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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
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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.

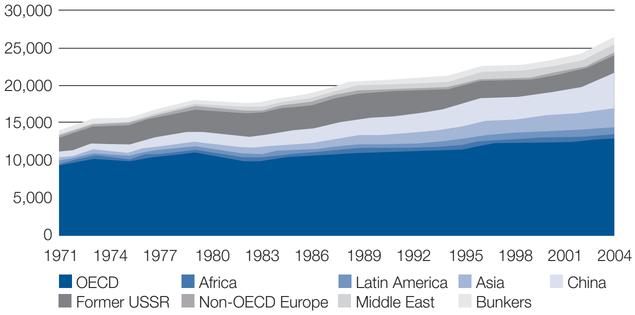
- ***Accessibility*** is the provision of reliable and affordable modern energy services for which a payment is made. It depends on policies specifically targeted to meeting the needs of the poor, in the context of increasing reliance on market signals. The best way to ensure that a growing number of 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

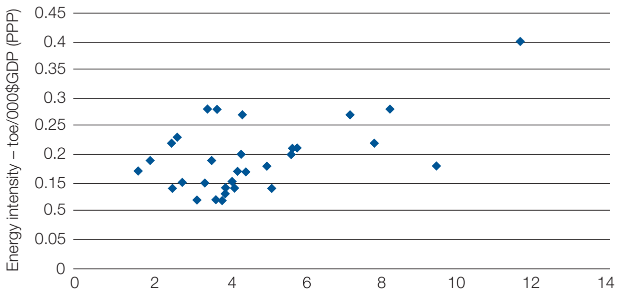
CO_2 emissions, GDP and population of selected countries

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.

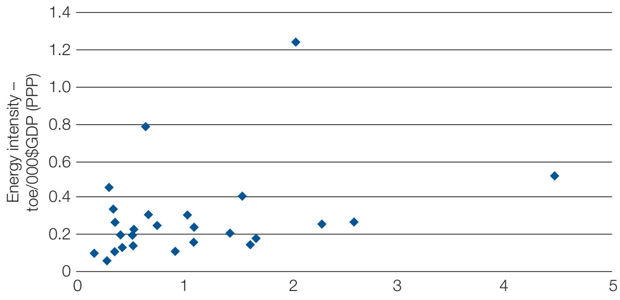
Energy intensity

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.

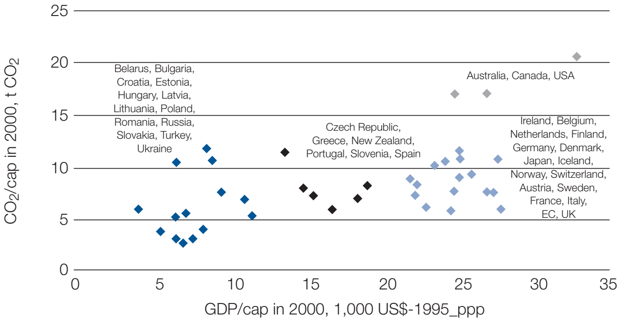
For instance, biomass in OECD countries is generally assumed to be carbon neutral. In developing countries, population pressures may mean that use of biomass involves extensive deforestation or loss of agricultural productivity (because of animal wastes that might otherwise be used as fertilisers, and 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

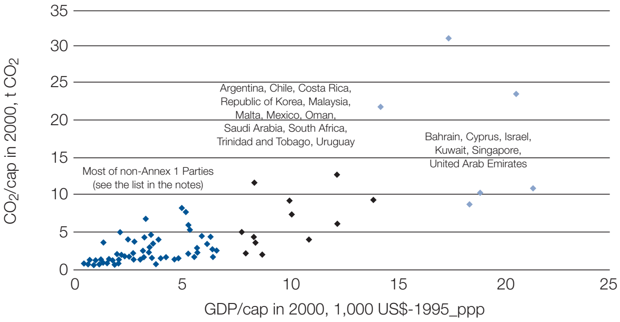
Just as energy intensity is only loosely related to energy demand, so **energy demand growth itself does not necessarily lead to an increase in emissions** – it depends on the final element in the equation, the carbon content of energy. Again, this varies very considerably between countries, as shown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