on particular natural phenomena. The fuel is easy to store and not dependent on insecure world markets. Uranium is a very concentrated energy source – one tonne of uranium produces the same electricity output as 20,000 tonnes of coal. Technological development is both increasing the efficiency of fuel use and opening up the possibility of alternative fuel cycles (such as thorium).

There are limitations – current identified uranium resources would last for less than a century at current usage rates. However, (as with other reserve and resource figures) there is no reason to believe this is an absolute ceiling – a realistic view of ultimate fuel availability would probably lie in the thousands of years. Availability is more likely to be limited by acceptability issues – either direct public acceptance or because of the interaction with military uses of nuclear fuel, which has led to an international regime of governance.

Accessibility **

As with other aspects of the nuclear issue, it is not simple to judge its impact on accessibility; the economics of nuclear are hotly debated. Some countries (e.g. the US and UK) have found it an expensive option. It also seems clear that free markets are reluctant to invest in nuclear, because of the risks involved, unless there are clear indications of government support. On the other hand, countries that have made a significant commitment to nuclear, like France, enjoy relatively

Nuclear power	Assessment	Remarks on the current position
Acceptability	* – *****	Nuclear power is controversial and countries will make their own judgements. But its potential for emissions reduction is huge and those rejecting this option must ensure that they have effective alternatives.
Availability	****	Can make a major contribution to energy security and reliability.
Accessibility	**	The economics are disputed and nuclear power may not suit all countries.

low electricity prices and have not suffered in terms of accessibility. Furthermore it is not just advanced industrial countries that are considering the option, indeed the most active current focus of nuclear activity is in countries like India and China, with their vast energy needs, which are pursuing the option actively.

What is clear is that nuclear is capital intensive – in round terms investment costs are about $1,500 per kW or more, compared with $1,000 or so for coal and around $500 for gas. (The OECD study of the costs of electricity generation gives a figure of $1,000 – $2,000 for nuclear, with some countries having plant construction costs exceeding $2,500; for coal the equivalent, range is $1,000 to $1,500, for gas $400 to $800). Developing countries often face both shortages of capital and relatively high costs of capital, making high capital cost options more difficult. Also, up to now the technology has not been very scalable – a typical plant is large scale and the newest plant being built in Europe is huge (1.6GW), making this a very difficult option to integrate into a small system. This could change – the Pebble Bed Modular Reactor, for instance, should be viable in relatively small units; but even small reactors involve complex technology and the associated safety and maintenance requirements, and may not be suitable for all countries.

The message here is similar to that in the previous section – governments and companies wishing to promote the future of nuclear must do what they can to improve its economics by appropriate r & d efforts, and by creating a level playing field – for instance, by setting a long-term carbon price or emissions trading scheme and clarifying issues of risk and liability so that there is a firm basis of investment.

Technological development has the potential to improve nuclear's score against all the headings below, and this is further discussed in the following section.

The potential of technology deployment should never be underestimated.

4 Technology

This section is somewhat different from the others because of the fundamental importance of timescales. Many technological options which could be hugely important in addressing the climate change problem are still under development. Even for existing technologies, further development (if properly directed) is likely to enhance the contribution to the 3A's, for instance by reducing costs and so increasing accessibility (as is expected in relation to many renewable technologies). In addition, the subject is both wide-ranging (the number of actual and possible future technologies is huge) and vulnerable to enormous uncertainty (the outcome of technological development cannot be guaranteed in advance).

The subject will therefore be discussed in broad terms under two main headings:

- near-term options in the area of technology **diffusion** – deployment (i.e. of existing best practice technologies) and technology transfer (to developing countries) **(Section 4.1)**;
- the potential of technology **development** for the future (including short discussions of particularly promising technologies) **(Section 4.2)**.

4.1 Technology diffusion

4.1.i Deployment of best practice technologies

Acceptability ****

The potential of technology deployment should never be underestimated. While new technology development is inevitably going to be a key element in the world's response to the climate challenge, huge emissions savings can be made simply by the deployment of existing best available technologies. Part 2 discussed the efficiency gains available in power generation from clean fossil technology. If existing leading edge technologies were deployed more widely, this could of itself have a major impact on global emissions. For instance, average thermal efficiency of power stations in many developing countries is around 30% or less and in developed countries generally under 40%. The best modern coal stations manage well over 40%, while some gas stations are approaching 60%. If such best practice could be replicated worldwide, emissions from power generation (the fastest growing source of ghgs) could be stemmed or reversed. This need not involve excessive complication or cost – as noted, in OECD countries many fossil fired power stations are aging and due for replacement in any event, while developing countries in many cases have major investment programmes under way to meet their rapidly growing energy demand. Since existing best practice technology involves few technical or economic risks, it would be relatively easy for governments to change incentive structures to encourage investment in such plants, rather than less acceptable alternatives.

Availability ****

In most cases, new technology offers higher efficiencies: as Part 2 noted, simply encouraging equipment turnover is often an effective way of increasing the overall efficiency of energy use. These higher efficiencies should reduce demand, or at any rate slow the increase in demand, so reducing the pressure on world energy supplies and improving energy availability. Incentives for technology deployment can also be used, of course,

Technology deployment	Assessment	Remarks
Acceptability	****	Stimulus to technology deployment is an effective way of reducing emissions.
Availability	****	Technology deployment can also contribute to energy security and reliability.
Accessibility	***	The contribution to accessibility depends on the circumstances but should generally be positive.

Technology transfer	Assessment	Remarks
Acceptability	****	Technology transfer is an effective, and under-used, way of reducing emissions – provided the many practical problems can be addressed effectively.
Availability	****	Technology transfer can also make a significant contribution to global energy security.
Accessibility	****	Given the will, technology transfer can also be an important tool for improving accessibility.

to encourage the use of indigenous or alternative technologies such as renewables, with a further potential contribution to energy security.

Accessibility ***

Finally, technology is in general positive in terms of accessibility. In some cases it will add to costs (which is why it does not get the highest marking), but in general the wider deployment of existing technology should be a relatively low cost way of reducing emissions and hence more likely to promote accessibility than many of the alternatives.

4.1.ii Technology transfer to developing countries

The transfer of technology to developing countries has already been highlighted in Part 2 as a very important area in combating climate change. It is the global counterpart of technology deployment, and therefore particularly relevant in the context of a global issue on which, as this study has noted, it is often more difficult for developing countries to take action because of the constraints they face. Given the very high potential rate of growth of emissions in developing countries, and the social and development imperatives which they face, measures which can help square the circle by enabling clean development must be a global priority. In general, technology transfer scores very highly against all the WEC criteria, as discussed below.

The problems with technology transfer are primarily practical – dealing with all the complicated sovereignty, intellectual property, “appropriate technology” and other issues it raises. But these practical problems raise complex issues of principle. In many cases, it is difficult for governments to deal with these issues in any simple fashion. Governments do not generally own technologies; technology is not free – it represents billions of dollars and years of effort in research and development work; where companies have made this investment they are naturally unwilling to give the rights away for nothing, or compromise the security of their intellectual property ownership.

Acceptability ****

Measures to promote the transfer of efficient technologies to developing countries have the potential to be enormously effective in combating climate change. Developing countries are likely to be the main growth area for ghg emissions in coming decades while, for well understood reasons, they are not subject to emissions caps. They also often contain the lowest cost mitigation options. So a focus on transferring emissions reducing technology is likely to meet several goals at once and prove highly acceptable in environmental terms.

Availability ****

Similar considerations apply as with technology deployment in general. Developing countries have the fastest growing energy demand and this is already putting pressure both on world supplies and on their own indigenous sources. Transfer of more efficient technologies will help mitigate this demand growth and produce benefits for global energy security.

Accessibility ****

Technology transfer should also improve accessibility by ensuring that the best technology is widely available and that economic constraints do not prevent developing countries from having access to it. The only cautionary note is that, of course,

The strategic significance and long-term potential of technology is unlimited.

this all depends on the terms of the transfer – and it is here that the major problems referred to above normally arise. This Study cannot itself provide solutions to these problems, but it can underline the great importance of finding solutions. Technology transfer has enormous potential to help the world combat climate change, while meeting all 3A's. It is essential that governments and others make every effort to unlock this potential by addressing the obstacles to transfer.

4.2 Technology development

The importance of technology development should not need underlining – it has featured in many of the assessments and analyses in earlier sections, in a variety of ways. For instance:

- Technology development promises to reduce the cost of solar power and other renewables and thus remove the main obstacle to their wider deployment.
- Technology development is improving the safety, and reducing the waste, arising from nuclear generation.
- Technology development is needed to provide alternatives to oil in transportation.

In fact, in one sense, **the strategic significance and long-term potential of technology is unlimited** – we do not know what future energy sources might be developed or exploitable with better technology (nuclear fusion? deep ocean currents? bacterial hydrogen generation?). The discussion below (and in the transport section) focuses on a limited number of areas of technology development which seem relatively near to commercialisation, and to have major potential in terms of greenhouse gas emissions reduction, but that it is not to say that there are not many others which, over time, might not also have an important part to play.

Medium-term technology options (likely to be viable over the coming decade or so)

The potential application of CCS technology is huge – a policy aimed at reducing emissions on these large sites should be able to deliver significant and rapid results.

4.2.i Carbon capture and storage

As discussed in Part 2, although this is not an established technology, it is very much more than a paper possibility and has huge potential – if fossil sources can be enabled to be used in an environmentally acceptable way, many of the world's current challenges in the energy sector will be removed, or at least significantly reduced.

Acceptability **

Carbon capture should be able to remove about 90% of the CO_2 from fossil fuel combustion in stationary applications, thus making a hugely significant contribution to emissions reduction. At present, however, there is not enough experience of storage to enable judgements to be made definitively about its longer-term acceptability. Taking geological storage first, on the one hand, existing storage sites (such as Sleipner and Weyburn) have been extensively monitored and no problems have been identified to date. Nor is there necessarily any reason to expect problems – after all, natural gas stored in underground strata has generally remained intact for hundreds of millions of years, and there are cases of underground CO_2 reservoirs of similar age. On the other hand, underground storage inevitably involves not original strata, but layers which have been drilled into, and therefore may have been damaged. In some circumstances, as volcanic structures such as those underlying Lake Nyos have demonstrated, CO_2 can leak from underground and create hazards of a serious nature. It seems likely, though not certain, that further research will enable scientists to be confident that appropriate strata will be chosen and appropriate methods used, ensuring that such problems do not arise.

There is a wider question, of a more metaphysical nature, as to whether it is right to rely on "back-end" solutions of waste disposal, rather than approaches which avoid the waste creation in the first place and in the long run. For this reason, the use of non-fossil sources is likely to be the best outcome. But given the scale of the current challenge, and the difficulty of rising to it, it is important that all options with significant potential should be developed to enable that potential to be tested and, if appropriate, put to use.

Other forms of storage have been considered – deep ocean storage raises larger issues of acceptability since the CO_2 is being added directly to the natural environment rather than sequestered from it, and the uncertainty about its potential impacts is therefore that much greater. On the other hand, very few, if any, acceptability issues are raised by mineral sequestration (incorporation of the CO_2 into rocks like magnesium oxide to create a mineral, magnesium carbonate, which already occurs widely in the Earth's crust). Although this option seems a long way from practical viability.

Availability **

There are two conflicting aspects here: on the one hand, if carbon capture and storage makes it possible to use sources like coal, which could otherwise be very difficult to integrate into a low carbon energy system, this could improve the effective availability of fossil fuel. On the other hand, carbon capture in particular involves a significant energy penalty. The IPCC points out that: "A power plant equipped with a CCS system (with access to geological or ocean storage) would need roughly 10–40% more energy than a plant of equivalent output without CCS, of which most is for capture

Carbon capture and storage	Assessment of potential	Remarks
Acceptability	****	If developed commercially, should enable significant emissions reductions.
Availability	****	Main contribution would be in improving the acceptability of fossil fuel use.
Accessibility	**	Will involve extra cost – but may still compare favourably with alternatives.

and compression.” This energy penalty could be a serious drawback for countries like China and India, which are concerned with making the most effective use of their indigenous resources in the effort to meet growing demand. Technology development might in principle reduce the energy penalty significantly, but is unlikely to remove it altogether.

CCS is likely to be economic for large point sources, i.e. probably not for personal transport, home heating and the like. However, this is not such a limitation as it may appear at first sight. The IPCC report estimates that well over half of current CO_2 emissions come from such large point sources. (The sources concerned include power stations: on their own about 5000 power stations account for fully 40% of global CO_2 emissions. However, there are also a number of large industrial sites, such as oil refineries, steel works etc. The IPCC figures include sites emitting over 100,000 tonnes of CO_2 a year, but the average is far higher – around 1.5 million tonnes per site).

The proportion of emissions accounted for by these large sites is very likely to increase, rather than reduce: first, because of the increasing share of electricity in the energy mix; second, because of likely developments in the oil and transport market. Higher oil prices and the possibility of conventional oil production coming to a peak are increasing the attractiveness of unconventional sources. Nearly all the options involve more upstream energy use for conversion, whether of heavy oil and oil sands; gas-to-oil; or coal-to-oil, with the likelihood of significant associated CO_2 emissions. Even more, apparently acceptable, alternatives could involve significant CO_2 emissions. The implications of electric vehicles for greenhouse gas emissions will depend on the carbon intensity of the electricity source. Even biomass plants can involve significant local emissions – for instance the IPCC estimates that current biofuel plants emit nearly 100 million tonnes of CO_2 per year. This CO_2 should already be offset by the gas captured in plant growth. Nonetheless, if the CO_2 emitted from the manufacturing process can be captured, that would make an additional contribution to emissions reduction. In short, the potential application of CCS technology is huge – and, more generally, a policy aimed at reducing emissions on these large sites should be able to deliver significant and rapid results.

Accessibility **

The accessibility challenge may be more difficult. Carbon capture and storage will inevitably carry a cost penalty – while this may reduce over time, it is unlikely to disappear, so there will always be a tendency to reduce accessibility. On the other hand, the cost penalty may be comparable with, or less than that of, other sources. Most forecasts see the cost of carbon capture and storage as likely to be around \$50 per tonne of CO_2 by 2010 or so, and perhaps \$25 or less in the longer run. While that is a significant amount, it is not necessarily excessive compared with other options – for instance, prices under the ETS have reached over \$30 per tonne and are likely to increase as the limits tighten, and the implicit cost of mitigation under many renewables schemes is in the hundreds of dollars.

Intelligent technologies	Assessment of potential	Remarks
Acceptability	****	Can help make significant emissions reductions without requiring changes in consumer behaviour.
Availability	****	Should have a positive effect on energy security by reducing demand.
Accessibility	***	Likely to be a fairly competitive option.

4.2.ii Intelligent technology, BEMs and micro CHP

Intelligent technology already shows great potential as Part 2 noted. But the future potential may be even more significant, in enabling a wholesale restructuring of the energy market into millions of individual sources, coordinated via intelligent technology, so that energy wastage and unnecessary energy transportation, with the inevitable associated losses, are minimised or eliminated.

BEMs are buildings energy management systems: an application of intelligent technology to the management and optimisation of energy use within buildings. Such systems already exist, but, with the development of more sophisticated IT, show great potential for the future (for more detail, the reader is referred to the electricity end-use study undertaken as part of the WEC Scenarios exercise).

Micro-CHP refers to very small scale cogeneration – for individual residences or sites. Although in the past it has been impractical to generate electricity at this level, advances in the generating technology itself and, importantly, in the IT which would allow electricity to be traded at a very local level (neighbour to neighbour), may make micro-CHP a feasible way of meeting residential heat (and cooling) and electricity needs efficiently at the same time. In addition to the efficiency gains from co-generation, there would be gains from local electricity generation and the associated reduction in transmission losses. In principle, very high levels of efficiency (of over 90%) are possible, with corresponding emissions reductions, and some of the wider issues over CHP discussed in Part 2 would be overcome. At present micro-CHP schemes are usually gas-fired, but in principle fuel cell technology could be used, further improving environmental acceptability.

Acceptability ****

Micro-CHP should prove an effective and publicly acceptable means of reducing emissions if the technology develops as hoped. It would still use fossil fuels (normally natural gas), but in most systems the efficiency gains would lead to significant emissions reductions compared with alternative fossil sources. In existing houses in the UK it has been estimated that it reduces emissions by around 20% (though the figure would vary in different countries).

Availability ****

Similarly, the reduction in demand (again around 20%) resulting from micro-CHP should help reduce pressure on world supply.

Accessibility ***

While micro-CHP is not at present fully competitive, it should not in principle involve significant extra cost, if the technology can be refined, and should prove an attractive option.

Future energy efficiency technologies	Assessment of potential	Remarks
Acceptability	****	Can help make significant emissions reductions.
Availability	****	Should have a positive effect on energy security by reducing demand.
Accessibility	****	Likely to be competitive options provided costs can be reduced.

4.2.iii Energy efficiency applications: heat pumps, LEDs etc

As Part 2 noted, energy efficiency measures already offer very significant emissions reduction opportunities, though the savings may in practice not always be easy to realise. **Future technologies offer even more potential – in forms which may make it easier to secure savings**.

Heat pumps are essentially a way of transferring heat from one source to another. The principle of operation is essentially the same as that of the heat transfer in a domestic refrigerator, though they can be used in reverse mode – i.e. to extract heat from the surroundings (air or ground) and transfer it to the interior of a building. Their chief advantage is in their efficiency. Most forms of energy generation have less than 100% efficiency (i.e. energy output is less than energy input). Heat pumps, on the other hand, because they transfer, rather than create, heat, can have an output higher than their energy input. Already, this ratio (expressed in the concept Coefficient of Performance – COP) can be in the range of 3 to 6, and future potential may be higher. At present the problem with the technology is usually with the high capital cost, but as efficiencies improve and costs come down and energy prices rise, the future potential could be very considerable indeed.

LEDS (light emitting diodes) already exist as light sources, for instance on calculators and watches and recently in such applications as traffic signals and displays. They are small, durable, controllable and energy efficient (as compared with, say, traditional incandescent bulbs which normally convert only around 5% of the energy input into light). Their potential, as costs come down with technological development, is huge – in principle they could replace all existing forms of lighting, with huge associated gains.

Of course, these examples illustrate only a few of the vast range of efficiency technologies, discussed in more detail in other studies such as the End-Use Electricity Study or the IEA Study on *Energy Technology Perspectives* produced in support of the G8 Plan of Action. The assessment below is intended only to reinforce the point that the potential of these technologies is enormous.

Next generation nuclear	Assessment of potential	Remarks
Acceptability	*** – *****	Nuclear power will remain controversial, whatever the technical developments. Nonetheless, such developments could substantially address many of the current objections to nuclear.
Availability	****	Nuclear could make a major contribution to energy security and reliability.
Accessibility	***	Technical development could substantially improve the economics of nuclear power, making it fully competitive in most countries.

4.2.iv Next generation nuclear

Previous sections have discussed the problems of nuclear in the area of acceptability – such matters as safety, waste disposal and proliferation as well as the uncertain economics. In all these areas there is potential for technological development to improve performance against the 3A's.

But the key point is that **nuclear programmes of the future need not be judged in terms of the past**. The industry has worked to solve the problems of the last century. For instance, in terms of acceptability, improved designs (so-called Generation III) offer passive safety features, such as passive cooling to ensure safe shut-down in the event of an accident, much lower levels of waste production than current reactors, and better economics.

Future reactors (Generation IV) could go even further. They have the potential to use different fuel cycles, including unconventional uranium and thorium, vastly increasing nuclear's availability potential by removing any effective resource constraints. They could also help overcome the waste problem by bringing forward designs which can run on recycled or spent waste from existing nuclear plants. The final high level waste could be one tenth or less of the currently planned volume and have a much shorter half-life, decaying to natural background radiation level in hundreds, rather than thousands, of years. Costs could similarly come down considerably, improving economics and accessibility for developing countries.

However, the issues go beyond the purely technical; it may, for instance, be necessary to explore different social and political options (for instance new consensus building approaches within countries to deal with long-term decisions such as decommissioning; researching not simply technical issues of waste management, but also social issues on site selection and community involvement in decision-making). Even then, there is no advance guarantee that public acceptance will be obtainable.

Nuclear fusion could be a long-term option (its place would then be in the following section) but, as with fission, it is likely that public acceptability will be a key issue. While there is at present no clear indication that the economics are likely to fall sufficiently to make it viable, this too may eventually change with further concerted international development efforts, including those which are now in progress.

Hybrid vehicles can make a contribution to emissions reductions but they are not a final solution.

4.2.v Transport measures

It is not practical to survey the range of possible transport measures in a study such as this – further detail is, however, available in the parallel transport study being undertaken as part of the WEC Scenarios Study, to which the reader is referred. However, there are some areas of direct transport /energy overlap, such as the biofuels discussed above, and this study has stressed the importance, in a climate change context, of finding alternatives to oil for use in transport if the inexorable rise in transport emissions is to be stemmed.

Transport also illustrates three key points about technology development and deployment which have much wider application:

- First, that it is important not to wait for the perfect technology to come along – ensuring the widespread deployment and improvement of available technology is one of the most important tools for combating climate change. While there is considerable interest in fuel cell vehicles, the best estimates are they will not really be competitive before about 2050. Meanwhile, there are many options such as hybrid (and plug-in hybrid) technology which could be introduced in the shorter-term. Indeed, fuel cells may eventually disappoint – there have been false dawns before in transport, such as the interest in battery cars in the 1990s. Solutions to the transport emissions challenge will not necessarily depend on the discovery of a magic bullet.
- Second, that acceptability is often not just a matter relating to a technology in isolation – this was pointed out above in relation to nuclear, but also applies to transport. Transport emissions involve not just vehicle technologies, but such factors as urban planning, social attitudes, availability of public transport etc. Technology should not be treated as something independent which can be slotted into any social context, whether it is a matter of development or deployment. Equal attention should be paid to these wider factors – how to make the technology work effectively and be accepted – as to purely technical issues.
- There are major inequalities in transport energy research funding, as in other areas. Most takes place in the developed world and has regard to developed world priorities (in which accessibility usually comes fairly low down) – hybrid vehicles and fuel cells are examples. Yet climate change and sustainable development are global issues and solutions will have to be capable of global application.

While these wider issues relating to transport are beyond the scope of this study, two particular areas of transport technology development are briefly surveyed below in view of their potential for contributing significantly to emissions reduction: hybrid vehicles and fuel cells.

Hybrid vehicles

Hybrid vehicles involve the use of both electric (battery) and gasoline energy to provide the motive power – typically the electric power is used on its own in urban environments to reduce emissions, while the gasoline is used to power the vehicle for inter-city travel.

Hybrid vehicles	Assessment of potential	Remarks
Acceptability	****	Can make useful, but not deep, emissions reductions.
Availability	***	Unlikely to have a major impact on energy security.
Accessibility	**	An accessible route to emissions reduction in some countries; less relevant to others.

Acceptability ****

Hybrid vehicles involve significantly lower emissions than their pure gasoline equivalents and should in particular contribute to a reduction in urban pollution.

They help overcome one of the key problems with pure electric vehicles – the limited range available with battery technology. Normally in hybrids the battery in the vehicle is charged during driving by the gasoline engine itself. However, it is also possible to design the vehicles to be recharged, particularly during off-peak demand periods, from mains electricity – so-called "plug-in hybrids". This should in principle be cheaper, more efficient and further reduce emissions (depending to some extent on the structure of electricity generation in the system involved). Such vehicles can also act as mobile electricity storage systems for use during the majority of time when the vehicles are not being used for transport.

So hybrid vehicles can (and indeed are – vehicles like the Prius are already selling in significant numbers) make a contribution to emissions reduction. But it must be conceded that they are not a final solution. While hybrid vehicles have lower emissions than their gasoline equivalents they are not the lowest emitting vehicles available – in Europe some small cars, most motor bicycles and scooters, and all pedal bicycles of course, offer better performance. Emissions also depend on driving style – as with the CAFE standards, many drivers find that in practice they achieve poorer performance than official tests suggest, especially if they do a lot of inter-city travel.

Availability ***

For the reasons discussed in the previous section, hybrid vehicles are unlikely to make a significant impact on availability, although they may help in a modest way.

Accessibility **

Hybrid vehicles cost more than conventional ones (though government support can help offset the extra cost). They may therefore raise barriers to access to mobility – indeed, in many developing countries where bicycles, motor scooters and small cars tend to provide access to mobility for poorer consumers, hybrid vehicles may have fewer advantages than in the OECD.

4.3 Longer-term options

This section looks briefly at some technologies which are not likely to be viable in the foreseeable future but which could have very significant longer-term potential (i.e. looking forward to the middle of this century and beyond). Since this is not a scenarios exercise, the section does not go into detail – for that the reader is referred to the WEC and other studies referenced above.

4.3.i Energy storage

The impracticality of electricity storage underlies the whole economics of electricity systems – electricity supply must match demand at all times, so there needs to be sufficient capacity to meet maximum demand. It is also a major impediment to the further development of many renewable sources. In many cases, these sources are intermittent or unpredictable, like the natural forces which underlie them. Better means of electricity

Electricity storage	Assessment	Remarks
Acceptability	****	Has the potential to enable very significant emissions reductions.
Availability	****	Should significantly improve energy security both directly and by improving flexibility.
Accessibility	*	The key storage challenge – if costs could be brought down, it could make an enormous contribution.

storage would vastly improve the economics of many renewable sources and remove many of the practical obstacles to their integration in the system.

Of course, such an underlying problem has long been the subject of research and it is not obvious that any breakthrough is in sight. But the potential of storage is such that it is worth a mention here – improvements in storage technology could prove the tipping point that enables renewable sources to develop of their own momentum. There are various approaches – e.g. pumped water storage; compressed gas; battery arrays; advanced flywheels; reversible fuel cells; and hydrogen storage for instance. At present all are either expensive or limited by such factors as site availability but continuing research may help overcome these problems.

Acceptability ****

If storage technology could be developed it would both be very acceptable in its own right, and make a major contribution to the development of renewables, so improving the acceptability of electricity supply.

Availability ****

By the same token, storage would improve availability; it would enable intermittent sources to be used more effectively, improve the overall efficiency of electricity systems and reduce investment needs. It would also improve security directly in the same way as oil, coal and gas storage do.

Accessibility *

The low ranking here simply reflects the present state of the technology. If accessibility could be improved by significant cost reduction, storage could make a major contribution to energy access worldwide.

4.3.ii Hydrogen and fuel cells

Fuel cells use chemical energy to produce electricity rather than producing heat by combustion. Hydrogen can be used together with oxygen in this way, with water vapour as the only waste product. (Other fuels can also be used, but this section concentrates on hydrogen because it seems to offer the greatest long-term potential for emissions reduction). One significant advantage of fuel cells, at least potentially, is that they may be viable for personal transport use, as they offer much greater capacity for energy storage than conventional batteries. For the same reason they might prove a suitable means of energy storage in general – electricity could be used to produce hydrogen when it was available, the hydrogen could then be recombined with the oxygen to produce electricity when needed. A system on these lines is being deployed in the Norwegian island of Utsira to enable it to use nothing but wind power as an electricity source, and Iceland is exploring options for a similar programme to exploit its hydro and geothermal power. Energy storage is discussed above; this section focuses on transport use, but it should be borne in mind that the successful development of fuel cells would have much wider potential benefits for the energy system.

Acceptability ** – ****

Hydrogen is not a source of energy but an energy carrier – it is not naturally occurring so has to be manufactured, e.g. by the electrolysis of water or by chemical means from hydrocarbons.
The trouble with these options is that they often involve significant emissions themselves, particularly when fossil fuels are used as the energy source, so negating the effect of the low emissions hydrogen. In principle, this need not occur – hydrogen can be

Fuel cell vehicles	Assessment	Remarks
Acceptability	** – ****	Acceptability depends very much on the source of the hydrogen fuel.
Availability	*****	Could have a major positive impact on energy security.
Accessibility	*	At the present stage of development, would not contribute to accessibility.

produced by the use of zero-emissions electricity from nuclear or renewable sources – but it means that the acceptability of fuel cells depends significantly on the precise method of production of hydrogen, and the composition of the electricity system concerned if the hydrogen is produced by electrolysis.

Availability *****

Fuel cells should offer significant benefits in terms of availability. Because they aim to substitute for oil in transport, but can in principle be produced from water plus any energy source, they would add to the diversity energy mix and enable indigenous sources to be used.

Accessibility *

The ranking reflects the current situation and immediate prospects. Clearly, in the longer-term, technology could improve and costs come down significantly. But at present there are significant problems of accessibility in relation to fuel cell and hydrogen technology:

- First, in the fuel cell engines themselves. They are around ten times as expensive as their gasoline equivalents, significantly increasing the cost of vehicles and therefore creating obstacles in relation to access to mobility.
- Second, hydrogen production is quite energy intense. Thus the economic cost of hydrogen production is relatively high unless a very low cost source of bulk electricity can be made available.
- Third, in hydrogen storage. At present, most storage options are expensive, heavy and inefficient, making them unsuitable for vehicle use. Hydrogen can be manufactured on-board the vehicle, but this creates further problems (for instance it increases emissions).
- Fourth, in developing a hydrogen distribution system. There are a number of technical and safety issues involved. While these may be soluble, they create accessibility problems for developing countries which cannot afford to invest in parallel gasoline, electricity and hydrogen distribution.

5 Conclusions

At present most assessments of climate change measures are partial and incomplete. A more holistic assessment – against all 3A's – would not only ensure that the measures were likely to be more effective in a wider sense in promoting sustainable development, but would also help make them more viable in a narrower sense: that is, more acceptable to those affected and therefore easier to introduce and get supported, and thus more likely to achieve their environmental goals. A number of indications of current deficiencies are given in the discussion above: the conclusions of this section are contained in Part 4, which draws out some important lessons for future policy making.

Part 4: The Future Direction of Climate Change Policies

Introduction

This part of the Study is in two main sections. This first section offers an overview of the way forward on energy and climate change. It draws in particular on the analysis in the Study, but also on a wider range of sources. For this Study has not, of course, been undertaken in isolation. While it has been going on, other studies of energy and climate-change related issues have also been under way, including, in particular, the WEC Scenarios Study referred to at a number of points in earlier parts of the text. Unlike the present Study, the Scenarios work has taken a detailed forward look at possible developments in the energy policy environment, embracing all regions of the world and all aspects of the energy scene, and it is hoped that the two Studies will prove complementary and mutually reinforcing.

In addition, of course, many other significant reports have also been produced in the course of 2006 – for instance the Stern report for the UK government and the IEA Study of Energy Technology Perspectives referred to above. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change is also being published in 2007. While the present WEC Study is not the place to comment in detail on these other reports, the opportunity has been taken, in the first section of this part of the Study, to produce a wide-ranging vision of the way forward on energy and climate change, informed by the most up-to-date research, analysis and expert opinion.

The second section of Part 4 relates more directly to the specific results of the present Study. It brings out some key strategic messages, general themes and specific recommendations from the analysis in Parts 1-3. These recommendations are aimed particularly at governments, who will have the main responsibility for developing climate change strategies and policies. However, as the Introduction to Part 2 pointed out, responding to climate change is not just a matter for governments; firms and individuals play an equally important part. The recommendations are therefore directed at them too.

Throughout history, mankind's ability to master its environment has been dependent upon the availability of energy.

1 Overview: The way forward on energy and climate change

Climate change is one of the most complex issues on the international policy agenda. Experts remain divided on the severity of the problem and the uncertainty and nature of policy responses. Practically any course of action implies that today's societies will incur costs as they deviate from the status quo, and any benefits will accrue primarily to future generations. Compounding the problem is its truly global scope. A few nations account for most ghg emissions, yet in a global economy, policies reflecting global interdependence and cooperation will be required to achieve sustainable progress in emissions reduction.

Throughout history, mankind's ability to master its environment has been dependent upon the availability of energy. Only through universal access to commercial energy, made possible by continued advances in technology, can the worldwide demographic "climate change", now underway, be solved. Some two billion people will be added to the world's population over the next 30 years and another billion in the following 20 years. Every three years the world's population is growing by about the size of the United States, and 98% of that growth is in developing countries. Economic growth is not keeping pace in many of the poorest countries, (most notably in Africa) and since 1960 the per capita income gap between the richest and poorest of the world's nations has widened from 30 to 1 to 80 to 1. Universal energy access is the essential precondition to eliminating this global poverty threat.

The 3A's (Accessibility, Availability, and Acceptability) frame the WEC assessment of energy systems value and utility around the world. However, in the context of this Study, achievability is also an important consideration. In many cases, energy policies around the world tend to ignore achievability as largely determined by the local social, political and economic environment. Within this reality, strategic climate concerns understandably take a backseat to the priority placed on national development and shorter-term economic prosperity.

As a result, reducing ghg emissions is a particularly difficult challenge facing the international community, and the world is now at a critical juncture in terms of addressing this challenge. Climate change is a common global issue that requires long-term sustainable solutions, based on international cooperation, at levels never yet achieved. Efforts to curb ghg emissions (principally CO_2) will not be easy and will almost certainly be costly. On the other hand, the response to climate change may also become a very effective stimulus for sustainable global development.

Perhaps the greatest hurdle is the extended time period, of several decades, required, even under the most optimistic circumstances, to achieve a significant reduction in CO_2 emissions from the world's energy economy. For example, it is likely to take a decade or more, after achieving a universal global commitment, to curb emissions in order to realise a measurable slowing in the rate of emissions growth. An additional fifteen to twenty years will be needed to stabilise CO_2 emissions and begin the process of global reductions.

This reality is underscored by the emissions trends resulting from global energy policies in a business as usual (BAU) scenario. These indicate that CO_2

Efforts to stabilise, and then begin to reduce CO_2 emissions between now and 2050 will require a **portfolio of technological options**.

emissions are likely to more than double by 2050, from 23 gigatonnes per year today to about 50 gigatonnes per year. This potential rise in CO_2 emissions is being driven primarily by economic growth and a corresponding increase in energy demand in both developed (OECD) and developing nations. The rate of economic growth in the developing nations is projected by the IEA to average 3.9% per annum over this period, while the OECD nations will likely moderate to an average of 1.8% per annum. Based on these trends, developing nations' CO_2 emissions are likely to rise at least 200% by 2050 from their current baseline of 9 gigatonnes per year, while those from the developed nations are expected rise nearly 70% relative to their current baseline of 13 gigatonnes per year (though of course emissions per capita will remain low compared to those of developing countries).

Over this same time period, in a BAU scenario, fossil fuels are expected to maintain their dominant role and continue to provide nearly 85% of global energy supply. The electricity and transportation sectors would also continue to be the primary fossil fuel consumers and the source of about two-thirds of the resulting CO_2 emissions. The opportunities to reduce CO_2 emissions are therefore particularly focused on these two sectors, with electricity showing the greatest potential over the coming several decades.

Efforts to stabilize and then begin to reduce CO_2 emissions between now and 2050 will require a **portfolio of technological options** tailored to meet the individual needs of both developed and developing countries. This portfolio includes increased energy efficiency (over and above historic trends), new transport technologies and modes, renewables, clean coal, nuclear, and potentially carbon capture and storage (CCS). These technologies can typically be implemented at an additional cost of about \$25/tonne of CO_2 avoided – the cost assumed by the IEA's *Energy Technology Perspectives* study. The accelerated application of this portfolio of measures has the potential to return global CO_2 emissions to today's level while significantly moderating the expected rate of growth in both oil and electricity demand, with minimal risk to global economic productivity.

At this time, however, there is no evidence that such a portfolio is or will be implemented on the global scale, or with the urgency required to achieve this potential result by 2050. The IEA projects that, in order simply to meet rising world energy demand and replace existing capacity, energy investments of \$20 trillion will be needed between now and 2030. Making this investment climate friendly will be a huge additional challenge.

There is broad agreement that international efforts to reduce ghg emissions need to be implemented, to a large degree, at the level of the commercial company, though there is clearly a critical role for governments in setting the economic, legal and regulatory framework to incentivise this corporate behaviour. Private investment is now rising substantially beyond levels of official public development assistance; authorities are increasingly entrusting public policy objectives to the private sector; and investors now have a global perspective that requires an alternative governance system to that developed for the nation state.

Technology transfer and diffusion, however, remain a major challenge to ghg emission reduction

For many developing countries, the transfer of environmentally sound technology is a necessary commitment pacing their own commitment to ghg emission reduction.

progress. For many developing countries, the transfer of environmentally sound technology is a necessary commitment pacing their own commitment to ghg emission reduction. However, technology transfer needs to take account of a range of complex issues, including intellectual property rights – much of the technology is owned by the private sector. This sector often sees technology transfer to potentially developing country competitors as commercially damaging and very costly. The challenge is to implement appropriate public policies and mechanisms that facilitate the desired technology transfer, while protecting the legitimate commercial objectives of the private sector. Successful technology transfer is not simply limited to ensuring technical success, but transferring the associated business and entrepreneurial skills as well.

There are a number of funding streams available, including official aid programmes, private investment and other market-based solutions. The Clean Development mechanism (CDM) represents the first attempt to address a global commons problem using a global market. The CDM was designed around the insight that the marginal cost of emissions reduction in developing countries would be less than for developed ones. Unfortunately, the CDM market, as it has developed, has not been as effective as many expected or hoped in encouraging low carbon intensity energy infrastructure in the developing world. Problems have included the high administrative costs and the relatively low value of emissions reductions achieved through this route. There are also limitations on the range of eligible projects, and the relatively small renewable energy projects currently typical in the CDM portfolio are unlikely to be more than marginal contributors to the global energy market. This has compromised the notable political success of CDM in gaining the active participation of developing countries with relatively high rates of economic growth. Nevertheless, the concept of CDM has proven to be a valuable vehicle for influencing technology choices by developing countries. With the appropriate improvements and support, CDM has the potential to become a powerful tool for technology development and transfer.

One way of engaging developing countries in significant ghg abatement efforts is via infrastructure investments that accommodate the high energy demands of economic growth and developments. Successful implementation of these energy infrastructure investments will, however, require attention to three general areas. First, the participating developing countries need credible, but flexible, policies that can adapt to potentially significant energy infrastructure changes. Second, private entities adept at managing technical and political risk need to be actively involved. Lastly, a new funding paradigm is needed to recognize the significant investment cost of advanced technology. Current prices under the CDM are unlikely to provide sufficient incentives for the desired energy infrastructure investments in developing countries.

As a result, international investment for climate technology transfer needs to be considered as part of overall national industrial development, with implications for the competitive portion of indigenous industries, and the terms of trade with countries which fear subsidised competition as a result of such investments. Such investments should carefully consider the implications for local industries and development, and for dependency on imports from developed nations. The most immediate topics needing clarification are: which government policies

Evidence indicates that without strong public/private partnership reinforcement, dependence on markets alone is a highly speculative strategy.

may accelerate international investment in climate technologies; and which agencies or investors should pay for the local integration of imported technology.

A strong national industrial policy framework may be the most effective means of allowing foreign investment to provide local economic development benefits, while minimizing the impacts on indigenous industries. However, it seems clear that foreign investment may initially mean some loss of indigenous competitiveness and greater regional specialization in export-oriented technology development. Thus foreign investment in climate technology development in developing countries may lead to production becoming more regionally specialized, but also increasingly internationally owned.

The results of this ECC study reinforce the relevant findings of the WEC 2050 Regional Energy Policy studies. These also indicate that reductions in ghg emissions can be most confidently and cost-effectively achieved through strategies that emphasize **global cooperation and interdependence**. Equally important is the role of government, which can vary considerably depending on local conditions. Evidence indicates that without strong public/private partnership reinforcement, dependence on markets alone is a highly speculative strategy. Above all, governments need to establish and maintain the market transparency, security and stability needed for investment confidence. In the developed nations with established, stable markets and policies, the government role is principally to protect these conditions. On the other hand, in developing countries that lack infrastructure and are still establishing a stable market economy, considerably greater governmental leadership may be required. This is necessary to ensure that the rule of law prevails, property rights are respected and contract obligations are enforced.

Electricity provides the essential key to greater and more sustainable energy access. Electricity also serves as the energy prime mover enabling technological innovation and productivity growth – the lifeblood of a modern society. Global data indicate a robust relationship between electric power consumption and economic development of about $3/kWh ("World Development Indicators 2002" – of course, correlation does not necessarily imply causation). Although electricity has been extended to over 1.3 billion people over the last 25 years, this rate has not kept pace with global population growth, and under current trends 90% of the world's people born between now and 2050 will live at electricity access levels below 1,000 kWh/year – an essential energy threshold for rising out of extreme poverty. At least an annual 2%-3% per capita improvement in global rates of output will be required over this same period if sustainable well-being is to be universally achieved.
Only through universal access to electricity can these rates of progress be achieved.

The opportunities for electricity to transform the global transportation sector are also very significant, particularly in the face of the sector's high petroleum dependency and the problems this entails. One notable approach which is already serving to accelerate this transformation is the emergence of hybrid electric vehicles (HEVs) from a variety of manufacturers. These vehicles can provide a technically and economically viable transition to increasing levels of personal transport electrification. Plug-in HEVs are particularly promising, combining

A successful global ghg control strategy over at least the next several decades depends primarily on significant reductions in CO_2 emissions from fossil fuels.

commercial electric storage technology with smaller internal combustion engines. This can potentially lead to a major reduction in gasoline consumption and associated emissions, without the range and performance disadvantages that have limited total electric vehicles. This trend toward greater transport electrification will also facilitate the ultimate goal of zero-emitting, electro/hydrogen, fuel-cell powered vehicles. The potential availability of hydrogen as a complementary energy medium generated from off-peak electricity offers clear strategic benefits for the world's future economy. However, current development trends and the status of the enabling technology and infrastructure suggest that it will be the second half of the 21st Century before the electro-hydrogen economy can become a large scale commercial reality.

A successful global ghg control strategy over at least the next several decades depends primarily on significant reductions in CO_2 emissions from fossil fuels, particularly coal combustion which remains far and away the most significant fuel for electricity generation worldwide. Coal is projected to maintain this dominance until at least 2050, as China and India in particular continue to develop their economies. Realistically, this progress must depend on the deployment of technologies that are already advanced in the development cycle. Foremost is the application of coal gasification technology. Nearly 200 **coal gasification** facilities already exist worldwide. This coal "refining" technology has several relevant advantages: First, it can significantly improve the efficiency of electricity generation when used to fuel combined cycle power plants; second, the cost of CO_2 capture from the coal gasification process is much lower (although not insignificant) than from conventional coal combustion (as discussed in the IPCC Report referred to above); and third, the gasification process produces a clean synthetic gas product composed primarily of hydrogen and carbon monoxide which can be used as feed stock for synthetic petroleum and chemical production, as well as for power generation.

Coal gasification is, however, considerably more expensive than conventional coal combustion and would require an incentive on the order of $350/kW (US) to be commercially competitive in the absence of CO_2 control requirements. Coal type and quality are also important considerations in the choice of coal utilization technology. Ultrasupercritical pulverized coal combustion and fluidized bed combustion technologies are generally more adaptable, for example, to lower grade (high ash and/or moisture content) coals with competitive efficiencies. While both can achieve significant emissions reductions, based on their higher thermal efficiency, neither is readily adaptable today to CO_2 capture.

Natural Gas is the cleanest burning of the fossil fuels and it emits less CO_2 than either coal or oil. It has therefore become the fuel of choice for energy consumers seeking a reduced environmental impact at relatively low capital cost. As a result, natural gas now fuels about 20% of the world's electricity generation, with total global consumption at about 100 trillion cubic feet per year. This consumption is equally distributed today between developed and developing nations, although by 2030 developing nation consumption is expected to double. This rapid growth has also increased the geopolitical importance of natural gas. Proven global reserves, in oil equivalent terms, total over one trillion barrels, with Russia holding 30% of these reserves and Middle East nations, notably Iran and Qatar, nearly 50%.

CO_2 Capture and Storage (CCS) systems have the potential to achieve major reductions in global energy-related CO_2 emissions.

A critical factor in the globalization of the natural gas market is the availability of liquefied natural gas (LNG). As natural gas demand grows and its supply increasingly depends on LNG, its cost can be expected to increase proportionately. However, it is also likely that natural gas will remain an important option in any serious global ghg emission control strategy for at least the next several decades.

CO_2 Capture and Storage (CCS) systems have the potential to achieve major reductions in global energy-related CO_2 emissions, if they can be made available in a timely manner at costs sufficiently low to be commercially viable. For example, the IPCC estimates that the potential for geological storage of CO_2 is about 2,000 gigatonnes. Furthermore, many component technologies for CCS systems already exist. However, the lack of real-world operational experience, coupled with the high incremental cost, discourages large-scale application in the absence of explicit CO_2 control requirements. Carbon capture technology is also not readily retrofittable to conventional coal combustion facilities, and the global infrastructure required to transport the captured CO_2 could potentially exceed that for oil and natural gas combined. In addition, there are many uncertainties as to the viability of long-term (multi-century) geologic storage of CO_2, plus the lack of proven procedures and regulatory structures to ensure environmental and public safety. Public acceptability is, in fact, already proving to be a significant issue in terms of even implementing CO_2 storage experiments. But these technologies will be essential if coal is to have a prominent role in a carbon constrained world.

Although there is considerable optimism and enthusiasm for CCS, it remains a complex technology system that is, at present, unproven in terms of its potential contribution to CO_2 emission control before 2050, under the current pace and scope of development. This caution is not meant to diminish the potential of CCS as an essential cornerstone of a sustainable global energy decarbonisation, in a world which is expected to continue to rely significantly on fossil fuels. For example, if CO_2 emissions are to be reduced to their current level or below by 2050 in a fossil fuel intensive world, 90% or more of the CO_2 produced must ultimately be captured and stored. This simply underscores the fact that fulfilling the CCS potential will require much more significant and urgent worldwide collaborative efforts. For example, the largest storage experiments today are at the scale of one megatonne of CO_2 per year. This represents less than 10% of the annual CO_2 emissions from a typical commercial coal-fired energy facility.

CCS cannot be considered credible until several full-scale integrated technology system demonstrations have been successfully completed. These should incorporate capture from several alternative combustion and conversion technologies, and involve transport and storage over a range of geologic storage conditions and within a publicly acceptable regulatory policy structure. At present, market forces alone do not create an economic incentive for companies to undertake such major projects, and a major government commitment will be needed. This has been recognised, for example, by the 12 large scale demonstration projects announced in the European Commission’s recent “Energy Package for Europe”.

Renewable energy sources could be significant in many sectors – not just electricity, but also heating and potentially in transport.

Renewable energy sources which do not admit ghg or exhaust finite resources such as coal, oil or natural gas have considerable strategic potential in any global ghg control strategy. They could be significant in many sectors – not just in electricity, but also in heating and potentially in transport. However, as discussed earlier in this report, renewable energy sources and technologies are not all equally beneficial to the environment, nor are they equally consistent with the principles of sustainable development. The role of different renewable energy technologies depends on the relative costs and availabilities of alternative fuel sources, and these vary according to location and the development of energy markets. In most developed nations, for example, renewable energies other than large-scale hydro, and more recently wind power, are in a long-term transition from being advanced technologies with only a niche market role to becoming mainstream technologies of choice. In some developing countries, however, the role of renewable energy – particularly biomass – is far more important and represents a relatively high level of application expertise.

As regards electricity, there is also the question of how large a role renewable energy technologies can play in bulk power grids. Today, the integration of many renewable energy sources (not large scale hydro) into grid systems at a significant level is subject to a variety of technical constraints, based on the intermittent nature of the sources. Large quantities of compensating fossil capacity are often required to ensure that power demand and grid reliability can be met simultaneously. An alternative approach would be to resolve these limitations by extending interconnection capacity, or applying electronic control advances in transmission and distribution technology, as discussed further under Intelligent Technology. Also, in the absence of ghg control requirements, most non-traditional (i.e., non-large hydro) renewable energy sources are not cost-competitive with fossil fuels in centralised power applications. On the other hand, minigrids can be constructed to transmit low voltages of electricity from local renewable energy sources for individual villages. In this way, renewable energy is often the most cost-effective option and can uniquely play a major role in bringing electricity to the rural populations in developing countries. Over the longer-term, it is likely that larger renewable energy plants will become feasible in population centres by incorporating distributed solar photovoltaic systems into building structures.

In the case of biomass generation or low technology solar thermal devices, manufacturing capacity is expanding rapidly in developing countries, and these technologies can also be successfully deployed through a process of horizontal integration, rather than specialised pursuit by multinational corporations. More developmental, high-technology sources such as photovoltaics may, by contrast, require concentrated production, marketing and distribution by a single corporation and its subsidiaries in end-user nations. Experience suggests that the key to success lies in incorporating the objectives of the various stakeholders into each project, i.e., the recovery of costs for investors; addressing local basic needs and the desire to generate income; and the governmental requirement to achieve low-cost power supply.

Nuclear power remains the most technically confident large scale approach to CO_2 emission-free power production before 2050, and a key contributor

As an emissions-free energy source capable of producing electricity on a large scale, nuclear is one of the primary global alternatives available to achieve CO_2 emission stabilisation.

to the world's clean energy portfolio. If CO_2 emissions were subjected to a penalty, nuclear power would become a particularly competitive alternative. Although capital and construction costs remain an issue, these concerns contrast sharply with the comparatively low fuel and operating costs of nuclear reactors. More than 400 nuclear power plants are currently operating worldwide, supplying about 16% of the world's electricity. The vast majority of these reactors are derived from earlier naval designs. These are now being superseded by reactors incorporating greater standardisation, passive safety capabilities, longer operating life, reduced core melt potential, and much higher fuel efficiency.

It is technically feasible to triple worldwide nuclear generating capacity to 1,000 GWe by 2050. This would avoid about eight billion tons of CO_2 emissions per year relative to equivalent fossil-fuel power generation. Such expansion will depend, however, on cost-effectively resolving to global public satisfaction, the perceived issues of safety, waste management and proliferation. Fortunately, a variety of advanced nuclear systems are currently in various stages of development. These could enable a robust global future for nuclear power within the coming 20 to 30 years, if the necessary additional development investments are made without delay. (The opportunities are evaluated and described in considerable detail, for example, by the nuclear Generation IV International Forum (GIF) technology roadmap.) The systems all employ a closed fuel cycle to minimise high-level waste and maximise the fuel resource base. As an emissions-free energy source capable of producing electricity on a large scale, nuclear is one of the primary global alternatives available to achieve CO_2 emission stabilisation. It is therefore essential to maintain the excellent safety record of nuclear power over the past 20 years and to launch concerted efforts to win over global public opinion concerning the strategic importance of nuclear power in achieving a confident sustainable energy future.

An important, cost-effective, and widely available yet often overlooked, technological contributor to improved energy efficiency and CO_2 emission reduction is so-called **intelligent technology**. This largely reflects the conversion of electricity transmission and distribution systems worldwide to electronic control. Electricity today remains one of the last industrial bastions of outmoded analogue: electromechanical control systems. These outmoded systems are incapable of operating with the speed and precision demanded by today's digital economies, thus inhibiting efficient end-use innovation while adding otherwise avoidable end-use equipment costs. These existing analogue control systems produce major inefficiencies in the use of electricity infrastructure. The conversion to electronic control systems that operate at the same speed-of-light as the flow of electric energy can effectively eliminate all of these inefficiencies while enabling a more secure, self-healing power delivery network.

Intelligent electronic control of the electricity transmission and distribution system is also an important asset in terms of facilitating the cost-effective contribution of renewable energy to the electricity generation portfolio. This advantage stems from the ability of electronic controls to maintain the power system in absolute supply/demand balance at all times, literally at the speed of light. As a result, electronic controls can significantly reduce the dependence on back-up power sources (typically fossil fuelled), and/or the need for massive energy

Transport is carbon intensive and as yet there are no fully viable carbon-free options for personal transportation, air and maritime transport.

storage capacity to compensate for the intermittent nature of most non-hydro renewable energy resources. Lacking these electronic control capabilities, cost and reliability penalties will continue to constrain the growth of clean renewable energy utilization. An additional advantage of electronic grid control in terms of facilitating renewable energy is its ability to enable the seamless incorporation of direct current (DC) circuitry into today's alternating current (AC) electricity grids. This technical advancement will have rapidly escalating economic and efficiency value, as both renewable energy sources which produce DC, and digital electronic end-use devices which use DC, proliferate throughout the 21st Century global economy. These capabilities are equally applicable to both centralised urban power systems and rural distributed systems in the developing world. Intelligent technology also transforms the electricity supply business from one where supplier profitability is based on selling as many kWh as possible, to one that rewards efficiency based on the combined energy and information service value conveyed by each electron.

Transport is another key sector. Emissions from transport have risen steadily over past decades and seem set to go on increasing worldwide as incomes grow, car ownership increases, long distance trade expands with globalisation, and former luxuries such as air travel become increasingly affordable. There is no easy answer to the problem and certainly no single answer. Countries' transport needs vary widely with geography, settlement patterns and social conditions. Transport, in nearly all modes, is carbon intensive, and as yet there are no fully viable carbon-free options for personal transportation, air and maritime transport. This means that reducing emissions is a major challenge – but it is not an impossible one. There is a wide range of measures available and under development which can rein in the growth of transport emissions. Because of the huge national variations, the package to be adopted will vary from country to country, but it could include such measures as fuel taxation; road pricing; permit trading in some sectors such as aviation; measures to improve vehicle efficiency; use of alternative fuels such as ethanol and bio-diesel; development of public transport; encouragement of modal shifting to lower carbon forms of transport; electrification of rail and ultimately road transport (using low carbon electricity); and in the longer-term, development of fuel cell/hydrogen transport systems (again, where there is a low carbon hydrogen source). As earlier parts have discussed, all these options have their advantages and disadvantages, and not all will be applicable in all situations. But if the growth in global emissions from energy use is to be contained, the transport sector too will have to be addressed, despite the difficulties.

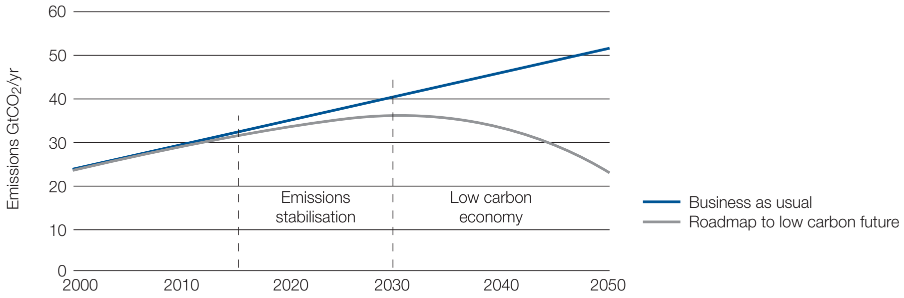
The challenge: With a growing consensus for action, the world now faces the **challenge** of designing an effective, stable climate policy response. The main impediment is the lack of a viable framework for universal global commitment and cooperation. Although a wide range of climate policy approaches have been proposed, none have so far comprehensively resolved the conflicting priorities among the world's diverse community of nations. However, the commitment by more and more countries and corporations to incorporate sustainable development as a performance criterion is creating a more constructive global atmosphere for resolving the fundamental issues of equity, cost, flexibility, timing and technology transfer, and so enabling the achievement of a sustainable global climate policy structure. Above all, there must be confidence in the long-term stability of the international policy framework in order to provide the incentives for the necessary major infrastructure investments.

Given the diversity of national interests, a hybrid policy approach that recognises diversity is likely to be most successful in achieving global agreement and collaboration on climate change. New approaches need to be considered, and a number of interesting ideas have been put forward, including the so-called McKibbin/Wilcoxen proposal for a hybrid trading scheme. This sort of creative thinking could be explored further – such an approach is put forward here, for the purpose of stimulating discussion. It would be aimed at incorporating emissions trading and taxation in a single scheme, and would not force a choice between caps on emissions or coordinating emission taxes. Instead, governments would set targets for emission quantities and also for prices. Any government that participates in the system could issue and sell new emission permits at the agreed price. If the national trading price rises above the target price then firms could simply purchase less costly permits on the open market. Finally, enforcement would rely mainly on buyer liability. Such an approach could be particularly attractive in managing the multiple, but still uncertain and debated, risks associated with ghg emissions; though of course, like any other approach it has its problems – for instance in not setting absolute emissions limits.

In such a system, the use of fossil fuels will require permits in proportion to their CO_2 emissions. Those fossil fuel users who can reduce their emissions most inexpensively will do so, and those who cannot will purchase more permits. In this manner, the system would flexibly encourage the least-expensive emission reductions without constraining any fuel user. Over time, the resulting investment in technology and in the infrastructure of developing nations will both reduce abatement costs and create significant new markets. The resulting global economic growth will far outweigh the cost of CO_2 emission control (about 2% of global GDP). It is therefore important to the global economy that unnecessarily expensive immediate emission abatement methods not be arbitrarily imposed when more cost-effective alternatives will soon be available.

Thus the market and incentives for the purchase of these permits would be designed to implement a least-cost global policy that takes advantage of flexibility in both time and location to achieve the desired ghg emissions control goal. The permits would be financial assets that increased in value at the real interest rate plus the rate of atmospheric depreciation (about 1% for CO_2). This would produce a nominal doubling in permit value every 12 years and encourage early purchase. Calculations suggest than an initial carbon permit value of about \$15 per tonne of CO_2 would raise about \$400 billion per year. This is the amount needed, for example, to achieve universal electrification by 2050, and to stimulate the advancement in electricity production and utilisation needed to substantially decarbonise power generation. The scheduled reconsideration of the Kyoto Protocol offers the opportunity to develop alternative strategies on these or comparable lines. These policy considerations are discussed further in Appendix 1.

Figure 4-1
Global CO_2 emission scenarios



Sources: Platts (2001) and IEA analysis.

Arguably, the most practical and equitable common denominator for achieving prompt, worldwide agreement and global CO_2 control would be a global strategy based on reducing emissions intensity per unit of GDP. As described in Part 1, this criterion has a relatively small national dispersion (about a factor of two) today, around the world average of 0.51kg CO_2/US$ GDP (ppp). This fact is particularly relevant to the largest and fastest growing economies in the world who have the greatest impact on global CO_2 emissions. In order to constrain the growth in emissions and return to the current level or below by mid Century, sustainable worldwide agreement will be needed on reducing emission intensities to 0.2kg CO_2/$GDP (ppp) by 2050. This is based on a global GDP in 2050 of $100 billion (2006 $US). This represents a 60% reduction in CO_2 emissions intensity achieved over a period of 40 years (assuming that universal agreement and commitment is achieved by 2010). The resulting CO_2 emissions reduction would be, according to the Intergovernmental Panel on Climate Change (IPCC), consistent with keeping atmospheric concentrations of CO_2 below the limit of 550ppm, as shown in figure 4-1. This contrasts with the business-as-usual baseline projection that is expected to result in an atmospheric CO_2 concentration this century of 800 ppm, more than twice the current level.

Reducing the global CO_2 emissions intensity to 0.2kg CO_2/$GDP (ppp) by 2050 is considered to be achievable through aggressive development, and deployment of the advanced energy technologies described in this Report, at an annual cost equivalent to about 2% of world GDP. It is also probable that such a sustained investment would produce benefits to the world economy, independent of CO_2 emission reductions, which are far greater than the cost. For example, the economic value of the improvements in productivity, efficiency and creation of new markets could easily exceed the total cost by a factor of ten, just over this 40 year time frame. These benefits would, for example, include a net 15% increase in global GDP and as much as a net 35% increase in developing world GDP, relative to business as usual. Each country would also be able to tailor its verifiable CO_2 emissions intensity reduction trajectory to best conform with national development objectives, energy resources and infrastructure.

The study concludes that, so far, the response from governments and others has not been up to the challenge.

2 Specific messages and recommendations of the study

The main message of this Study is the need to take a **holistic view** of the energy and climate change issue in two key respects:

- **The need for energy** As this Study has pointed out, energy and climate change are in many respects opposite faces of the same coin. Energy-related emissions make up such a large proportion of anthropogenic greenhouse gases that it is impossible to deal with climate change without affecting energy systems; equally, whatever happens with energy systems will have an impact on climate change. But although energy is about climate change it is not just about climate change – energy meets a range of basic human needs, and powers wider social and economic development worldwide. Furthermore, many people still lack access to modern energy forms – 2 billion or more worldwide do not have electricity and are unable to access all the benefits it brings. Energy availability, accessibility (and affordability) are goals quite as important as acceptability, and policies must be designed to meet all three goals, or those policies will not themselves be sustainable.
- **Energy is a system** Energy is a complex and interacting system – an increase in demand in one part of the world affects the whole world through its impact on prices and world markets; a change in demand for one fuel will affect demand for other fuels; short-term decisions may have long-term effects in an industry where investments typically have a lifetime of decades or more. Decision making for energy, to be effective, needs to take account of these wider system effects – to look at individual policy measures in isolation and assume that the rest of the energy system will simply go on as before is unrealistic. As has been highlighted at a number of points, the uncertainty created by climate change policies is, in some cases, inhibiting investment and thus undermining the achievement of all energy goals.

These general propositions lead to some key **strategic messages**:

- The importance of policies and strategies which focus on **sustainable growth**.
- The need for long-term stability and predictability in energy policy to encourage investment in cleaner technologies.
- The need for a **balanced deployment of resources** to achieve equity and sustainability.
- The need to **keep all energy options open** – there is no single solution to the energy and climate change issue.
- The importance of **education and effective communication** – public acceptability is part of energy acceptability.
- The importance of eliminating **energy poverty** by increasing availability and accessibility for the billions of people in the world deprived of commercial energy.
- The importance of **technology** and the need to encourage the development, deployment, transfer and selected application of appropriate technologies.
- The fact that **all countries are different** – they have different energy resources, different development needs and different priorities. No single approach will work equally well in every region.

There is **no “magic bullet”** – i.e. no single measure which will, on its own, provide the whole answer.

- There is **no “magic bullet”** – i.e. no single measure which will, on its own, provide the whole answer. Each country will therefore have to adopt a portfolio of measures adapted to its own circumstances.
- Irrespective of the portfolio of measures chosen, it will take **considerable time** to get to the point of reducing carbon emissions globally. A **sense of urgency** must be applied by all nations.

More **specific messages** arising from the Study include the following:

The global picture

- Energy-related ghg emissions have been growing steadily and many **developing countries** show rapid energy and emissions growth, but from a very low relative base of energy use per capita. Their energy and development needs are still high and need to be addressed in any overall policy approach.
- Even at similar levels of development, there can be significant differences in per capita emissions between countries. There is no **automatic** link between economic growth and energy use, or between energy use and emissions – decoupling emissions from economic development is not in principle inconceivable.
- However, this requires **well-directed policies**. Areas deserving particular policy focus are energy intensity and the carbon intensity of energy. The two factors are not, however, strongly correlated; nor is energy intensity strongly correlated with levels of energy use. It is over-simplistic to assume that improving energy efficiency will result in a proportionate reduction in emissions.
- The evidence suggests that, to date, the most significant impact on emissions has been made by **reducing carbon intensity** rather than energy intensity. Currently, the sector which gives most scope for reduced carbon intensity and emissions is **electricity**, because of the scope for changing to low or zero carbon technologies. So a strong focus on electricity in relation to near term emissions reduction should be a major part of any policy approach.
- The **transport** sector is also very important but policy intervention may be more difficult – major technological or behavioural changes may be needed to show significant reductions. Policies should focus both on achieving near term reductions, primarily efficiency improvements, and other measures, and on developing ways of delivering the more fundamental longer-term changes which will be needed for a truly sustainable transport sector.
- The **building and industrial** sectors, as major consumers of energy, also have significant technical opportunities to improve energy efficiency. Advances in the design, construction and operation of commercial and residential buildings, as well as industrial processes, provide opportunities for major reductions in energy use. As a result, it is now feasible for many structures to become net zero energy consumers and even energy resources. This progress has been demonstrated in a variety of circumstances worldwide. Here again, electrification in the form of combined heat and power will typically play a major role.
- Policies introduced to promote other goals (e.g. energy security) may also have a beneficial impact on emissions. However, this is not guaranteed and varies case-by-case. Governments considering any new energy policy measures should pay attention

Present policies to combat climate change are failing to rise to the scale of the challenge.

to **all the consequences** for accessibility, availability and acceptability, not just the particular goal the policy measure is aimed at. In particular, more attention needs to be given to accessibility – most assessments to date are concerned with cost and environmental effectiveness.

- As well as considering the likely impacts of their energy policy measures, governments should give much more attention to **monitoring their effects** in practice. There is evidence that many measures are not in practice meeting the objectives they are aimed at, like lowering emissions. Very few policy measures have been assessed in a holistic way against all 3A's.
- Global, energy-related, CO_2 emissions seem certain to continue to increase for at least the next 20 years given the lack of commitment to emission reductions and existing infrastructure limitations. In spite of this robust trend, it is technically feasible to return CO_2 emissions to the current level by 2050 and to maintain a downward trend thereafter. This will, however, require all the world's nations to align on and adopt strict emission control constraints within the next decade. A price equivalent of the order of $25 per tonne of CO_2 appears necessary to provide the incentives for the necessary global technology portfolio deployment.

The limitations of existing policy approaches

It is difficult to avoid the conclusion that present policies to combat climate change are failing to rise to the scale of the challenge. In general, existing policies are proving:

- **Ineffective** and inadequate. Even in Europe, which has the strongest programmes, they are no more than restraining the growth in emissions, not delivering the substantial reductions which are needed over the longer-term.
- Confusing and **unfocused**. They are not taking account of the complex dynamics of the energy market and are doing more to create uncertainty and to inhibit investment than to promote investment in cleaner technology – we therefore risk getting increasingly locked into an unsustainable energy system.
- Too **narrow** in scope. They are not giving enough attention to accessibility and social and development issues, so offering little to developing countries – where much of the growth in emissions is taking place. They impose serious real and perceived **equity issues** among nations that effectively block global policy alignment – without global adherence energy-related ghg emission stabilisation, let alone decline, will be impossible.

This is not so much because the wrong policies are being followed as because these policies are not effectively targeted, not implemented consistently and not monitored effectively. All policy approaches have their limitations. For instance:

- **Fuel taxation** is important but not a panacea, given the problems of competitiveness and accessibility, and the difficulty of establishing the long-term credibility needed to promote the right sort of investment. It is a particularly difficult option for developing countries, so cannot form the heart of a global approach.
- **End-use energy efficiency** is undoubtedly worth pursuing, as it helps meet all 3A's. Nonetheless, there is no clear case to be made for significant emissions reduction as a result of

Each country will need to adopt a portfolio of measures appropriate to its own circumstances.

existing efficiency programmes. It would be unrealistic to expect energy efficiency to provide the substantial and rapid emissions reduction needed, at least until governments can ensure that their programmes are properly targeted and monitored.

- **Renewables** certainly help but there are still enormous practical problems of cost, availability etc, which can prove particularly difficult for developing countries. Renewables can make a useful (and growing) contribution to emissions reduction, but in practice, apart from those countries with substantial hydro (or geothermal) resources, it is unlikely that they will deliver a significant overall decarbonisation of electricity quickly enough to meet the climate challenge.
- **Emissions trading**, while a very strong approach in theory, is fraught with practical complications and at present there is insufficient experience of trading schemes in practice to demonstrate how effective a route they are to significant reductions. A comprehensive, workable, long-term global scheme of proven effectiveness would be needed before trading can deliver on the scale required, and we are a long way from that.
- **Subsidies for fossil fuels** should be closely scrutinised. Often subsidy removal will be an effective first step in combating climate change in a sustainable manner. Nonetheless, subsidies are introduced for a reason, and simply advocating their removal does not of itself resolve the underlying problem. For many developing countries, this is still a difficult issue.
- **Regulations and standards** are also important and will form part of any policy package but they need to be designed and monitored more carefully than in the past to be really effective. By and large regulations and standards to date have been based more on short-term political expediency than on achieving sustainable decarbonisation progress.
- **Voluntary agreements**, information and awareness and other non-interventionist approaches are important in promoting flexibility and acceptance, and can work very well in some countries. However, in general they are not sufficient on their own to make a major difference and are unlikely to work as a global approach.

Recommended policy approach

Taking account of the analysis above and in the main body of the Study, it is clear that a much more focused and consistent approach is needed, which integrates existing measures into a clear overall strategy. This will still involve national variations – as indicated above, each country will need to adopt a portfolio of measures appropriate to its own circumstances. However, they will need to involve some key common features, including an emphasis on:

- **Electrifying the world** as the essential means for bringing modern energy to the 1.5 billion people who still lack access.
- A strong push to **decarbonise electricity** (whether via market instruments or more interventionist measures, as discussed below).
- Measures to contain the growth in **transport emissions** and develop carbon-free alternatives.
- In parallel, a new impetus for **technology development and deployment**. Although the lag time between research and large-scale commercial deployment is sobering, global funding for energy R&D continues to decline

– so action is needed now. While technology cannot provide the whole solution it is an essential component.

The analysis shows that measures in these areas (unlike many existing measures):

- Would attack the **heart** of the problem – the areas where large emissions reductions are needed.
- Have demonstrated **effectiveness**. Experience shows that significant reductions can be delivered in these areas in a way consistent with the 3A's.
- Offer huge future reduction **potential**. Technologies are available already, or are under development, which could make an enormous difference to future emissions trajectories.

As this Study has shown:

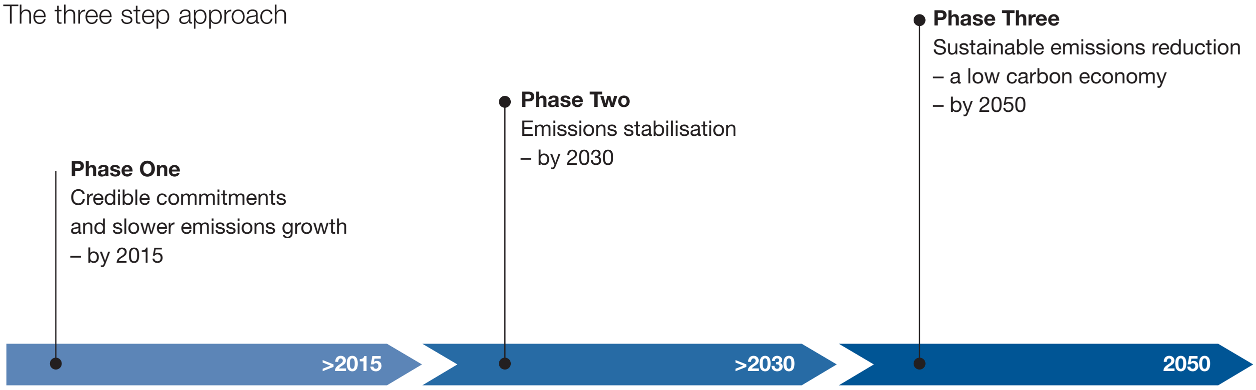
- **Electricity** is a proven route to major emissions reductions and to achieving sustainably low emissions. There are many options for decarbonising electricity – nuclear for those who find it acceptable, but also a range of other options including cleaner fossil fuels; renewables; and in the medium to longer-term, advanced technologies of various sorts and carbon capture and storage. Electricity is also an important vehicle for improving energy efficiency throughout the value chain. Existing measures have not focused on getting the investment in the full range of cleaner power sources; they have tended to be marginal in terms of their overall impacts (as with many renewables programmes); or have acted so as to inhibit rather than encourage investment (emissions trading); and have not dealt effectively with developing country needs and priorities. Governments should be introducing much more targeted measures aimed at getting the required cleaner investment in place quickly. In liberalised markets they need to develop new measures – which might include such things as: wider portfolio obligations (e.g. a low carbon or non-fossil obligation); long-term carbon tax credits with a specific focus on promoting investment (i.e. unlike existing taxes); specific schemes of support for low carbon power generation alternatives etc. Those countries with a more command and control-based approach (most developing countries) can mandate the low carbon options directly, but will need help in doing so because of the cost implications – see below.
- **Transport** is a difficult area because emissions are growing, but at present there are no viable carbon-free alternatives. The sector is likely to rely primarily on petroleum for some considerable time to come. A two track approach is called for: first, **restraining the growth** in emissions by a combination of measures – technical approaches via vehicle efficiency, hybrid vehicles, biofuels etc, but also non-technical measures aimed at changing behaviour to lower carbon transport modes, via taxation, regulation or other means. Measures analogous to those proposed for electricity could be considered and the scenarios study shows that there is a considerable range of options to choose from. Second, to develop viable **carbon-free alternatives** for the longer-term, by a much stronger and more concentrated r&d effort. There is a lot of promising looking technology around but it needs much more work to make it viable – and deployment will also require considerable effort because

WEC members are ready to take their part in this process. They firmly believe that the energy sector can make a positive contribution to solving the problem.

of the complexity of existing infrastructure. Again, electricity can play an important role in decarbonising global transportation as technology advances rapidly in this sector.

- In both areas there is clearly a technology dimension. Here again, the analysis suggests a two-track approach:
  - First, a major new international effort at **technology deployment**. The problem for many developing countries is that they cannot afford the cleaner technologies which in many cases are already available, and cannot always identify the right technologies for their circumstances. Better technology mapping and a **new international financing stream** may be needed. In the long-term this should ideally be part of a new international climate regime, perhaps via a global trading system. But, as noted, the goal of a viable, comprehensive trading system with low transaction costs is a long way off. The world cannot wait. In the short-term, it probably means a new international fund, perhaps on the general lines of the GEF, but with a much stronger focus on securing carbon reductions from large emitters.
  - Second, a scale increase in funding for **technology development**. Despite the challenge of climate change, energy r&d spending has fallen over past decades. The challenge requires a much stronger response and (because it involves a major market failure) governments will have to be involved. Much more is needed and it should be focused on **ensuring that technologies meet the 3A's**. For instance, in the area of renewables this would involve improving accessibility by bringing down the costs, and improving reliability to make this a more viable option for developing countries; with fossil fuels, improving acceptability by efficiency increases, and in the medium-term improving availability by making carbon capture viable; with nuclear, minimising waste and demonstrating and securing consensus on waste management; with transport, improving acceptability and availability by developing alternatives to oil; developing new energy efficient products to meet all 3A's etc.

Figure 4-2
The three step approach



3. Road map to a low carbon future

Decades will be required, even with the most effective application of policy and technologies, to achieve significant sustainable reductions in CO_2 emissions from the world's energy economy, in large part because of the time and cost involved in replacing existing, and building new, infrastructure. Just to keep pace with the world's growing energy demands will require $800 billion per year of investment over the next 25 years, according to the IEA. To make this investment climate friendly is an even greater challenge, but it is possible to scope out a road map enabling the world to meet this challenge, in three stages.

Phase one: credible commitments and slower emissions growth – by 2015

This phase will effectively begin when there is a universal and credibly sustainable global commitment to curbing ghg emissions, particularly CO_2. In the decade following this commitment, progress will rely significantly on greater efficiency and lower carbon intensity in energy production and use, particularly in the electricity sector. Measures might include long-term carbon tax credits with a specific focus on promoting investment; specific schemes of support for low carbon power generation alternatives; and stronger renewable energy portfolio standards facilitated by intelligent electricity delivery technology, along with the broad commercial introduction of advanced clean coal technology, particularly in rapidly industrialising nations such as China and India.

In the transport sector, the aim should be to restraining the growth in emissions by a combination of measures – technical approaches via vehicle efficiency, hybrid vehicles, and biofuels, along with non-technical measures aimed at changing behaviour to lower carbon transport modes, via taxation, regulation or other means. The result of such approaches would be a demonstrable slowing in the rate of CO_2 emissions growth. Equally important is achieving and maintaining a significantly greater global investment in technology development and deployment. This lays the essential basis for realising subsequent sustainable carbon reductions.

Phase two: emissions stabilization – by 2030

In this phase, CO_2 emissions can be stabilised and the process of absolute carbon emission reduction initiated, by a decoupling of economic growth and ghg emissions, building on the foundations of Phase One and reinforcing the measures introduced at this stage. It will in time be possible to take advantage of new energy related infrastructure and major technology advances, in areas such as advanced nuclear power plants, some utilizing breeder technology, and carbon capture and storage enabling zero carbon emission fossil-fired power plants.

Other important emission reduction technologies will include advanced solar thermal, building-integrated photovoltaics, and micro combined heat and power plants. All of these may be further stimulated by breakthroughs in energy storage technology. In addition, advanced building technologies will produce major energy savings, even including converting buildings from energy consumers to net producers. Hybrid vehicles, plus other advanced clean transportation options, including the widely expanded production and use of biofuels that do not interfere with the food cycle, will also significantly contribute to lower carbon emissions while reducing petroleum consumption.

Phase three: sustainable emissions reduction – a low carbon economy by 2050

Over the succeeding decades CO_2 emissions will steadily decline below current levels without compromising the universal availability of energy or global economic development. The combination of ever-cleaner energy resources, plus an increasingly robust portfolio of advanced power generation and transportation technologies. Will facilitate further carbon reductions while enabling sustainable economic growth worldwide. As time goes on, zero carbon technologies, coupled with advanced energy storage, will continue the decline in emissions, leading to a truly post-carbon world. The potential for nuclear fusion and a universal electro-hydrogen energy economy may also be established. All of this continued progress is, however, predicated on sustained major global commitment to technological development with prompt transfer and deployment into the world's energy infrastructure.

This timeline may seem lengthy but it only underscores the urgency needed if global CO_2 emissions are to be returned to or below current levels by 2050. These efforts to curb emissions will not be easy and some will be costly in the short-term, even while producing longer-term benefits. The sooner society acts against climate change by a real commitment and effective measures to stabilise and reduce CO_2 emissions, the better. WEC members are ready to take their part in this process. They firmly believe that the energy sector can make a positive contribution to achieving a sustainable future.

Appendix 1 of section 4

Alternative policy strategies for greenhouse gas emissions control

Although there is as yet no international agreement concerning the severity of the climate change threat and its relationship to other policy priorities, the consensus for action is growing as a matter of universal enlightened self-interest. In developing countries the predictable effects of climate change are typically more severe because incomes are lower and the capacity to adapt is therefore less robust. In developed nations the risk of a climate catastrophe, such as rapid sea level changes, is becoming a compelling issue. The probability of such a catastrophe may be low but the effects could be extremely costly and overwhelming to any adaptation strategy.

Controlling emissions is the best way to address the potential consequences of climate change, but governments must do more than simply focus on emissions. They must, of course, continue the development of more confident and detailed scientific knowledge concerning global climate change and its regional and local implications. But they must also invest in new knowledge that can lower the cost of emissions control, adopt policies that increase the ability of societies to adapt to climate changes, and explore geo-engineering possibilities that might be needed to reduce the impact of climate change irrespective of cause. Equally important is the continued development of more confident and detailed scientific knowledge concerning global climate change, and its regional and local implications.

Over 50 distinct international climate policy approaches have been proposed over the past decade. The difficulty of the challenge is reflected by the fact that none has fully succeeded in resolving a variety of conflicts reflecting the diverse priorities among the world's community of nations. These conflicts include: economic efficiency versus environmental effectiveness; absolute versus flexible emission targets; voluntary versus mandatory commitments; industrialised versus developing nation commitments; and building on the Kyoto Protocol versus an entirely new protocol. Integrated efforts to reach universal accord on a climate policy architecture is obviously a very complex process that must be conducted on many levels including, for example, agreement on: the long-term goal and intermediate progress levels; the target value; the types of commitments when and by whom; and the definition of the accounting rules for the commitments.

It is beyond the charter and scope of this study to proposed specific solutions. However, it can put forward ideas to stimulate discussion. The following is offered as one possible experience-based approach to ultimately achieving a viable and sustainable architecture for coordinating international efforts. This must also reflect the fact that there are a number of policy criteria that, qualitatively at least, are considered by all nations to be essential in successfully achieving and maintaining any such global climate policy architecture. These most prominently include:

- Equity.
- Cost certainty and effectiveness.
- Account for structural differences among countries.
- Economic predictability.

- Stability.
- Dynamic flexibility (for national optimisation).
- Stimulate technology development, transfer and deployment.
- Compatibility with national development goals.
- Environmental effectiveness.

The increasing commitment by countries and corporations to environmental excellence is encouraging a more constructive global atmosphere for achieving sustainable progress in controlling greenhouse gas emissions. While the struggle to meet national development goals in a carbon-constrained world is far from over, more and more countries are willing to collaborate on finding sustainable solutions within the context of these universal criteria.

In the face of these realities, what are the alternative architectures for coordinating international efforts? The first option is the “cap and trade” architecture, as embodied in the Kyoto Protocol. In effect, this sets targets for the quantity of emissions and leaves it to the market to determine the cost of achieving those targets. This approach would be particularly attractive if there were universal agreement on a specific climate risk threshold. Trading could ensure that the agreed emissions caps were being honoured by every nation. Unfortunately, it has thus far proven impossible to negotiate an emissions allocation that does not either cause major emitting nations to withhold commitment, or discourage participation by developing countries. Also, it requires international enforcement institutions of unprecedented strength to monitor and enforce compliance.

One alternative to capping and trading would be an international agreement that sets emission prices rather than emission quantities. When the cost of controlling emissions is uncertain but potentially large and the benefits accumulate slowly, as is the case for ghg, it is generally more efficient for governments to manipulate prices (through taxes) than to cap quantities. Unfortunately, it is very difficult to monitor the real impact of such taxes that are applied to economies in tandem with other taxes. Also, the weakness of international law makes the necessary monitoring and enforcement of such a coordinated tax system very difficult, and the impact on emissions reduction equally uncertain.

A third policy architectural approach would use a system of coordinated policies and measures. This would not require imposition of identical policy instruments in each country. Instead, countries could pick and choose what best suits their local circumstances and national political systems. In principle, this approach is attractive not only because of its flexibility but also because it forces governments to focus on realistic actions to control emissions. In practice, however, it invites countries to adopt an array of policies that resist mutual scrutiny and monitoring, and requires intrusive international institutions that are empowered to pass judgment on national policy – politically an extremely sensitive challenge.

The fourth, and arguably most practical architecture, would be a hybrid of the above three options, which would be designed to reduce the most troublesome disadvantages of each. This approach would not force policy makers to choose between caps on emissions or coordinating emission taxes. The approach should therefore be attractive in the current international climate policy arena, where the goal is to resolve and manage the risks caused by growing atmospheric concentrations of ghgs. Governments would set targets for emissions quantities and also agree on a maximum price for the tradable permits. In effect, the target price would cap the cost of acquiring permits and thus also give private corporations greater surety about the cost of compliance. In practice, this approach could provide advantages relative to the critical criteria of allocation, monitoring, and enforcement; though, as with any other approach, a host of practical details would need to be worked out.

In terms of allocation, countries would have greater surety about the effect on prices, and thus also be less risk-averse in terms of accepting stringent limits that seriously use novel mechanisms such as CDM. Also, greater cost surety makes it easier for governments to negotiate an allocation that corresponds with their marginal cost of abatement. Monitoring emissions, trades, and permit sales compliance is relatively easy because the permit market governs the price. It would also be advantageous to initially restrict ghg emissions control to CO_2 emitted by fossil fuels. There are still too many measurement problems in relation to the other ghgs, which could not, therefore, provide such a firm basis for national commitments for which accurate measurement is required. The international architecture should, however, provide for the coordination of national policies addressing these other emissions.

Adopting an architecture that promotes more price transparency would help focus a reasoned policy debate leading to realistic international commitments. The current difficulties with the current international ghg policy regime stems, among other things, from a mismatch between the ambitious emission control claims and the limited attention to prices and economic consequences. More capable institutions will be needed to oversee the broader and deeper commitments required for any effective effort to limit global ghg emissions. Particularly urgent is the need for institutions that can gather and assess the information necessary to assure compliance and inform allocation negotiations. Today, the international reporting framework is inadequate for analysing uncertainties and biases in emissions estimates.

In practice, any concerted effort to control ghg emissions will require the significant intrusion of international environmental law. This may appear to be a radical and dangerous policy inflection point, but in other areas of international law the industrialised nations are already passing this point. For example in trade, the World Trade Organization constrains policies on food safety, governmental procurement, taxation and other areas that were traditionally considered to be entirely within the domain of national policy.

Ultimately, the success of any international climate policy architecture will be measured by its ability to focus and sustainably harness the enlightened self-interest of every country. That is a universally shared challenge on which we will all be judged by future generations.

Appendix 1

Terms of reference

Rationale

Climate change is seen by many people as one of the most serious issues facing humanity, and anthropogenic greenhouse emissions, resulting inter alia from our current energy use patterns, are widely perceived to be a critical contributing factor.

Clarification of the underlying science is immensely complicated, calling for the integration of a wide range of scientific disciplines including, but not restricted to, meteorology, oceanography, microbiology, agronomy and forestry. Developing a full understanding of the global climate, with all its inputs and feedbacks, is probably the most ambitious scientific undertaking yet tackled. Nonetheless, many people are of the view that response to potential climate change damage cannot await definitive clarification.

Growing global concern about climate change since the 1980s led to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988, and made it a focal point of the Earth Summit in Rio de Janeiro in 1992, at which the United Nations Framework Convention on Climate Change (UN FCCC) was negotiated. The Convention committed all its 189 signatory governments to take actions to achieve "the stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthroprogenic interference with the climate system". The Kyoto Protocol of the UNFCCC, which has now been ratified by 149 governments and which came into force in February 2005, is a subsidiary treaty of that Convention, committing 23 countries (the co-called Annex 1 countries, which have ratified the Protocol) to specific emissions reductions by 2012 (a very short timeframe in terms of the investments needed). In addition, at the regional, national and even sub-national level, numerous climate change response initiatives are being launched.

As emissions from the use of fossil fuels are seen as one of the contributory factors most amenable to corrective action, many of the policies and measures being implemented or considered are directed at the energy sector. At the same time, energy is a crucial input to economic and social development. It is thus of the utmost importance that energy policies and measures to respond to climate change do not compromise other vital goals, or at least that they are optimised for all key goals, both in respect to their long-term effects and during the transition phase.

Proposal

The World Energy Council clearly recognises the importance of such optimisation. As one of the Conclusions of the 2004 World Energy Congress states:

> ***Climate change is a serious global concern, calling for changes in consumer behaviour, but offering potential win-win opportunities. These include increased transfer of efficient technologies from industrialised to developing countries and incentives to investment through emerging voluntary and regulated emissions trading and other mechanisms.***

With its global and all-energy coverage, WEC also brings together the broadest energy experience base available. It is therefore proposed that it undertake a study to assess the range of climate change response energy policies and measures being implemented or considered in terms of their short, medium and long-term effects for the achievement of WEC's three goals for energy sustainability: Accessibility, Availability and Acceptability. The objective would be to lay out the expected effects of the various options for decisions makers, as a contribution to the development of future climate change response arrangements.

This work would build on the series of 14 Climate Change reports which WEC produced up to 2000, and on the Energy and Climate Change Working Paper prepared for the "Climate Change: Beyond Kyoto" Round Table at the 2004 World Energy Congress.

Output

A short concise statement for decision-makers (possibly also to serve as 2007 WEC Statement), supported by a report providing detail of the underlying analysis.

The report is envisaged in 3 parts:

- Part 1 would set the scene with a factual presentation covering the current status of energy-related emissions in both industrialised and developing countries including, for example, data about energy supply and use trends, energy mix (correlated with low emissions per GDP unit), and data on changes in energy mix of countries. Available data from organisations such as the IEA, UN, EIA, would be used.

- Part 2 would provide an overview of energy-related climate change response policies and measures being implemented or considered, which fall primarily into the two broad categories of supply responses (reducing emissions from emitting sources and reducing the emitting sources in the supply mix) and demand responses (energy efficiency to fundamental modification of consumption). The range for response policies and measures would be established through a questionnaire to members.
- Part 3 would assess each approach in terms of its expected impact on energy accessibility, availability and acceptability. Options assessed would cover market-based measures (eg. emissions trading, green certificates) and non-market based approaches (eg. taxes, direct support for emissions-reducing technology development), including their mandatory and voluntary variants. It would do this with respect to short, medium and long-term effects, so as to highlight the transition implications (including for the technology development and deployment which must underpin any practical approach), and with respect to cost-effectiveness based on the principle of "least-cost emissions reduction".

Constraints

There are a number of important constraints which would need to be respected:

- The report would not attempt to judge the underlying climate science, as the relevant disciplines are outside the WEC's area of competence.

- It would not address the range of response options known as adaption strategies (as opposed to mitigation strategies). These generally involve areas, for example agriculture and forestry, which are also outside WEC's area of competence. Rather, the study would be restricted to examining those mitigation strategies focused on energy.
- It would not seek to judge whether the likely energy related emissions trajectory would pass the ICPP's "level that would prevent dangerous atmospheric interference with climate systems" (550 ppm). WEC's study on Energy Scenarios to 2050 will look at this question. The energy and climate change study would simply take as a working assumption that it is desirable to reduce ghg emissions from energy production and use.
- In assessing the different response approaches, it would need to recognise that the experience of most of them is still quite limited.

Timeline

2005

11 May:	Studies Committee decides on proposal. If approved:
Q2/3:	Inform all WEC Member Committees calling for Study Group volunteers
	Appoint a part-time Study Director or Research Assistant (see Resources below)
	Further refine methodology and develop questionnaire
Q4:	First meeting of Study Group, Sri Lanka, finalise questionnaire and issue to MCs with deadline of end-October
	Finalise range of policies/measures to be examined

2006

Q1:	Issue report structure and preliminary draft to Study Group
Q2:	Issue preliminary draft to Studies Committee
May:	Studies Committee considers draft report
September:	Symposium at Tallinn Executive Assembly
Q4:	Issue draft 2007 Statement to Officers Council and draft report to Studies Committee

2007

May:	Publish 2007 WEC Statement and Energy & Climate Change report

Appendix 2

Committee membership

Study group

Chair:
Mr. Kurt Yeager (USA)

Director:
Mr. Malcolm Keay (UK)

Ex Officio:
Mr. André Caillé (Chairman)
Mr. C. P. Jain (India)
Mr. Gerald Doucet (Secretary General)
Mr. Robert Schock (USA)

Members:
Mr. Murray J. Stewart (Canada)
Mr. Bagaman Kassi (Côte d'Ivoire)
Dipl.Int. Vladimir Jelavic (Croatia)
Dr. John M. Christensen (Denmark)
Mr. Maher Aziz (Egypt)
Mr. Jean-Eudes Moncomble (France)
Ms. Nicole Dellero (France)
Mr. Jouko Ramo (Finland)
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Mr. Christopher Koroneos (Greece)
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Mr. Abbas A. Naqi (Kuwait)
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Dr. Natasa Markovska (Macedonia Rep.)
Mr. Jan Korff (Netherlands)
Mr. Francisco Parada (Portugal)
Dr Ionut Purica (Romania)
Dr. Taha Zatari (Saudi Arabia)
Ms. Cristina Rivero (Spain)
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Mrs. Sirintornthep Towprayoon (Thailand)
Mrs. Dawan Wiwattanadate (Thailand)
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Mr. Atif Al-Jemaili (Kuwait)
Mr. John Hawksworth (PwC UK)
Mr Mohamed Hamel (OPEC, Austria)

Special Advisor to Director of Studies:
Mr. J.K. Mehta

Appendix 3

List of advanced country assessment reports

As part of the study some study group members have carried out individual country assessments. The reports of these assessments are available for downloading on the World Energy Council website at www.worldenergy.org.

The following reports are available:

1. Report of country assessment for the Baltic States

2. Report of country assessment for Egypt

3. Report of country assessment for the Netherlands

4. Report of country assessment for Portugal

5. Report of country assessment for Switzerland

6. Report of country assessment for Spain

7. Report of country assessment for the United States of America

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