Working Paper

Global Energy Perspectives to 2050 and Beyond

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Summary

GLOBAL ENERGY PERSPECTIVES TO 2050 AND BEYOND

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Summarized here are the key findings on global energy-related issues presented in the joint WEC and IIASA Report Global Energy Perspectives to 2050 and Beyond. The Report is based on an evaluation of six scenarios.

The world's energy use will rise in the coming decades because of population growth, economic and social development, and increasing demand for the services which energy provides. To meet the growing demand for energy services commercial energy provision will expand, with both a continuing reliance on fossil fuels and increasing non-fossil fuel supplies. These non-fossil fuel supplies will include a variety of renewable energy sources. Nuclear energy provision will also increase if challenges posed by public concerns with safety, costs and scale can be met.

Electricity and other energy forms delivered through dedicated supply networks are likely to benefit from future developments, as part of a general emphasis on the delivery of energy services in convenient, flexible and clean forms. The pace of development in the various sectors of final energy use between OECD, transitional and developing economies will differ. Greater emphasis will be placed on residential and commercial needs in the first. In the latter the industry and transport sectors expand comparatively rapidly. There will be an increasing emphasis on efficiency improvements in conversion and end-uses of energy, and on satisfying consumer requirements. This shift requires changes in corporate focus and structure, and more rapid technology innovation and diffusion.

These changes have costs and the financing of energy developments could prove problematic. Local and regional pollution and its mitigation, together with potential climate change, will also pose challenges and impose costs. Sulphur and nitrogen emissions are seen as particularly requiring abatement. The pressures of population growth and urbanisation are expected to impose their own severe challenges. These, and many of the other challenges covered in this Report, call for institutional changes. Given that many developments taking place occur in the now developing countries of the South, a significant eventual shift in the world's geopolitical balance towards the South is anticipated.

For energy policy-makers and decision-makers the key finding is that, given the lead-times in infrastructural and other major capital investments, there is little divergence between the six different scenarios until after 2020. But action is required long before 2020 if desired development paths are not to be blocked and options foreclosed. This requires reconsideration of the traditional separation of energy supply and end-use investments.

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1 Introduction

The world's energy use will rise in the coming decades. This is because people desire the services which energy provides – such as heating and cooling, cooking and lighting, mobility, modern communications and information processing, and the motive power of machinery. In today's world huge numbers of people do not have access to the services provided only by modern energy forms. Nearly 2.5 billion people are without electricity. There are 600 people for every car in China. Over 70% of Africa's population has no motive power other than human or animal muscle. In the coming decades the world's population will also grow. There are now some 5.8 billion people on Earth. By the year 2050 the total is expected to exceed 10 billion; and by the year 2100 to be in excess of 11.5 billion. They, too, will want the services provided by energy.

This study addresses the prospects for improving the global availability of energy services, and the wider implications this may have. The anticipated rise in energy use, most of it coming from what are now termed the developing countries or "the South", requires the greater harnessing of existing resources and the accessing of new resources. It also requires considering the options available, over realistic time frames and at affordable costs, bearing in mind the wide variability of resource endowments between countries – and of income and wealth between individuals and between countries.

This paper provides a summary of the main findings of a Report on "Global Energy Perspectives to 2050 and Beyond", prepared jointly by the World Energy Council (WEC) and the International Institute of Applied Systems Analysis (IIASA). The main time-horizon of the study is to 2050, thereby extending in time and detail the main focus of the WEC Commission's study: "Energy for Tomorrow's World", first published in 1993. The WEC Commission's main focus was out to the year 2020, but some elements were considered in outline to the year 2100. The year 2100 is the main time-horizon for several major issues and the organisations examining them, particularly potential climate change associated with greenhouse gas emissions from fossil fuel use and other human activities.

The present study considers the post-2020 period in greater depth and detail than the WEC Commission did, using alternative sets of assumptions about future possibilities. These different sets of assumptions are descriptions of alternative possible futures – termed scenarios. They are not predictions of what will happen. The possibilities considered include different rates of economic growth, changes in energy productivity (or intensity), primary energy demand, the volume of fossil fuels that can be realistically exploited, renewable and nuclear energy possibilities, technology dynamics and costs, the availability of finance, institutional developments and policy responses. Six scenarios have been developed for this study. The key features of these scenarios, and their quantification, are outlined in the Technical Annex to this paper.

For this Paper we concentrate on the main findings and implications of the study. Readers wishing to examine the study findings, scenario methodology, quantification and outcomes in detail are referred to the full WEC/IIASA Report "Global Energy Perspectives to 2050 and Beyond". This subject will also be revisited after 1995, starting from the position of (and prospects for) eleven world regions. This will allow the results of the present top-down examination to be tested and checked against an evaluation which will be completed as a regional or bottom-up exercise. Local realities, perceptions and aspirations can then be more closely integrated, as was achieved by the WEC Commission: "Energy for Tomorrow's World".

There is one general point about the six scenarios which needs to be emphasised at the outset. They are all regarded as viable. But none assume that developments can be taken for granted. All assume, to varying degrees, that domestic and international policies will promote the free exchange of goods and technology or overcome the restrictions which regional bloc formation may impose from time to time. All assume an adequate investment climate, and a supply of labour with the necessary skills to diffuse and maintain the technologies required. All assume that fossil fuels to the extent required, or non-fossil fuels to the volumes desired, will become available to sustain the development path of each scenario. These are the necessary foundations for the productivity increases of labour and capital needed to realise the economic growth assumed for all the scenarios. The various assumptions are not independent of each other, but taken together result in consistent scenarios. Internal consistency has been tested by the use of formal models.

There is a risk that temporary bottlenecks could emerge in the energy sector. It will have to compete successfully for much needed investment from a multitude of economic and development concerns. It is possible to conceive of financial requirements becoming unmanageable, or of local pollution reaching unacceptable proportions (the latter particularly through failure to ensure coal-fired electricity generating plants are fitted with scrubbers, and/or because of failure to tackle vehicle emissions). In the event of such adverse developments the scenario paths described may not be achieved. In all the scenarios developed here it is assumed that sufficiently effective responses to the key challenges have been forthcoming.

2 The Main Findings

2.1 Energy Supply and Use

2.1.1 Energy Use Grows

The world's primary energy use will rise markedly. In the absence of widespread, determined and effective steps to curtail demand growth – by dramatic efficiency improvements, technological developments and because of environmental concerns – primary energy demand is likely to expand 2 to 2.5-fold by 2050; and by 3.5 to 4.5-fold by 2100. Scenarios driven by ecological concerns and effective policy responses seem likely to produce significantly lower trajectories, as indicated by the ecologically driven scenarios in this study.

2.1.2 Commercial Energy Provision Expands

To provide the greater volumes of energy required, in the forms desired, it is commercial provision which will expand: electricity and natural gas through interconnected systems which make energy readily available at point of use; liquid fuels; and an increasing variety of fuels for heat and power provision from non-fossil sources that become technically and economically feasible if appropriate research, development and technological innovation take place.

In many developing countries there is still heavy dependence on traditional fuels – fuelwood, crop wastes, animal dung – that are consumed locally and without any conversion. It is neither practicable nor desirable to anticipate larger volumes of energy coming from traditional sources to meet future requirements if they continue to be provided in non-sustainable ways. Even the present 10 to 15% of world primary energy supply coming from traditional fuels is unsustainable over large areas – in Latin America, sub-Saharan Africa and in the Asia/Pacific Region.

2.1.3 Continuing Reliance on Fossil Fuels

Commercial fossil fuels now supply over 75% of the world's primary energy. This study confirms the availability of large volumes of fossil fuel resources which should be economically and technically viable to exploit over the coming decades. In comparison to the estimated ultimately recoverable volume of coal resources, the world since the earliest times has used just over 4% of the amount available. For oil, the corresponding figure is about 13.5% (assuming substantial volumes of unconventional oil are also ultimately recoverable). For natural gas the corresponding figure is about 6%. The issue is not whether geological resources are constrained (although in the long term to 2100 the finite nature of the fossil fuel resource base would inevitably become evident). The real issue is whether because of lack of technological development, great distances from markets, financial constraints, environmental considerations (local, regional and global), and the eventual availability of more attractive and viable alternatives, substantial fossil fuel resources will be left unexploited. This study therefore provides alternative estimates of cumulative resource consumption for the six scenarios to reflect the differing extent to which the fossil resource base may be exploited.

In the period to 2050 this study concludes from its six scenarios that, by comparison with usage from the earliest times to the present:

- in the lowest coal scenario, the same amount of coal would be used again;
- in the highest coal scenario, 2.5 times the coal would be used;
- in the lowest oil scenario, twice the volume of oil would be used;
- in the highest oil scenario three times the volume of oil would be used;
- in the lowest natural gas scenario four times the volume would be used;
- in the highest natural gas scenario nearly six times the volume would be used.

The implications for various energy industries and for regional fuel producers are given in more detail in the full report "Global Energy Perspectives to 2050 and Beyond".

Natural gas is accorded great importance in all six scenarios, and varies least of the fossil fuels between the scenarios. Oil also continues to be important across the scenarios, reflecting the belief that transportation demand is likely to grow inexorably in many countries and that it will be difficult to introduce viable alternative fuels in sufficient quantities within the next four or five decades. With the rise in relative importance of natural gas, however, is expected to come a decoupling from oil. Natural Gas will be a fuel in its own right, with its own markets – including those where it has hitherto not competed effectively with oil.

2.1.4 *Expanding Non-Fossil Fuel Supplies*

The lead-times required to achieve massive changes in the world's fuel mix are many decades. The WEC Commission in "Energy for Tomorrow's World" stressed that this means action must start now if the process of change is to be instituted in the decades leading up to 2050. "Global Energy Perspectives to 2050 and Beyond" takes this theme further, pointing out the likelihood of diverging development paths and locking-out desirable options. References to long lead-times are therefore not to be interpreted as suggesting "do nothing". Realistic time-frames for change require recognition of the lead-times involved, as well as appropriate government, industry and consumer decision-taking.

There are barriers to the expansion of renewable energy supplies which exist within the fossil fuel sector. These include the plentiful availability of fossil fuel resources, their generally low costs, and the huge existing investments in fossil fuel provision and use. Especially in developing and transitional economies there is also the widespread existence of subsidies to end-users, which encourages waste and inefficiency. The view that non-fossil fuels are unable to compete "on a level playing field" with fossil fuels due to failure to incorporate internalisation of all costs in prices is widely held; but costs and available technology have hitherto also been a major barrier.

The present study examines the prospects for a diversified portfolio of new renewable forms of energy – particularly modern biomass and solar; and for nuclear power. Each of the scenarios makes somewhat different assumptions about the pace of expansion for renewable forms of energy; and more or less optimistic assessments of the prospects for nuclear power.

Renewable energy developments will vary geographically in response to available resources and technologies, and to the level and structure of energy demand. The spread of new renewable technologies will be critically dependent upon learning and experimentation, and there is great uncertainty about how far policy interventions will be able to shortcut this process.

Compared to a number of other published scenarios, this study concludes that growth of renewable energy supplies will be more gradual in the near to medium term. Total renewable energy supplies are expected to grow from 1.6 Gtoe (gigatonnes oil equivalent) in 1990 to between 2.3 Gtoe and 3.3 Gtoe in 2020. This more modest near-term growth is, however, counterbalanced by much higher growth rates in the long term. All scenarios show a substantial increase in renewables, but with a considerable variation in the percentage of total primary energy supplied by renewables. By 2050 renewables could account for between 16% and 30% in a High Economic Growth set of scenarios; and for between 35% and 40% in the Ecologically Driven Scenarios.

These differences reflect the different driving forces the study expects to be at work. The overall pattern of development is broadly in line with previous WEC studies: "Energy for Tomorrow's World", 1993 and "New Renewable Energy Resources: A Guide to the Future", 1994. However, a somewhat slower evolution under this study's middle course scenario is assumed than under the comparable scenarios in the two earlier WEC publications. This study reflected the possibility of a more gradual phaseout of traditional biomass and a smaller contribution of large hydropower than assumed in the WEC's earlier work.

The study has also considered the long-term potential of modern biomass, and found that although additional land areas for both agriculture and biomass energy are available in principle, they would stretch future land requirements to their ultimate limits. By 2100 agriculture (1,700 million hectares) and biomass (700 – 1,350 million hectares) could require as much land as is currently covered by forests. Land-use conflicts and ecosystems concerns are likely to prove a major constraint, particularly in high population density areas such as Asia.

Perhaps the biggest difference between the fossil fuels and renewables is that the former can be regarded as a (large) stock; the latter by hugh annual or seasonal flows. For instance, the earth annually intercepts about 130,000 Gtoe of solar energy compared with 9 Gtoe total global energy consumption in 1990. But these huge renewable flows are dispersed and diffuse, and generally offer very low energy densities by comparison with the fossil fuels. Therefore, rather like the fossil fuels, modern renewables require elaborate systems of energy conversion, transport and distribution to make them useful.

It is the conclusion of this study that by the year 2050 renewables could provide as little as 16% of primary energy (Scenario A1) or as much as 39% (Scenario C1), with volumes expanding at a steady pace in all scenarios. This study's middle course scenario assumes renewables provide 33% of global primary energy by the year 2100 or 11 Gtoe (which is more than total current world primary energy use).

So far as the prospects for nuclear power are concerned, there is little difference across the scenarios in terms of installed capacity in the year 2020. Thereafter the paths diverge, with a range between a 5-fold increase 1990–2050 and almost no increase to 2050, followed by phasing out during the second-half of the next century in the latter scenario. One scenario envisages nuclear power in the long run emerging as a "swing" supplier – but having adopted more sophisticated fuel cycles, advanced reactors, and smaller-scale processing units which gain general public confidence.

The main barriers to nuclear power's expansion at the present time are public concerns with operational safety, waste disposal and proliferation, and high initial capital costs. Those scenarios in this study which assume vigorous development of nuclear energy require 70 GW_e new capacity per year to 2050, including the required replacement of existing plants. This implies build-up rates up to ten times higher than the recent construction pace. This in turn would require new and convincingly safer reactor designs, a substantial decrease in construction costs and times, and in the longer run the standardisation and introduction of a series of small units.

Nuclear power's contribution by the year 2050 could have risen to a figure in the 11% to 14% range, or could be lagging in the 4% to 6% range. Thereafter, if the necessary positive responses are made to public concerns and technological and financial requirements then nuclear power's share in primary energy supply could rise to nearly 30%. If such positive responses are not forthcoming and effective then a virtual moratorium could emerge. Thus nuclear has the most divergent prospects of all energy sources.

Nuclear power expansion in the long-term future will require either breeder reactors or a combination of new developments in fuel cycles, conversion rates, and the recovery of lowgrade uranium widely occurring in the earth's crust and oceans. No assumptions have been made about nuclear fusion, or indeed other forms of "new" energy which may emerge but which do not exist today. For both renewables and nuclear the greatest expansion is expected to occur in the current developing countries. In this study's high nuclear contribution scenarios the developing countries would have an installed nuclear capacity about double the current global level, which is now located mostly in the OECD countries.

2.1.5 *Increasing Electricity Use*

The demand for easily accessible, clean energy forms will provide the basis for increasing electricity use. In the longer term hydrogen is also expected to perform an increasing role. In the period to 2020 the role of oil products in electricity generation will continue to decline, but the contribution of all other established fuels will increase. Renewable sources of energy and, in some scenarios, nuclear power play an increasing role. In all scenarios except one fossil fuels represent a declining share of electricity generation to 2020 and beyond. This indicates the wide supply diversification which will have taken place by 2050, provided the desirable options have been chosen and necessary technology path established before 2020. Thus policies and decisions taken in the next two decades with respect to research, development and demonstration will largely determine the economic effectiveness and environmental appropriateness of future electricity generating options.

Important developments are expected to occur among those providing electricity. Their emphasis is likely to switch to the provision of energy services rather than just kilowatt hours, although this process is likely to begin later in transitional and developing economies. The number of independent producers is expected to increase. Production is likely to become more decentralized. And deregulation and common carrier rights will transform production, transmission and distribution into separate businesses.

2.1.6 *Expanded Use of Dedicated Supply Networks*

Developments in electricity distribution will be paralleled by some similar developments for natural gas, district heat, and eventually – post 2050 – probably for hydrogen. In particular, these energy forms will be delivered to an increasing degree by dedicated transport systems, such as pipelines and grids. This will enhance trade possibilities and promote similar end-use patterns across regions, even where fundamentally different primary energy supply structures exist.

The main exception to this trend is expected to be locally appropriate and delivered renewable energy systems in rural areas (modern biomass, micro-hydro, solar photovoltaic, wind) and dedicated solar photovoltaic and biogas systems in urban residences. Some renewable developments, however, could be connnected to grids both as decentralised sources of energy and to obtain back-up from the grid.

2.1.7 *Further Emphasis on Convenient and Clean Energy*

Less than a hundred years ago people in the industrialised nations still relied heavily on horses, draught animals more generally, and their own feet for mobility. Less than fifty years ago these people still handled and used coal and fuelwood directly in their homes for heating and cooking purposes. The rise of the motor vehicle, and of electric and gas appliances, have given immediate access in the industrialised countries to the energy service desired, freedom and choice have expanded, and what was initially a luxury for the few has become the norm for a majority.

Over the next century, even in countries which today are characterised by most of the population being unable to access commercial energy (and unable to afford it if they technically could), huge changes can be expected. What is for many now out of grasp will have become a reality. Access to commercial energy will expand, and this will increasingly provide energy services in convenient, flexible and clean forms. This requirement will not only reflect greater economic prosperity and expectations, but should also lead to the mitigation of pollution which would otherwise occur as more and more people use greater amounts of energy in the current developing and rapidly industrialising countries. This development will most obviously be seen in a pervasive shift from energy used in its original form – such as traditional direct uses of biomass and coal – to elaborate systems of energy conversion and delivery, and to the ever-widening application of end-use devices which conform to customer requirements. After 2050 the likelihood is that direct uses of biomass and coal will have been phased out.

2.1.8 Changes in Final Energy Demand

Over the next few decades final energy use in the industrialised countries of the OECD is expected to show residential and commercial needs growing faster than those for industry and transport. With high levels of affluence and leisure, new services and new activities emerge that shift final energy requirements further away from traditional industrial production.

In recent years in leading OECD countries demographic changes associated with ageing, increasing male/female cohabitation without children, and a rise in the number of single-person households have been reflecting this trend. The elderly are more mobile and prosperous than their predecessors. Younger couples and single adults are more mobile and even leisure activities are widely associated with commercial energy consumption. Families with children are also more mobile (whether out of choice or, in the context of taking children to and from school, out of perceived necessity), and both outdoor and indoor leisure pursuits are associated with a range of energy-using devices, including electronic equipment.

These trends could well continue and spread in the industrialised countries, and extend over the next century to an increasing number of countries now engaged in the industrial development process. But for the next few decades final energy needs in the current developing countries are more likely to grow fastest in the industry and transport sectors, and comparatively slower in the residential and commercial sectors. Globally there is likely to be a shift – already discernible in some of the leading industrial nations – towards communication and services replacing some mobility and production. This process is expected to result in lower material and energy intensities.

2.1.9 Introduction of New Energy-Using Devices

Changes in the fuel mix, the expansion of commercial energy availability, the increased role of networks, the demand for convenient and clean energy services, and developments in final energy use could well all combine to promote new energy-using devices. There will be changes promoted by quality improvements in the fuel mix and conversion processes, which will in turn encourage efficiency gains. There is likely to be increasing consciousness of the scope for technological change in end-use devices (cars, lighting, cooking stoves, and space heating and cooling systems are the most obvious examples) to meet the ways in which final energy use is evolving. Technological change is also expected to occur in power plants and in industrial processes to meet emerging requirements of quality, efficiency and environmental acceptability.

2.1.10 Energy Increasingly Service Driven and Consumer Orientated

In the past there was a tendency for the energy industry to be supply-orientated, focused on large-scale engineering excellence, and on volume. In the coming decades the stance is expected to change radically and rapidly.

It is now widely recognised that consumers do not seek energy as such, but the services which energy provides. Suppliers of energy are therefore required to see themselves as providing easy, efficient and competitive cooking, lighting, heating and cooling, mobility and motive power, communications and information processing. Consumers will become increasingly demanding of high quality, efficient and relatively low cost energy services. They will be increasingly aware, and made aware, of the environmental impact of their energy use. They will provide increasing challenges to the providers of such services. Even in those developing countries where the lack of commercial energy availability is now the key issue, and this remains the most potent obstacle, these forces will become apparent and intensify over the next century.

2.1.11 Energy Efficiency Increases

There is a clear historic trend for overall energy efficiency to improve as countries industrialise. Energy intensities are lower at higher per capita Gross Domestic Product. More efficient energy conversion and end-use technologies become affordable at higher income levels, their costs fall and higher quality energy carriers are made available. These trends can be expected to extend to the economies in transition and to the current developing countries over the coming decades.

Recently, however, energy intensity improvements in the OECD area have come to a standstill due to low energy prices since 1985 and widespread economic recession or sluggishness. In the economies in transition a drop in primary energy demand has been exceeded by a dramatic fall in economic output, with the result that energy intensities have risen significantly. Only in the developing countries have energy intensities fallen steadily in recent years. While their total primary energy demand has been rising at 2% per annum (3% per annum for commercial energy) their Gross Domestic Product in aggregate has been rising at 4.8% per annum. Thus their aggregate energy intensities have fallen by nearly 3% per year (and commercial energy intensities by nearly 2% per year).

In the light of these recent developments the present study adopts a more modest set of assumptions about the pace of future energy efficiency gains than did the WEC Commission in "Energy for Tomorrow's World", 1993. The world average for the period 1990–2050 in the present study is 1.0% per annum reduction in the high economic growth scenarios; 0.8% per annum in the middle course scenario; and 1.4% per annum in the ecologically driven scenarios (the WEC Commission range 1990-20 for the world was 1.3–2.4% per annum).

The energy intensities adopted here are a function of the internal consistency of the six scenarios – the relationship between economic growth, capital turnover, technological change and efficiency improvement.

This downward adjustment in energy efficiency assumptions brings them more closely in line with long-term experience. The world may well be able to do better in future, especially if policy-makers directly and effectively address the issue of raising efficiency in both energy conversion and use. Energy users have little experience of such policies and what they could achieve. A number of conclusions concerning energy efficiency improvements are detailed in the full report "Global Energy Perspectives to 2050 and Beyond":

- the faster the growth of Gross Domestic Product (GDP) per capita the faster is productivity growth, the rate of capital stock turnover therefore increases and energy intensities can be expected to improve more rapidly;
- where there is negative per capita GDP change energy intensities deteriorate (as recently demonstrated by the economies in transition);
- a region at a given level of per capita GDP can be assumed to achieve similar energy intensities or better (due to learning and general technological advance) as industrialised countries did at a similar per capita GDP level;
- there are significant variations between countries due to historical developments, culture and settlement patterns;
- there is a tendency for commercial energy intensity to rise, reach its maximum, and then decline. In a number of developing countries overall energy intensity (non-commercial and commercial energy combined) is in decline, but commercial energy intensity is rising;
- energy intensities are lower where the whole (or a larger proportion) of a country's economic activity is incorporated in the comparison than when only the formal economy quantified in national accounts is included.
- energy intensity improvements are generally lower using purchasing power parity as the basis for GDP rather than GDP at market exchange rates.

2.2 Corporate, Technological and Financial Challenges

2.2.1 Changing Corporate Structure and Focus

All energy industries will see substantial growth to at least 2020, although in some more prosperous and/or environmentally sensitive countries specific sectors are likely to be on the defensive. There will nevertheless be much change within and between energy sectors.

Many new business opportunities will arise linked to cleaner and more convenient fuels, to liquid rather than solid fuels, to grid and other networked supplies, and to more locally appropriate – often small scale – energy sources and conversion technologies.

Prospects will begin to diverge after the year 2020, however, with different energy industries embarked on often mutually exclusive development paths. Coal, despite its huge resource base, could be particularly threatened unless its use forms change markedly – due to increased competition from other energy sources and environmental constraints in response to sulphur dioxide, particulates, methane, carbon monoxide and carbon dioxide emissions. This could prove especially important for some coal-rich developing countries. By contrast the oil industry, and the natural gas industry to an even greater extent, have a long future ahead provided today's strong exploration and resource development effort continues. The full report gives more detail on different production profiles in the six scenarios including international energy trade and export revenues.

New markets will have to be developed for the traditional fuels, recognising that the shift from selling primary energy to marketing energy services will continue and intensify. The traditional fuels will also experience intensifying competition from a widening range of renewable energy sources for electricity generation, from other sources of heat and power (anaerobic digesters and photovoltaics, for example), and for motor vehicle propulsion (methanol, for instance).

The demand for convenient, flexible, clean and efficient energy services by consumers will be a powerful force for greater consumer-orientation and dialogue between energy suppliers and consumers. Energy companies will increasingly be expected to provide services, and perhaps widening packages of related services. It is possible that specialised suppliers of fossil fuels – with particular competitive advantages in exploration, production and transportation – may still be able to treat the fossil fuel they deal in as a commodity. Most of the pressure is likely to be in the opposite direction, especially where vertical integration exists and companies diversify as a strategic response to perceived threats or expanding opportunities in growth markets. Structural changes can clearly be anticipated over the next century. Although the energy industry has many long established companies, this is the exception across industry and commerce generally. The greater the service orientation the more scope there is for change as efforts are made to maintain and increase competitive advantage, and the scope for new entrants increases.

Deregulation and privatisation – which have recently occurred in a number of countries and in different ways are being watched closely by many others – can also be expected to change strategies and operating goals. Deregulation and privatisation will usually enhance service orientation and the satisfaction of short-term operating goals such as efficiency, profitability and shareholder returns. Deregulation and privatisation may well not enhance long-term strategic thinking, research and development for longer term advantage, or diversification in the absence of anticipated short-term gains. The corporate focus may therefore become more short-term in ways that do not lend themselves naturally to the taking up of some of the long-term strategic options which this study would suggest are desirable – and probably inevitable in most scenarios. In this situation new entrants are likely to fill the gap, but these may not have the initial capital or the history of relevant learning and experimentation which would allow relatively rapid process.

2.2.2 Technology Innovation and Diffusion Play a Key Role

New energy technologies on the supply side and for energy-using devices are expected to lie at the heart of efficiency improvements, cost reductions, and better services provided by energy. The present study drew on IIASA's data bank of 1,400 technologies covering the whole energy system. However, energy options that are not technically feasible today were excluded (while technically feasible options which are not yet commercially feasible, were included).

In high economic growth scenarios where relatively large quantities of fuels will be required there need to be considerable advances in hydrocarbon exploration and extraction, renewable and nuclear electricity generation, hydrogen and bio-fuel production and conversion, and more efficient appliances. In ecologically driven scenarios low-carbon fossil and renewable technologies are favoured, together with greater emphasis on end-use efficiency. There is likely to be an increasing number of situations where end-of-pipe technology approaches are not the most appropriate solution. For efficiency and environmental reasons a new or alternative total systems approach is likely to yield the best results. Moreover, it may result in greater competitive advantage.

This study's scenarios clearly indicate the need for an adequately high level of research, development and demonstration expenditures. The ecologically driven scenarios, with their emphasis on renewable energy and efficiency, especially require a shift of R&D flows, more innovation, faster diffusion, and greater capital intensity in future. However, there is a high rate of technology learning and improvement which tends to reduce capital costs.

Currently R&D expenditures are generally lagging perceived requirements, especially for raising energy efficiency and environmental mitigation. Yet technology innovation and diffusion is a cumulative experience of learning and experimentation which takes time, and which cannot normally be greatly accelerated by policy interventions. More needs to be spent on R&D, by companies and governments alike. Joint government/corporate research is likely to increase, for mutual and greater societal benefit. There have, for example, been great benefits in recent years arising form the enhanced recovery and tangential drilling techniques of the international oil industry. There is considerable scope for cleaner coal conversion and use, for reducing local pollution from oil use, and for accelerating renewable energy provision.

2.2.3 Costly Investments – Financing Is Problematic

The expected changes which have been listed so far suggest that they cannot be achieved except with large financial investments. This study estimated that cumulative investments in energy supply projects between 1990 and 2020, in the various scenarios, would range between U.S.$ (1990) 13 and 20 trillion (10^{12}) for the world. Between 2020 and 2050 the range is U.S.$ (1990) 18 and 34 trillion.

These estimates include capital for production capacity, for transmission and distribution infrastructures, and for complying with environmental standards. As a share of projected GDP globally, and by region, they are modest except for the economies in transition (where they represent 7%–9% of GDP 1990–2020). The study also concludes that its estimated capital requirements for energy supply projects are manageable in relation to current savings rates (globally about 22% of GDP – 21% in industrialised countries and 24% in developing countries), and in relation to capital markets (which have been growing faster than GDP and are expected to continue to do so). But these simple comparisons may encourage unwarranted complacency.

For many supply-side investments the real challenge is likely to be not the scale of financing required but the uncertainties of risks and rates of return. Returns in the energy sector have long been low in relation to infrastructural investments in urban development and transport. Rates of return considerations discriminate against most smaller-scale, clean and innovative energy supplies, and against investments in energy efficiency improvements. Market size and product mobility often favour investments in oil exploration over, for instance, energy conservation. International funding has also tended historically to favour large schemes backed by local government even when front-end costs are high and substantial external indebtedness is incurred.

Two developments in recent years are expected to change this situation in some important respects. First, privatisation and deregulation has been a response in part to heavy debt burdens built up by the publicly-owned energy sector which has existed in many countries in the past. Secondly, stagnation in international development finance and the view in international funding agencies that their share of energy sector financing will decline. Both developments indicate that energy financing must therefore come increasingly from the private sector and local sources. In many countries this will require new or modified institutions to mobilise local finance, and the adaptation of local energy industries to provide acceptable and secure returns. Privatisation and deregulation are also likely to make it easier for governments to countenance the reduction/elimination of subsidies, and setting energy prices to reflect real costs. Such steps together with the maintenance of a stable political climate, in order to reduce investment risks and broaden access to international capital markets, are essential if private financing of energy investments is to be maximised. However, it is clear that the energy sector will have to compete with other sectors for investment financing – and that some of those sectors, as indicated earlier, have a history of offering substantially higher returns.

There is also the challenge posed by the fact that these estimates do not include investments in end-use technologies such as furnaces, appliances and vehicles, as these traditionally count as durable consumer goods or business investments. The fact that the performance of end-use technologies plays such an important role in all this study's scenarios is a strong argument in favour of new approaches to evaluating energy sector investments. Integrated resource planning has begun to extend the traditional energy sector perspective to take into account investments in end-use technologies. Approaches that assess together both supply options and end-use options, both expansion and conservation, will be increasingly important.

2.3 Environmental Pressures

2.3.1 Local and Regional Pollution Remains a High Priority

The WEC Commission "Energy for Tomorrow's World", 1993 found that local and regional issues were ranked higher than potential climate change by eight of the nine world regions surveyed. The exception was Western Europe, which concluded that potential climate change was important. All regions considered local and regional pollution important. Both this study and another recent WEC report: "Local and Regional Related Environmental Issues", 1995 emphasise the importance of local and regional pollution.

Two categories of pollution are highlighted. First, that arising from poverty: poor sanitation; polluted water; high levels of indoor air pollution caused by burning traditional fuels –

impacting with particular severity on women, children and the elderly; and high concentrations of particulate matter in urban areas. Secondly, pollution of modern origins: resulting particularly from dense motorised traffic and from low-efficiency coal combustion in electricity generating plants, industrial premises and homes. Concentrations of suspended particulate matter, lead, volatile organic components, tropospheric ozone, and sulphur dioxide widely exceed World Health Organisation guidelines.

Four conclusions are reached:

- improving conversion efficiencies in end-use devices has a key role to play in conserving traditional resources such as fuelwood and reducing indoor air pollution;
- structural shifts away from many traditional energy end-use patterns and energy-carriers towards more efficient modern conversion technologies and cleaner energy carriers are urgently necessary;
- there is a need for a long-term shift towards energy services provided through clean, grid-dependent fuels;
- increasingly, local solutions to local problems would come forward that are appropriate in nature and scale to local circumstances, and may include locally appropriate renewable energy provision as well as end-use devices.

Widening education, health and welfare awareness, and social and economic development will be accompanied by increasing dissatisfaction with avoidable local pollution and greater means to tackle it. Pollution of a more regional nature, through energy-related emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x), have also been examined in this study. Acid deposition is of particular concern.

The RAINS model developed at IIASA was used to calculate unabated scenarios of sulphur deposition in Europe and in South and East Asia. It became clear that unless scrubbers and other mitigating technologies are used in coal-fired generating plants then any coal-intensive scenario will have unacceptably high sulphur emissions. In Europe over the next 30 years sulphur emissions would increase by about 50% leading to sulphur deposition in excess of 16g.S/m^2 per year over large areas of Central, Western and Northern Europe. This level exceeds the maximum laid down in the Second Sulphur Protocol of the European Community on Transboundary Air Pollution by more than 5-fold.

In the rapidly growing economies of Asia the challenge of coal-intensive scenarios is even greater. Sulphur emissions in South and East Asia could more than double by 2020 in the absence of effective abatement measures. Current national energy projections in the region actually exceed this level. Plans exist in China to triple coal use over the period to 2050, to 3.6 billion tonnes per annum (a quantity which is 10% higher than today's total global coal use). Unless scrubbers are fitted to virtually all new coal-fired plants air quality in South and East Asia will deteriorate significantly in both urban and rural areas. In the absence of abatement measures sulphur depositions could readily reach double the worst levels <u>ever</u> observed in the <u>most</u> polluted areas of Central and Eastern Europe. The model assessment reported in "Global Energy Perspectives to 2050 and Beyond" shows depositions would exceed "critical loads" for most of the ecosystems in Asia, and for economically important food crops by factors up to 10.

For this reason the six scenarios developed for this study all incorporate advanced coal technology, including scrubbers for new electricity generation capacity. Sulphur emissions are therefore lower in all scenarios than they would be without abatement – in fact 50% or less than implied by unabated scenarios. Sulphur abatement nevertheless imposes significant costs. With much greater investment it would be possible to reduce sulphur emissions further than has been assumed in this study, but the investment assumptions made are already challenging for developing and rapidly industrialising countries which may not attach high priority to getting depositions significantly below critical loads.

The prospect of a massive rise in road vehicle use, particularly in South and East Asia, along with heavy reliance on oil to meet most of this demand for several decades to come, also indicates that nitrogen emissions and other precursors of tropospheric ozone (smog) will be accorded high priority.

Environmental concerns of a local nature are also likely to rise from a different quarter; some renewable energy sources. Large hydro schemes have aroused increasing concern in recent years due to the population displacement, inundation of good agricultural land and loss of natural habitats they cause. This is why the present study has inter alia moderated the estimates of medium-term hydro development from earlier WEC studies, despite the relatively high conversion efficiencies (within the renewables sector) that the more effective schemes achieve.

Of even greater potential concern is large plantation biomass, if the prospect is that land areas of 1,350 million hectares or more may be involved. This would impose exceptional challenges for biodiversity, natural habitats and species protection, and visual amenity. Other, though probably less serious, local environmental threats may arise from renewable energy development. Increasing environmental awareness and desire to achieve balanced development will influence the pace and nature of renewable energy expansion, particularly in more prosperous countries with choices.

2.3.2 Greenhouse Gas Emissions Vary Widely

Using standard medium world population projections (as in this study), and assuming no dramatic shifts in the fuel mix to meet rising energy demand, a number of models have calculated future greenhouse gas emissions and their atmospheric concentration. Carbon dioxide (CO_2) is the greenhouse gas which has been looked at particularly closely in the context of energy provision and use, and potential climate change.

The work of the Intergovernmental Panel on Climate Change, which produced a number of emissions scenarios in 1992 (the IS92 Series IS92a-f), suggested that on comparable assumptions atmospheric CO_2 concentrations could rise 4 to 6-times from their current levels by the year 2100. The present study suggests at first sight that the range of possibilities is much wider. In a high economic growth and coal-intensive scenario atmospheric CO_2 concentrations could rise nearly 5-fold from their current level by 2100. On the other hand, if ecologically driven scenarios were pursued then atmospheric CO_2 concentrations might only rise some 65% from their current level.

In fact this study compares the emissions which emerge in six scenarios that have different, but internally consistent, assumptions about techno-economic development and policy measures.

Once such internal consistency is taken into account, by contrast to the widely varying assumptions of the IPCC scenarios, the emissions in the present study are essentially lower and mitigation becomes an integral part of the whole "minimum regret" development strategy.

The atmospheric concentration of greenhouse gases is believed to be the key factor in global mean surface temperature change, and hence climate. If the rise in atmospheric CO_2 concentration (currently approaching 358 parts per million by volume – ppmv) were to be contained at 580 ppmv or 590 ppmv by the year 2100 (the outcome of this study's two ecologically driven scenarios) then the implications are important. First, current climate models suggest that mean global surface temperature is likely to rise by less than 1.5°C over the period of a century. This would have some impacts on food production, precipitation, and human settlements, but of a modest order. Secondly, mean sea level rise would be modest (perhaps of the order of 25 cms above 1990 levels) and with geographically restricted impacts. Thirdly, given the great deal of uncertainty surrounding the subject of future climate change and its impacts, pursuit of ecologically driven scenarios would provide some confidence that significant climate change arising from human activities could be avoided. There are two further implications of this study that are important:

- the scope for improving energy efficiency, bringing on cost-effective non-fossil energy supplies, and mitigating local and regional pollution is so enormous that effective action in these three areas will have substantial all round benefits;
- the world has options for change, and for avoiding catastrophic or unattractive outcomes. The Intergovernmental Panel on Climate Change assumed for its 1992 emissions scenarios that few policy changes were made. This study has indicated the options, and the wide variety of possible outcomes if sound and effective policy decisions are made. Policies, if they are to be instituted rapidly and effectively, should aim at meeting both the high concern with local pollution and the curbing of anthropogenic greenhouse gas emissions, which are not widely regarded with the same urgency or seriousness.

2.4 Social, Institutional and Geopolitical Implications

2.4.1 The Significance of Population Growth

This study has taken a standard single medium population projection for the world. From its present level approaching 5.8 billion (10^9), world population is assumed to grow to 10.1 billion by 2050 and to 11.7 billion by 2100. Over 90% of that growth will occur in the current developing countries. By 2100 Asia and Africa combined are expected to account for over 80% of the world's population and the current developing countries for about 80% of the world's primary energy use. In 1990 Asia and Africa combined accounted for 72% of the world's population, but the developing countries for only one-third of the world's primary energy use. Population growth in the current developing countries, and the social and economic development which occurs in these countries, will be the main force driving the demand for energy services upwards.

2.4.2 The Importance of Urbanisation

More than 80% of the population of industrialised countries lives in urban environments. The figures for developing countries cover a much wider range, but in some cases already reach or exceed the industrialised countries' average. Some 2.2 billion out of the world's population of 5.3 billion lived in urban areas in 1990. Over the period 1990–2025 (a mere 35 years) the world's urban population is projected to increase to 5.2 billion. That increase of 3 billion accounts for nearly all the projected population growth (3.2 billion) in the period. According to the UN 60% of the world's population will live in urban areas by 2025, and if this trend continued some 75% of the world's population would live in urban areas by 2050. An increasing proportion are expected to live in "mega cities" of over 10 million inhabitants.

These prospects pose severe challenges. Per capita energy consumption levels in urban areas are now much higher than country averages, partly reflecting high urban incomes. This pattern is not immutable. Heavy investments and the avoidance of chronic poverty and deprivation will be required. Energy transport and conversion infrastructures need to be put in place. The urban centres of many developing countries are already characterised by overcrowding; inadequate housing and health provision; poor air, water and land quality; and a range of energy-related local pollutants. These problems will be exacerbated by growing numbers of people, increased demand for energy services, and negative environmental impacts. This suggests that local and regional environmental problems will continue to be accorded high and urgent priority. They also indicate that imaginative thinking, measures and massive investments will be required in order to deal with these challenges, otherwise urban living conditions could deteriorate significantly.

2.4.3 Offsetting the Pressures for Urbanisation?

Although all the present study's scenarios portray the same broad trend towards increasing urbanisation, one scenario offers the prospects of this being conducted at a slower pace. In the event that rural energy requirements can be satisfied more quickly and at acceptably low costs by locally appropriate forms of decentralised, small-scale renewable sources of energy then this would simultaneously offer the opportunity of providing the energy services desired and slowing the pace of migration from the country to the city.

Further along the development path other migratory forces may be at work – shifts to suburban areas from city centres, and eventually back to rural areas – but with employment and much economic dependence upon the city. These shifts in turn have their implications for the level and pattern of final energy demand.

2.4.4 Significant Recent Developments

Several recent developments of longer term significance have occurred since 1990. Two have already been mentioned. First, the stalling, and even reversal, of energy intensity reductions in OECD economies and the significant increase in energy intensities in transitional economies. Secondly, environmental developments including the 1987 Montreal Protocol on substances which deplete the stratospheric ozone layer and the Rio Earth Summit of June, 1992 (of which Agenda 21 and the UN Framework Convention on Climate Change – UNFCCC – formed a part).

Since 1990 the economies in transition have experienced a massive fall in economic output – of the order of 40% by 1995. The developing countries of East Asia have seen the most impressive growth. The world economy has expanded at a sluggish pace of under 2% per annum.

The World Trade Organization succeeded the General Agreement on Tariffs and Trade (GATT) in 1994, and there have been developments in regional bloc formation – the North American Free Trade Agreement (NAFTA), Mercosur (linking Argentina, Brazil, Paraguay and Uruguay with Chile and Bolivia in process of joining), and the enlargement of the European Union.

The global demand for coal has been in decline since 1990, but the demand for natural gas and nuclear power have expanded markedly at the global level.

All these developments have longer term implications. Among the most important is the moment when the economies in transition, and especially the Russian Federation, begin their economic recovery and improvement in energy intensities. The further out beyond the year 2000 the turn-around is placed the more significant the impact on both the global and the regional assumptions for performance in the 1990–2020 period. Regional bloc formation carries with it the possibility of disruptive impacts on trade with third parties. Deliberation on potential climate change, demands for extended and intensified commitments, and greater focus on the impacts of fossil fuel provision and use are also likely to have significant long-term implications.

There have been few signs so far that concern with environmental impacts of energy use at the local, regional or global levels is being translated into significant changes in patterns of energy end use and lifestyles. There remains the possibility that such real changes may occur in future.

2.4.5 *Institutional Changes in Prospect*

The various forces at work over the next few decades can be expected to create the need for both international and national institutional changes. Broad institutional and social issues were not directly addressed in this study, but a number of points are believed to be implied.

Continuing dependence on fossil fuels, with in many countries rising import dependency and lengthening supply lines, will create the conditions for reinforcing international institutions and establishing new ones. The need for exploration and extraction of unconventional oil and natural gas resources may have similar consequences.

The technological and financial needs of developing countries and transitional economies, especially the former with their rapidly rising populations and energy demands, are likely to promote the creation of international institutions geared to facilitating financial and technology transfers and cooperation. Similarly, the likely shift in the world's geopolitical balance from North to South can be anticipated to require the reinforcement of existing institutions (notably the UN and its agencies) or the creation of new institutions if the former are regarded as not up to their tasks.

International disputes over trade in fossil fuels and over water resources (for hydro schemes) could also become more frequent and promote the creation of international institutions for mediation purposes.

Regional and global environmental concerns are also likely to encourage the expansion or creation of relevant institutions. The UN Framework Convention on Climate Change and the series of Conferences of the Parties which have been instituted, as well as the Montreal Protocol and subsequent agreements on ozone depleting substances are a likely precursor of such arrangements. This Report assumes that if ecologically driven scenarios are to be achieved then an unprecedented level of international cooperation and agreement will be required focussed on environmental protection and enhancing international equity. This is more likely to come about as a result of strategic perception and power than of romantic ideals and the striking of attitudes.

At the national level deregulation and privatisation are likely to proliferate, creating the need for new framework institutions to guide competition and pricing. Growing concerns with energy efficiency and environmental impacts of energy provision and use are likely to have similar consequences. There will need to be a careful balancing between the benefits of creating regulatory frameworks and the costs of bureaucratic intervention, where economic instruments are frequently better suited to the task in hand. With the increased attention paid to services, and consumer-orientation, the need for detailed regulation will become less obvious as the capacity for consumers to vote with their purses increases.

2.4.6 The Coming Shift in the World's Geopolitical Balance

Population growth, energy demand growth, and elements of catch-up in economic welfare and technology all point to major shifts in the world's geopolitical balance. For the key demographic and energy parameters it is clear that future growth will be concentrated in the current developing countries.

This suggests that a major shift will occur in the world's geopolitical balance in favour of the developing world of "the South". This is likely to strengthen the South's ability to obtain and retain both internationally traded energy forms and access to technology. This anticipated shift in the geopolitical balance could find expression in many different ways. By 2050, if not long before, major countries now described as developing will no longer be so. They may also be moved to protect their own energy interests internationally, rather than relying upon the corporate, diplomatic or military strength of others to do so.

In some of this study's scenarios per capita GDP by 2040 in the Pacific Asia region (even with the Pacific OECD member countries excluded) will have risen to the level reached in Western Europe in the early 1970s. For this and other reasons, within 50 years the distinction between developed and developing countries will have disappeared in many instances, and the power of collective consumption of energy may well have passed from the OECD countries to others.

2.4.7 Options for Policy: What and When

This study on "Global Energy Perspectives to 2050 and Beyond" developed six scenarios covering a wide range of future possibilities and yet there is little divergence between them up to the year 2020. Existing investments and patterns of activity, and long lead-times in developing alternative means of providing and using energy, are the essential reasons for this apparent commonality.

Time is required for capital stock turnover and fundamental changes in the energy system. New energy resources and technologies have to be brought into being and widely diffused. New energy-using devices have to brought into use – power plants, motor vehicles, industrial processes, space heating and cooling systems, and lighting systems are of particular importance here. There is the likelihood of a shift towards a total systems approach from the traditional energy sector orientation, which becomes service-driven and consumer-oriented. There will be a need for new institutional capabilities – for financing, for facilitating technology innovation and diffusion, for new forms of cooperation and agreements, for new and more effective frameworks to achieve change.

However, this study's six scenarios also demonstrated increasing divergence post-2020, especially on the energy supply side. That longer term divergence, however, is critically dependent upon research conducted, decisions made and investments started long before 2020. Infrastructural investments, production investments, and electricity generating plants are anticipated to have life-times of decades. The main potential energy development paths are mutually exclusive to a large degree. Unless the appropriate decisions are taken within the next 25 years, there will be foreclosure on some of the key post-2020 options. This is possibly the key factor which has emerged from this study to date, and creates a considerable onus on governments to understand and react to this situation.

Among the appropriate decisions for a more sustainable future are increased and effective expenditure on research, development and demonstration of new renewable energy technologies and energy-using devices generally. Fossil fuel conversion and use should be made cleaner to support further deployment. Nuclear power provision needs to attract more widespread public confidence and support. Policies which promote energy efficiency, and encourage conservation on a cost-effective basis, and which price energy to cover costs in their broadest sense, must be planned and instituted rapidly.

Perhaps above all, in those developing and rapidly industrialising countries where the future growth in energy demand will mostly take place, it is desirable that adequate and sustainable energy policies and investments are instituted without delay. Simultaneously, the advanced industrial countries should re-examine their high levels of energy consumption, and through efficiency improvement and conservation efforts reduce them. In the economies in transition, a major overhaul of existing capital stock, appliances, metering and pricing systems will be required. In some of the latter countries gas and oil export availability should improve and, although market systems appear slow to develop, they will ultimately do so.

These options offer exciting prospects and business opportunities to those that seize them, whether in the traditional commercial fuels or in the new energy forms that will become increasingly available. They will also offer both challenges and opportunities in energy markets that are increasingly service-driven and consumer-oriented.

The single most important conclusion is that given the expected divergence of development paths post-2020, and the foreclosure of potentially desirable options unless relevant policies are initiated and decisions taken long before then, action needs to start now.

TECHNICAL ANNEX

The full WEC/IIASA "Global Energy Perspectives to 2050 and Beyond" Report is 100-pages in length, contains many colour graphics, and is organized into seven chapters. Chapter 1, the introduction, briefly presents the structure of the study, and its scenario-based approach. Chapter 2 lays out the six scenarios developed, and, in particular, how they were put together purposely to cover a broad range of possible futures.

All six scenarios start from the base year 1990 and the historical trends leading up to that year. Chapter 3 presents the basic interpretation of past data that underlies the extensions of historical tendencies into alternative future perspectives. It also summarizes key developments that have taken place since the base year, 1990.

Chapter 4 looks at the determinants of future energy use, and describes how they vary across the six scenarios, and Chapter 5 presents, using many illustrations, the essential quantitative characteristics of all six scenarios. It describes how they differ in their primary energy structures, resource use, and electricity sectors, and how similar they are in their final energy structures.

Chapter 6 turns to implications on a number of fronts: investments and financing, international trade, the constraints and opportunities facing different energy industries – coal, oil, gas, renewables, and nuclear – and environmental impacts, at the local, regional, and global level. Chapter 7 presents the conclusions.

The six scenarios developed were clustered around:

- A – High Economic Growth (Scenarios A1, A2 and A3).
- B – Middle Course (Scenario B).
- C – Ecologically Driven (Scenarios C1 and C2).

The internal consistency of the scenarios has been tested by the use of formal IIASA models.

There is a close and intentional link between A, B and C and the three Cases of the WEC Commission: "Energy for Tomorrow's World", 1993. The Commission's Cases were: A (High Growth); B (Reference – with B_1 as a Modified Reference Case to 2020); and C (Ecologically Driven). This study's scenarios can be broadly described as follows:

The High Economic Growth framework for the three A scenarios is characterized by enormous productivity increases and wealth. It is technology and resources intensive and presumes favourable geopolitics and free markets. High growth facilitates a more rapid turnover of capital stock and changes in economic structure, both of which spur efficiency improvements and technological progress. If A is extended all the way to 2100, global average per capita income surpasses even the highest levels observed today and current distinctions between "developed" and "developing" regions become obsolete.

A includes three scenarios addressing alternative key developments in energy supply. In the A1 scenario, there is ample future availability of oil and gas resources. At the other end of the spectrum, the A2 scenario assumes oil and gas resources fail to be recovered in sufficient quantities for technical, economic and political reasons – resulting in a massive return to coal. Finally, in the A3 scenario rapid technological change in nuclear and renewable energy technologies results in a phaseout of fossil fuels for economic reasons rather than due to resource scarcity. This unfolding into three different development trajectories results in three scenarios with almost identical energy end-use patterns but different energy system structures.

The single Middle Course scenario B is based on a more cautious approach regarding economic growth prospects, rates of technological change, and energy availability. In short, the scenario is perhaps best characterized by "muddling through" and derives its appeal primarily because it is "pragmatic". Overall, this scenario is "reachable" without relying on drastic changes in current institutions, technologies, or current perception of availability of fossil fuel resources.

The more modest energy use compared with the A scenarios implies that scenario B can rely on fossil fuel resources to an extent that is commensurate with current estimates of ultimately recoverable oil and gas reserves. Energy supply and end-use patterns are also closer to the current situation for a longer period in B than in A and C.

Beyond 2020, however, the depletion of fossil resources without counterbalancing technological progress will force more dramatic changes in energy supply structures. Nonetheless, a transition away from fossil fuel use is feasible and manageable. In the very long-term, the changes become much more dramatic, and an orderly transition away from fossil fuel use is not only feasible but appears to be manageable in terms of energy sector and institutional adjustments extending towards the end of the 21st century.

The Ecologically Driven framework for the two C scenarios presents challenging global perspectives. It is optimistic about technology and geopolitics, but it also assumes unprecedented international cooperation focused explicitly on environmental protection and international equity. It builds on substantial resource transfers from North to South, spurring growth in the South that will lead to a significant reduction in present economic disparities. In addition to stringent control of local and regional pollutants, a global regime to control the emissions of greenhouse gases is established. The goal is to reduce CO_2 emission levels to 2GtC by 2100, (corresponding to one-third of 1990 levels required to stabilize atmospheric concentrations). Ambitious policy measures accelerate energy efficiency improvements and develop and promote environmentally benign, decentralized energy technologies. One policy option considered for achieving this goal is a carbon tax that gradually increases to US$400 per tC in 2100.

The C1 and C2 scenarios describe a transition away from the current dominance of fossil fuels towards a dominance of renewable energy flows. The quality of the energy carriers delivered to end users is high in order to meet the environmental constraints so that renewable energy sources are transformed into electricity, liquid, and gaseous energy carriers. Nuclear energy is at a crossroads and this constitutes the main difference between scenarios C1 and C2.

Table A I provides the main features of the scenarios.

Table A I
A Summary of the Scenarios in 2050 and 2100

	A	B	C
Population in 10^9			
in 2050	10.1	10.1	10.1
in 2100	11.7	11.7	11.7
GWP in 10^{12}\$			
in 2050	100	75	75
in 2100	300	200	220
Energy Productivity Growth	medium	low	high
PE/GDP, %/yr			
World (1990–2050)	-1.0	-0.7	-1.4
World (1990–2100)	-1.0	-0.8	-1.5
Primary Energy Demand, Gtoe			
in 2050	25	20	14
in 2100	45	35	21
Recoverable Resources			
fossil	high	medium	low
non-fossil	high	medium	high
Technology Costs			
fossil	low	medium	high
non-fossil	low	medium	low
Technology Dynamics			
fossil	high	medium	medium
non-fossil	high	medium	high
CO_2 Targets	no	no	yes
Carbon Emission, GtC			
in 2050	9–15	10	5
in 2100	7–22	14	2
Environmental Taxes	no	no	yes

Table A II sets out the main world economic and energy characteristics of the six scenarios in 1990, 2020 and 2050.

Table A II
World

	199	2020						2050					
		A1	A2	A3	B	C1	C2	A1	A2	A3	B	C1	C2
Population, billion	5.3	7.9	7.9	7.9	7.9	7.9	7.9	10.1	10.1	10.1	10.1	10.1	10.1
GDP_{ppp}, US(1990)$,	25.7	60.6	60.6	60.6	53.0	54.1	54.1	121.3	121.3	121.3	92.9	95.9	95.9
GDP_{mer}, US(1990)$,	20.9	46.9	46.9	46.9	40.2	40.5	40.5	101.5	101.5	101.5	72.8	75.0	75.0
Agriculture	1.4	3.2	3.2	3.2	2.9	3.0	3.0	5.3	5.3	5.3	4.5	4.8	4.8
Industry	7.0	16.5	16.5	16.5	14.2	15.0	15.0	34.6	34.6	34.6	25.3	28.2	28.2
Services	12.5	27.3	27.3	27.3	23.2	22.4	22.4	61.7	61.7	61.7	42.9	42.0	42.0
Final energy, Gtoe	6.4	11.4	11.4	11.3	10.1	8.5	8.5	17.0	17.5	17.2	14.2	10.0	9.9
Solids	1.9	2.6	2.8	2.7	2.6	2.4	2.4	2.7	3.3	3.1	3.2	2.0	2.0
Liquids	2.5	4.4	4.3	4.1	3.5	2.8	2.8	7.2	6.3	5.6	4.7	3.4	3.4
Electricity	0.8	1.6	1.7	1.7	1.4	1.2	1.2	2.9	3.1	3.0	2.3	1.8	1.7
Other[a]	1.2	2.7	2.6	2.8	2.5	2.2	2.2	4.3	4.7	5.4	3.9	2.9	2.8
Primary energy, Gtoe	9.0	15.4	15.4	15.4	13.6	11.4	11.4	24.8	24.8	24.6	19.8	14.2	14.2
Coal	2.2	3.7	4.3	2.9	3.4	2.3	2.3	3.8	7.8	2.2	4.1	1.5	1.5
Oil	3.1	4.7	4.5	4.3	3.8	3.0	3.0	7.9	4.8	4.3	4.0	2.7	2.6
Gas	1.7	3.6	3.4	3.8	3.2	3.1	3.0	4.7	5.5	7.9	4.5	3.9	3.3
Nuclear	0.5	0.9	0.6	1.0	0.9	0.7	0.8	2.9	1.1	2.8	2.7	0.5	1.8
Renewables	1.6	2.5	2.6	3.3	2.3	2.4	2.3	5.5	5.7	7.3	4.4	5.6	5.0
Carbon emissions,	6.0	9.5	10.0	8.2	8.4	6.3	6.3	11.7	15.1	9.2	10.0	5.4	5.0

Note: Subtotals may not add up due to independent rounding.
[a] District heat, gas, and hydrogen.
[b] For 2020 and 2050, emissions exclude non-energy uses (feedstocks).

Table A III gives the energy resource estimates which underpin the study.

Table A III
Estimates of Energy Reserves, Resources and Occurrences
Global Fossil and Nuclear Energy Reserves, Resources, and Occurrences in Gtoe

	Consumption				Resource	Additional
	1850–1990	1990	Reserves	Resources	Base	Occurrences
Oil						
Conventional	90	3.2	150	145	295	
Unconventional	–	–	193	332	525	1,900
Natural Gas						
Conventional	41	1.7	141	279	420	
Unconventional	–	–	192	258	450	400
Hydrates	–	–	–	–	–	18,700
Coal	125	2.2	606	2,794	3,400	3,000
Total	256	7.0	1,282	3,812	5,090	24,000
Uranium	17	0.5	57	203	260	150
in FBRs	–	–	3,390	12,150	15,550	8,900

The study used significantly different energy intensity assumptions from those adopted in the WEC Commission Report: "Energy for Tomorrow's World", 1993.

Table A IV provides the differences.

Table A IV
Energy Intensity Improvements Assumed (% per Annum)

	A	B	C	B1 - C[a]
	1990–2050	1990–2050	1990–2050	1990–2050
OECD	1.2	1.1	2.0	1.9–2.8[a]
REFs[b]	2.1	1.7	2.2	1.2–2.7[a]
DCs	1.6	1.2	1.9	0.8–2.1[a]
World	1.0	0.8	1.4	1.3–2.4[a]

[a] Range of WEC Commission's Report on *Energy for Tomorrow's World*. Improvement rates not directly comparable as based on PPP. It should be emphasized that the WEC Commission specifically rejected adoption of any "business-as-usual" cases, and noted that in recent years groups of industrialized countries have achieved overall energy intensity reductions exceeding 1.5 percent per year (e.g., the European Union since 1974) and exceeding 2.5 percent per year if road transportation were excluded. But what can be achieved by a few countries over a relatively short period, and what can be achieved by many over a long period, may be two very different things.
[b] CIS Republics, Central & Eastern Europe, with economies in transition.

The present study has reviewed the cumulative energy supply investments of the various scenarios. Table A V provides the results.

Table A V
Cumulative Investments in Energy Supply by Region 1990–2020 and 2020–2050

	A		B		C	
Energy Investments	**1990–2020**	**2020–2050**	**1990–2020**	**2020–2050**	**1990–2020**	**2020–2050**
Cumulative in Trillion US$ (1990)						
OECD	8	10	7	10	5	4
REFs[a]	3	6	2	5	2	3
DCs	9	18	7	15	6	11
World	20	34	16	30	13	18
As Share of GDP (in percent)						
OECD	1.1	0.8	1.1	0.9	0.7	0.4
REFs	9.0	4.3	7.9	5.9	7.0	3.9
DCs	3.7	2.3	3.6	2.8	2.9	1.8
World	1.9	1.6	1.8	1.7	1.5	1.1
Per Unit of Primary Energy US$ (1990)/toe						
OECD	50	49	51	60	46	42
REFS	56	53	67	74	54	63
DCs	44	49	40	51	42	48
World	48	49	48	56	45	49

[a] CIS Republics, Central & Eastern Europe, with economies in transition.

The study produces data on various emissions including those of greenhouse gases. Table A VI provides a comparison of cumulative carbon emissions from fossil fuel use under various scenarios. It should be noted that the present study was a climate model updated since it was used for the WEC Commission report, the result of which would be to reduce somewhat the WEC Commission figures quoted here.

Table A VI
Cumulative Emissions 1990–2100 (GtC): IPCC[a] and WEC Scenarios Compared*

IPCC/IS92 emissions scenarios		
IS92 a (a "medium" case)		1,500
IS92 b (more environmental compliance)		1,430
IS92 e (faster economic growth)		2,190
WEC Cases: "Energy for Tomorrow's World, 1993		
High Growth	A	1,425
Reference	B	1,130
Ecologically Driven	C	625
WEC/IIASA 1995 Scenarios "Global Energy Perspectives to 2050 and Beyond"		
High Growth	A2	1,720
High Growth	A1	1,350
High Growth	A3	980
Middle Course	B	1,190
Ecologically Driven	C1	590
Ecologically Driven	C2	580

* On comparable world population assumption (UN medium projection)
[a] Intergovernmental Panel on Climate Change

Readers are recommended to the full report for much further detail and an academic treatment of the various issues covered.