Drivers of the Energy Scene

A Report of the World Energy Council

December 2003

Drivers of the Energy Scene

Published December 2003 by:
World Energy Council
5th Floor, Regency House
1-4 Warwick Street
London W1B 5LT
United Kingdom
www.worldenergy.org

ISBN 0 946121 10 9

ACKNOWLEDGEMENTS

The World Energy Council (WEC) has been involved in a number of global energy studies, in particular, *Energy for Tomorrow's World* (ETW) in 1993, the IIASA/WEC *Global Energy Perspectives* in 1998, its Millennium Statement, *Energy for Tomorrow's World—Acting Now!* (ETWAN) and the WEC/UNDP/UNDESA *World Energy Assessment* in late 2000. At the World Energy Congress in Buenos Aires in 2001, WEC also published a book on sustainable energy development for the general public, entitled *Living in One World*. All of these publications implicitly incorporated hypotheses on 'drivers', such as future economic growth, demography, energy efficiency, environmental concerns and energy policies. However, these studies were forward-looking and did not try to determine whether the impacts of the 'drivers' in the future would be consistent with past and present developments in the market for energy services.

The purpose of *Drivers of the Energy Scene* is to stimulate a reflection on how the energy system has worked in practice, what the dynamics of the energy markets have been and how energy availability has impacted on GDP growth and accessibility, either positively or negatively. The report does not propose another energy 'model' or different projections about the future but examines the challenges the energy scene faces today and what the most important economic, social, environmental or technological feedbacks are.

Understanding these dynamics is an ambitious task for which WEC, the only global multi-energy organisation with 97 Member Committees in both developing and developed countries, is especially well equipped. Thanks to its broad network, WEC decided to address *Drivers* in a present day market context and gathered a study group of renowned experts from a wide array of countries, organisations and energy services.

WEC is grateful to Dr Majid Al-Moneef, Advisor to the Minister, Ministry of Petroleum and Mineral Resources of Saudi Arabia, who has chaired this study, successfully engaging the Study Group members and other stakeholders in a fruitful debate. WEC also thanks the members of the Study Group and the invited experts (see Annex A) who helped broaden the scope of the initial position papers. Finally, WEC also thanks its Member Committees for bringing insights to the *Drivers* regional meetings and to a special symposium on the subject at the 2002 Executive Assembly in Cairo.

Jean-Marie Bourdaire, WEC's Director of Studies, took on the onerous task of Project Leader for the study. His varied background in energy economics and policy and his wide range of contacts have served the study well. WEC is indebted to him for preparing the background papers for the study and drafting the report.

Officers of the World Energy Council

Antonio del Rosario
Chair World Energy Council

Philip Aiken
Vice Chair Sydney 2004

François Ailleret
Chair Studies Committee

Asger Bundgaard-Jensen
Vice Chair Finance

John Derrick
Vice Chair North America

Alioune Fall
Vice Chair GEIS Initiative

Norberto de Franco Medeiros
Chair Programme Committee

Shige-etsu Miyahara
Vice Chair Asia

Kieran O'Brien
Vice Chair Europe

Fred Phaswana
Vice Chair Africa

Carlos Pierro
Vice Chair Latin America/Caribbean

Gerald Doucet
Secretary General

Member Committees of the World Energy Council

Algeria
Angola
Argentina
Australia
Austria
Bangladesh
Belarus
Belgium
Bolivia
Botswana
Brazil
Bulgaria
Cameroon
Canada
China (PR)
Congo (Dem. Rep.)
Côte d'Ivoire
Croatia
Czech Republic
Denmark
Ecuador
Egypt (Arab Rep)
El Salvador
Estonia
Ethiopia
Finland
France
Gabon
Georgia
Germany
Ghana
Greece
Hong Kong, China
Hungary
Iceland
India
Indonesia
Iran (Islamic Rep.)
Ireland
Israel
Italy
Japan
Jordan
Kenya
Korea (Rep.)
Latvia
Lebanon
Libya/GSPLAJ
Lithuania
Luxembourg
Macedonia (Rep)
Mali
Mexico
Monaco
Mongolia
Morocco
Namibia
Nepal
Netherlands
New Zealand
Niger
Nigeria
Norway
Pakistan
Paraguay
Peru
Philippines
Poland
Portugal
Romania
Russian Federation
Saudi Arabia
Senegal
Serbia & Montenegro
Singapore
Slovakia
Slovenia
South Africa
Spain
Sri Lanka
Swaziland
Sweden
Switzerland
Syria (Arab Rep.)
Taiwan, China
Tanzania
Thailand
Trinidad & Tobago
Tunisia
Turkey
Ukraine
United Kingdom
United States
Uruguay
Venezuela
Yemen

TABLE OF CONTENTS

ANNEXES:

EXECUTIVE SUMMARY

A. WHY STUDY ENERGY DRIVERS?

Drivers of the Energy Scene is the first report of the World Energy Council (WEC) Work Programme for 2002-2004. Its purpose is to stimulate reflection on how the energy system has worked in practice, what the dynamics of the energy markets have been and how the well established WEC goals of energy accessibility, availability and acceptability have impacted on GDP growth and vice versa.

The report takes a different approach from previous WEC work in this area because it does not propose another energy 'model' or different projections about the future in a multi-energy context. Rather, it focuses on past GDP and energy trajectories, examines the challenges the energy scene faces today and addresses the most important economic, social, environmental or technological feedbacks.

The report concentrates on oil and natural gas markets because of their importance in energy supply and pricing as a whole. It provides a context for separate work by the World Energy Council on coal, district heating, renewables, energy market reforms, end-use technologies, climate change and life cycle analysis which will be published at the time of the 19th World Energy Congress in Sydney, Australia, in September, 2004.

B. ENERGY DRIVERS AND GOALS

Modern industrial societies have three energy-related features that, to a large extent, define the global economy and the prosperity of individual countries: the role of energy in economic development, the evolution of the demand for increasingly sophisticated and acceptable energy services and the availability of primary energy in terms of both quantity and quality.

In this report, these features have been studied under three groups of drivers: the first is the *GDP Driver*, which describes the demographic, institutional and technology feedbacks on GDP growth; the second is the *Energy Demand Driver*, which covers the nature and evolution of energy consumption in the distinct services of heating, mobility and electricity and how they impact the environment; the third is the *Energy Supply Driver,* which deals with the availability and cost of energy and their feedbacks on the prospects for economic growth and energy demand.

It is not a matter of coincidence that these three sets of energy drivers play a key role in achieving the WEC mission of sustainable energy development for the greatest benefit of all:

- Past trends reveal that *energy accessibility* is central to economic development, a process that was established at the beginning of the Industrial Revolution but seems to have stopped or slowed down for many developing countries in the last 30 years;
- Past trends also reveal that *energy acceptability* is central to energy demand. Demand evolves towards cleaner and more sophisticated energy uses, thus driving the evolution of the primary supply towards cleaner and more versatile fuels; and,

- Past trends also show that modern *energy availability* is the key for the first two drivers, because sustained energy supply shocks or crises hamper economic development and force societies to adapt to a more costly energy environment.

From the beginning of the Industrial Revolution (roughly the mid-19th century) to 1973, the energy trajectory of the world, including both commercial and traditional energies, was accelerating:

- In the first part of this timeframe up to the end of World War II, energy demand accelerated slowly because of a combination of external events (for example, the severe economic crisis after 1929 and the two World Wars) and the domination of coal, an abundant but not versatile energy supply;
- In the 'golden' 1950s and 1960s up to 1973, world economic growth and energy demand accelerated at the rapid rate of about 5% per annum. Among the several reasons that contributed to this exceptional growth period were the absence of prolonged political or economic crises in major markets and the availability of oil – cheap, abundant and versatile because it is liquid – which played an increasingly essential role.

Since 1974, there has been a distinct change of perspective. Global energy growth began to slow-down gradually because of the combined impact of lower global economic growth and a decoupling between world GDP growth and primary energy demand. Doubts about the reported GDP growth in the USA, China and FSU and the energy intensity of GDP are discussed in the report because they could play a key role in building forecasts that might be derived in follow-up work to *Drivers of the Energy Scene*.

Beyond 2003, growth in total primary energy requirements in terms of tonnes of oil equivalent could continue to decelerate or accelerate. Most scenarios suggest acceleration, with energy acceptability (i.e., the environment and GHG emissions, especially in the developing countries where demand growth is expected to be very high) continuing to be the binding constraint on energy systems. Yet market factors and some key feedbacks suggest that, because of the binding constraints of energy availability and accessibility as well as higher real energy prices, deceleration in primary energy requirements is possible (with GHG concentrations which may never reach 550 parts per million). *Drivers of the Energy Scene* sheds light on which of these directions in energy demand is the more likely basis for business and government partnerships on sustainable energy development in the years to come.

The report highlights a number of feedbacks for each of the three drivers identified above, but some seem particularly important:

- For the *GDP Driver*, national institutional capacity (i.e. whether a country can tap cheap domestic or foreign capital and incorporate new technologies quickly);
- For the *Energy Demand Driver*, the final prices that combine the cost of primary energy (the fixed costs to make it a usable service), the variable transmission and other downstream costs and the taxes or shadow costs resulting from government policy or regulation; and,
- For the *Energy Supply Driver*, the costs of primary fuels and their delivery to where they are needed.

These drivers are not independent. There is no doubt that improved institutional capacity will foster economic growth, but it cannot prevent an economic crisis if energy prices skyrocket. New technology can result in the improved efficiency of energy services or an increased range of supply options, but it may be expensive and require the costly replacement of capital stock.

In a similar way, new energy sources may be tapped, but the full costs may be much greater than existing cheaper and abundant fuels. Last but not least, individual or collective behaviour plays a considerable role, for example, in favouring energy-intensive uses such as sport utility vehicles or in opposing the development of certain energy sources in favour of others (such as the perception of nuclear power in some regions of the world versus renewables).

C. THE 'GDP DRIVER'

The GDP driver has three key components: demographic trends, institutional capacity and technology. These components relate to energy through primary energy supply, final prices for energy services and the quality and versatility of energy systems.

In the period from 1850 to 1948, when average global GDP growth was about 1.7% per annum, the steady growth of world population from about one billion to 2.5 billion people allowed for slow but balanced growth. Institutions in several countries, particularly in Europe and North America, began to move toward democracy, with reliable property rights and banking systems, while electrification for motors and illumination spread quickly. Technology development was strong, with the steam engine, railways and cars coming to the fore, to name only a few that have had major energy implications. Primary energy was cheap, abundant and based on coal, but the versatility and quality of energy systems suffered from this dependence and from local and regional coal emissions.

In the period from 1949 to 1973, a young and rapidly growing population reached four billion people. This, and deepening property rights and savings, coupled with broader technological progress for mobility and electricity use (for example, aircraft and appliances), drove GDP to an exceptional world average of 5% per annum. The primary energy supply expanded rapidly, and dependence on oil increased dramatically thanks to its low and stable price. Because oil is more versatile than coal, it fostered a huge expansion of all types of energy-related services. At the same time, in the USA which had become a net oil importer from the end of World War II, the gap between domestic oil supply and demand grew quickly especially after 1970, when domestic USA oil production reached its peak and started to decline. This led to a growing reliance on the excess oil capacities in Middle East countries. The oil shock of 1973 was the end of the cheap energy era and a signal to energy suppliers to find new sources of oil or other competitive forms of energy to meet demand.

Since 1973, because of the now large share of oil in the global energy mix (as well as natural gas, which was linked to oil in terms of pricing), each sustained oil price hike has been associated with lower global GDP growth and a decline in energy intensity during the two following years. Oil became the energy at the margin, replacing coal, and it is the direct and indirect price-setter for all energy services today.

Many macroeconomic parameters also changed during the last quarter of the 20th century:

- Population increased from four to more than six billion people, and the pace of ageing and urbanisation accelerated, but the rate of overall demographic growth began to slacken, signalling the beginning of a transition;
- With a decline of global GDP growth to about 3% per annum, serious regional economic crises led to slower progress in terms of institutional or market reforms in both developed and developing countries;

- New technology, in the form of better or new equipment in response to energy prices, has resulted in a lower level of energy consumption per unit of GDP;
- Progress in providing commercial energy access flattened out, and the reliance on traditional biomass has remained a fairly constant 11% of total primary energies; and,
- The primary focus of energy policymakers shifted from energy availability concerns to those of energy acceptability and the environment.

By the end of the 20th century, further big developments in oil and gas markets generated additional feedbacks which need to be taken into account. If one excludes the growth of new oil production brought by new exploration and production technology (such as deep-water, Caspian oil and the accelerated depletion of Russian fields), oil production outside the Middle East started to decline at the end of the 1990s. It appears that natural gas production in North America has now also peaked, and this could soon be the case in Western Europe as well.

In the first years of the 21st century, with OPEC trying to balance producer and consumer interests, oil prices have moved up to and been stabilised in a range around US$25/b, which could bring on additional natural gas supplies in the form of LNG, but at a much higher price, thereby moving natural gas to a mid/peak load role in the energy mix. There are also signs that the environmental focus of the last years of the 20th century has given way to a renewed focus on energy availability everywhere and energy accessibility for the world's poor, albeit in a framework of potentially higher real energy prices which could have positive feedbacks on efficiency and environmental goals.

GDP growth does not depend solely on the behaviour of individual stakeholders – they will always draw the best from their business/institutional environment. Nor is it beholden solely to the unpredictable vagaries of Mother Nature, with temporary energy imbalances which could affect GDP growth negatively. In our complex societies, it also depends on governments. Unless they have the courage to push the broad agenda of institutional reforms, ranging from reliable banking systems and secure property rights in the poorest countries to the management of pensions, education, health and infrastructures in the rich economies, the benefits of technology and entrepreneurship will not spread to everyone.

The report's analysis of problems with GDP methodologies, particularly in the USA, China and FSU, along with demographic trends, the potential for higher real energy prices and the failure to adequately address institutional barriers to energy access problems in developing countries, has led to the conclusion that annual world GDP growth could be somewhat lower than 2% over the next few years. The report does not predict this but argues that, if this were so, the downward impact on total primary energy supply and requirements could be significant. However, it is necessary to look at other drivers of the energy scene to determine if there might be offsetting feedbacks which ought to be taken into account.

D. THE 'ENERGY DEMAND DRIVER'

Energy demand is made up of services for electricity, mobility and stationary fossil fuels. These services have followed different trends, both in terms of relative growth and in sensitivity to energy prices, with the biggest changes happening since 1974.

The Study Group found that electricity consumption has a regular growth trend compared with GDP in purchasing power parity; it is nearly linear, with no apparent impact from the energy events that happened during the period of the oil shocks. This is because the electricity market is 'captive', with very little room for users to switch back to fossil fuels directly, but it also results from real final electricity prices remaining nearly unchanged over a long period of time.

In the case of mobility, the trend has been nearly as steady as that of electricity. Mobility is the 'captive' sector of oil. Real final gasoline prices have remained steady in most regions with the exception of North America because high fixed costs (such as transportation and refining) as well as taxes (which account for up to 80% of the final price) have cushioned any impact of oil price increases.

The trend in stationary fossil fuel end-uses (such as heating and cooking in buildings and industrial processes) is quite different from those for electricity or mobility; each oil shock has led to a drop in this energy service, with the result that stationary end-use today is declining in developed countries but stable for the world as a whole. This is due in part to improvements in energy efficiency in transformation and industrial processes. The 'de-location' of major energy-using industries, such as steel, from developed to developing countries is also a significant factor in explaining the decline in stationary fossil fuel end-use in developed countries.

When it comes to electricity and stationary fossil fuel end-uses, the study notes that different fuels may be considered, e.g., the development of nuclear power and the 'return' of coal for power generation or the substitution of other petroleum products by natural gas for heating and for power generation, in the latter case often for environmental reasons. Mobility, on the other hand (excluding electric trains), is rigidly linked to the oil sector itself and accounts for well over 60% of total oil use. The report identifies synthetic liquid fuels and hybrid vehicles (or in the more distant future, electric or hydrogen-powered vehicles) as potential competitors for oil in the years to come.

These contrasting trends reflect the role of final prices and GDP in driving the demand for energy services. People seek ways to reduce energy consumption when prices increase and are sustained at a new level, but if GDP is growing and people feel their wellbeing has improved, they also find new uses for energy services, which results in higher consumption. Thus energy efficiency can play different but complementary roles, both of which are tied to technology: to reduce energy consumption when prices rise through the use of new materials or equipment, or to increase the value of a given level of energy service when energy prices remain unchanged. Energy efficiency and technology are two sides of the same coin, but final prices and GDP are the binding agents, assuming of course that people have access to energy services and to affordable new technologies in the first place (which is decidedly not the case in many developing countries).

The growth of demand for mobility and electricity is at an early stage in most developing countries and will strongly increase in the coming decades. Improvement in energy access -- the provision of modern energy services to the world's two billion poor people -- will have a relatively small impact on global energy demand but could contribute to a better-than-expected average rate of growth for world GDP, thereby multiplying the impact on primary energy requirements.

Many factors, such as market reform, technological breakthroughs, environmental constraints and other policies, will have an important influence on primary energy pricing and on the cost of final energy services to consumers. Energy market reforms should introduce a mix of competition to increase efficiency and trade, with clear, stable rules to maintain the high standards of fair pricing, reliability and quality of service. If they do not, they will have a negative feedback on energy demand growth in the future. WEC is completing a study on infrastructure, capacity and pricing reforms which addresses this subject for the Sydney World Energy Congress in September, 2004.

However, technology is by far the most important factor because it has a direct impact on energy supply or consumption, either to lower the cost of providing a given level of energy services or to help adjust the use of energy services in response to energy price changes, whatever their origin. Energy prices are therefore a fundamental driver of new technologies. For this reason, WEC is also preparing a report on important end-use technologies for the 21st century which will complement its earlier work on generation technologies. In this respect, WEC must better define what price triggers will be needed to foster the extensive use of new technologies across the spectrum of energy supply and utilisation.

The constancy of energy service trends over time in a context of stable final prices confirms that consumers behave rationally, with their aggregate behaviour closely tracking final prices. In particular, energy efficiency policies which do not affect final energy prices have had little sustainable impact on actual energy consumption trends but increase the welfare brought by this energy consumption.

E. THE 'ENERGY SUPPLY DRIVER'

The uncertainties in energy markets, particularly with respect to moving plentiful supplies to where they are needed, coupled with the long lead times for new investments in exploration and production to meet new demand, reinforce the view that market forces shape the future with ups and downs that reflect the dynamic dimension of the supply-demand equation. These spontaneous dynamics can be quite violent because most energy supplies (in particular, but not exclusively, oil and gas) have short-run marginal costs much lower than long-term marginal costs. Hence, as for competitive electricity markets, if market forces were the sole driver, prices would be very low as long as excess capacities exist but very high when they have been eliminated, until new investments in capacity come on-stream. It is the new investments in response to higher prices in times of sustained shortages that shift the ranking of primary energies.

Oil and gas supply dynamics explain why their price was very volatile when there was no dominant actor controlling or managing the market. As long as oil and natural gas – which is priced in lock step with oil – had a small share of the world energy supply and the energy market was dominated by coal with its more stable price (mostly driven by labour costs), the oil/gas price volatility had little global, macroeconomic impact. This situation changed during the 1950s and 1960s because of the rapid growth of oil and gas shares in the global energy mix but remained unnoticed because, up to 1959, the oil price was under the control of the major oil companies and the Texas Railroad Commission before passing under the control of OPEC and the 'majors' after 1960.

The control of the majors was certainly one factor explaining the stability of oil prices prior to 1973, but it is not the only one. The industry was vertically integrated and controlled by a few majors (the 'seven sisters'), who in 1928 had agreed to share the prolific Middle East fields under the 'Red Line' agreement as well as the growth in downstream markets; it was the ideal instrument to manage the smooth growth of the oil market. With the nationalisations of the 1970s and the different strategies adopted by major consuming countries, this control disappeared, leaving OPEC alone to manage a market that had become unpredictable because of the new swing role of oil and because of the growing dominance of spot transactions.

The new energy story that developed after 1973 has, therefore, very little to do with the former dynamics.

The oil price today is managed by OPEC as long as capacity margins exist in order to match demand and supply: if the price of oil is too high, this leads to lower GDP, economic recession and a shrinkage in demand for oil coupled with the development of alternatives, mostly affecting OPEC countries that are the swing producers of the swing energy; if the price is too low, as in the early 1970s, the capacity margins for producers disappear, and they tend to withhold marginal supplies and/or reduce exploration for new supplies, eventually leading to a price rise, lower GDP and ultimately, lower demand than before. Hence, what is important is the production capacity (called the 'tap') and not, except in the very long run, the ultimate reserves (often called the 'tank'). It is for this reason that this report does not dwell on the debate about what the resource base might be for the three fossil fuels, nuclear or even renewables. As the report shows, the growth and decline of specific primary energies over time has never resulted in the complete exhaustion of their reserves, because with the right price signals and international collaboration, new more competitive sources of energy emerge in time to take their place.

If cheap and versatile energy supplies were the main source of past productivity gains and higher economic growth at the world level, what are the prospects for the future? There are capacity constraints in non-OPEC oil supplies and even within OPEC itself. No one can predict when Iraq oil will actually return to pre-war levels or move on to its full potential of 4 or 5 Mb/d; no one knows how much and how fast the production of the Middle East fields, which on average are more than 50 years old, will decline, and the role of Russian oil and gas in global markets is changing dramatically too, to name just three areas of big unpredictable supply developments.

Other constraints that may impede the development of energy supply in timely fashion to meet demand are many:

- Additional costs that will affect all fossil fuels because of the policies aimed at reducing GHG emissions. Costs of up to US\$50/tCO_2 are mentioned, which would represent an additional cost of US\$20 per barrel of oil;
- The peaking of natural gas domestic production in North America and Europe, which requires additional imports, mainly LNG, because the high costs to develop new gas pipelines from Russia or Central Asia limit the potential for additional exports;
- The limits on non-fossil fuel supply, either because of lack of public acceptance for large hydro and nuclear power or because of the intermittent and/or dispersed nature of most modern renewable energies;
- NIMBY (not in my backyard) attitudes that may prevent the building of enough LNG re-gasification capacity, high voltage transmission lines, power plants, or adequate redundancy to increase the versatility and security of energy systems.

Such energy supply constraints may play an important role as a negative driver of the energy scene in the coming years in spite of the best efforts of governments and companies. They will not generally originate from a lack of energy resources in the absolute but will be triggered by two fundamental feedbacks working separately or together: from a sustained shortfall in primary energy production or supply bottlenecks in key markets (such as occurred for oil in the USA in 1973 or for coal in China after 1996, and could occur for natural gas in Russia in the years to come), or from a more fundamental shift away from one major energy source because of changes in relative costs or prices, external factors (e.g., wars or revolutions), public opinion (e.g., 'a nuclear accident somewhere is an accident everywhere'), or stringent environmental policies (e.g., the threat of climate change). It is worth examining to what extent such energy supply constraints will limit global GDP growth in the coming decades.

In contrast, increasing energy supply to provide affordable energy services to those who now have little or no access to modern energy could be a positive driver of the energy scene. While the extra call on production capacities, even small, may raise policy and business concerns, such broadened access will enhance the global economic system and its flexibility to overcome new challenges, including possible future economic crises. There could be more peace and security in the world and therefore more reliability of energy supply.

Given the far-reaching consequences of the change in the marginal energy supply -- coal prior to the first oil shock in 1973 and oil since that shock -- one might wonder whether similar dramatic changes may appear in the foreseeable future or whether oil will remain the marginal fuel for decades to come. Some analysts put enormous hope on natural gas, which, without intervention, is not as liquid as oil, while others speak of the hydrogen economy. The report highlights how natural gas today is to some extent mirroring the experience with oil in

the 1970s. As for the hopes for hydrogen, there are major hurdles in its way - the capacity to produce hydrogen cheaply, the development of new infrastructure and the availability of fuel cells at a competitive cost.

The report notes that the gasification of coal, unconventional oil, or biomass may provide, thanks to synthetic liquid fuels, a transition towards pure hydrogen. Such synthetic fuels can use existing infrastructure and devices available today, are closer than the hydrogen age and could become the next price-setter in energy markets. Many bifurcations in terms of the role of new technology at both the production and utilisation ends of the energy system exist, but in the view of this report, oil would retain its place in the global energy supply (largely for mobility and its increasing share of energy requirements worldwide) beside that of the new synthetic fuels and later, hydrogen.

F. GENERAL CONCLUSIONS

Aim of Study

This report was not intended to make forecasts or scenarios but to highlight the questions to be answered in any future WEC work. The most important of these relate to future global economic growth, the improvement of energy accessibility for the poor, the handling of security of supply and the threat of the harmful local, regional or global effect emissions, particularly anthropogenic GHG emissions to which the energy sector is the principal contributor. Each of these questions is linked, and their answers will drive the energy scene for many years to come.

Role of GDP

What is the rate of growth in global GDP likely to be, given the institutional barriers within economies and energy markets as well as the possible negative feedback of higher real energy prices? Most scenarios assume an average global GDP growth rate of 3% to 2030, which leads to a high level of demand for energy (as well as higher GHG emissions). This in turn leads some analysts to predict very large investment requirements for sustainable energy development.

The report highlights economic trends and feedbacks over the last 30 years, which suggests that annual global GDP growth will be substantially below 3% in the next few years. However, as we have also seen, the *GDP Driver* depends on feedbacks from many sources. In this respect, the direction of primary and final energy prices, in real terms, plays a major role.

The likely evolution will be increasingly characterised by 'stop and go' episodes, each episode exhibiting a decline in energy prices followed by a significant rise, with positive and negative feedbacks on GDP growth and new technology impacting production capacity and end-uses. Any sustained upward adjustment in real energy prices would benefit energy efficiency and help achieve environmental targets (availability and acceptability goals), while the fight to eradicate energy poverty (the accessibility goal) would become more difficult without offsetting policies and programmes.

Accessibility
How can real progress be made in providing commercial energy access for the poor, as well as more reliable service for those who do not enjoy it now, and what will this mean in terms of global GDP growth? The responsibilities of national governments to create an investor-friendly environment, promote regional trade and foster other links with the international community are central. If energy demand is reduced by higher real primary energy prices, which themselves translate into higher final energy prices and lower GDP, there is some doubt that it will be possible to reduce energy poverty, and the world will miss a great opportunity to establish a virtual cycle of economic growth and social stability.

Availability
If hydrocarbon supplies do not grow much or can only grow in a context of higher costs for environmental or other reasons, what will the sources of new energy services be, and how soon might they shift once again among oil, natural gas, coal, nuclear power, hydro and other renewables, or some new and unknown energy source? The outlook for hydrocarbon supplies and for energy-related GHG emissions will impact the outlook for GDP. Technology development will be critical in determining when and which new energy options will be available.

Acceptability
Finally, in a world of lower global economic growth and higher real energy prices, what is the precise nature of the climate change threat, and if it requires further action, what are the least cost carbon mitigation strategies, technologies or regulations to address it? We must ensure that the impact of sustainable development policies will be positive for the poorest developing countries while minimising their potential negative impact on the rich countries.

Some of these questions would be best studied anew in the context of fresh work on a set of realistic assumptions and scenarios looking well into the future. The World Energy Council is considering such a project as part of its 2005-2007 Work Cycle.

INTRODUCTION

Modern industrial societies incorporate three energy-related features that define the world economic and energy scene: the role of economic development, the evolution of the demand for increasingly modern energy services and the availability of primary energy in terms of both quantity and quality.

Economic development has several facets:

- Technological innovation with the take-off and possible 'leap-frogging' by less advanced countries, and the growing contribution of developing countries to global industrial production;
- Institutional factors such as education, public infrastructure, property rights, fair judicial systems, reliable banks and stock exchanges and entrepreneurial decision-making; and,
- Accessibility, availability and acceptability of energy as the three key elements of sustainable energy development, but also the slow-down development when access is affected for an extended period in the case of crises or steep energy price increases.

Energy accessibility is very much tied to economic development with three different links:

- While the provision of a minimum of reliable and affordable commercial energy services to the two billion people in the world who do not now have such access would add little to global demand, it is a key factor for development and social equity in many parts of the world;
- As economies grow they experience the faster growth of electricity, followed by mobility, with the share of stationary fossil fuel end-uses declining over time; and,
- The substitution across the factors of production -- labour, capital and energy -- when their relative prices diverge to adapt the stock of capital investment.

Energy availability and acceptability also have essential roles in development:

- Globally, stable sustainable energy prices are essential for access and economic growth but not necessarily for efficiency or environmental acceptability. Higher prices drive more efficient use of energy in the long run, but the transition from cheap to higher prices is painful for economies and individuals, especially the poor;
- In a climate of stability, technological gains and economies of scale push costs down in a uniform trend and allow governments to set policies that, by favouring access, enhance a country's economic performance; and,
- The demand for energy of 'quality' or 'modern' energy encourages the introduction of cleaner, more sophisticated fuels, which are produced and consumed with due consideration for their social and environmental impacts.

This report explores all these aspects. It is primarily focussed on developments in the oil and natural gas markets because of their importance in energy pricing as a whole and to provide a context for separate WEC work on coal, renewables, energy market reform, technologies and climate change which will be published at the time of the 19th World Energy Congress in Sydney, Australia, in September, 2004. The overall tone and vision of the report may be viewed by some readers as more pessimistic than most published analyses because it suggests that some 'drivers' -- future GDP growth, autonomous energy efficiency improvements and availability of primary energy, to name a few -- may not be strong enough to provide modern energy to the two billion poor who now lack it. Yet one cannot propose actions to achieve sustainable energy development (defined by WEC as a balance among the three goals of energy accessibility, energy availability and energy acceptability) without first identifying the present and future underlying constraints on energy supply and demand.

Most forecasts proposed today consider that neither energy accessibility nor energy availability will be the binding constraints on prosperity in global terms over the next few decades. This has led national governments and UN agencies to focus on environmental acceptability and the actions and policy shifts required to address GHG emissions. To the contrary, as this report suggests, the problems facing humanity today may be related more to inadequate economic growth, in particular in developing countries with no improvement in commercial energy access, and possible temporary energy shortages in terms of the availability of services than to local, regional or global emissions from energy production, transmission or utilisation.

In the view of WEC, these issues are linked in terms of sustainable development. WEC also believes there is real potential to address serious access and availability issues with technologies and regulations which significantly reduce harmful local, regional and global emissions. During the course of the *Drivers* study, the World Summit on Sustainable Development, held in South Africa in 2002, echoed the need to focus on poverty eradication and the role of affordable universal energy access as the principal issues of sustainable development.

In short, numerous scenarios that cover a wide range of outcomes tend to deliver a uniform message about the importance of environmental challenges and their urgency. *Drivers of the Energy Scene* takes a different perspective. It concentrates on the evolutions in energy supply and demand in the past, identifies what the positive or negative impacts have been in the present, and determines to what extent they bear insights about the future.

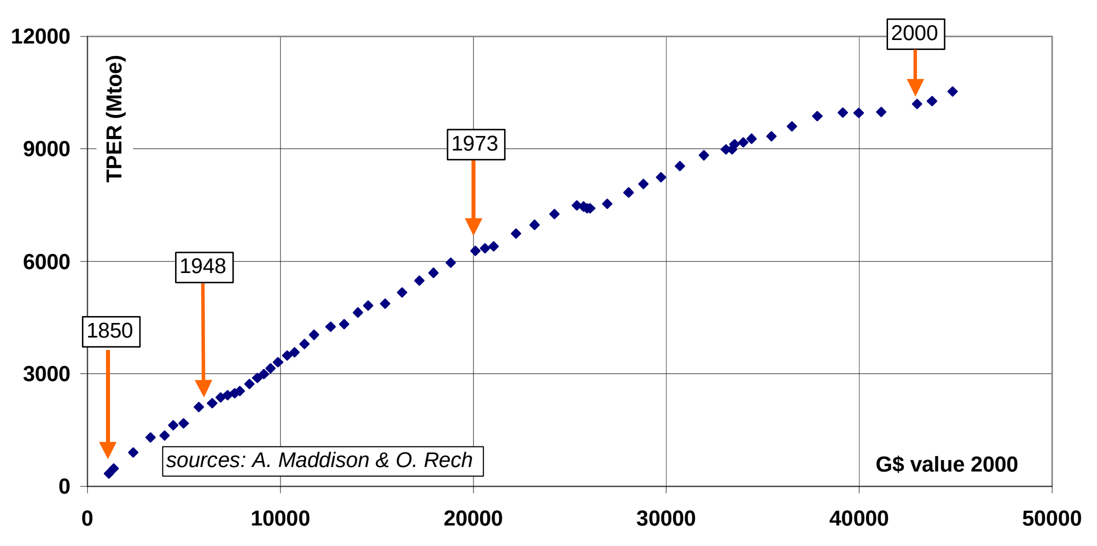
Important note: The graphs incorporated in the main body of the text are based on actual raw data without any smoothing. GDP data after 1960 are those of the CEPII (Centre d'Etudes Prospectives et d'Informations Internationales) database – the same as those used for ETWAN – and those of Angus Maddison (OECD) for the historic data since 1820. They are systematically expressed in purchase power parities in US$ for 2000 unless otherwise stated. Energy data come from three main sources: IEA, BP Statistical Review, and O. Rech (French Petroleum Institute which has compiled historic data since 1850). Primary energy data use the TPER (total primary energy requirements) methodology. Final energy services were compiled by F. Birol (IEA). A list of Abbreviations and a Glossary of Terms and Methodology is provided in Annex B. A list of Graphs and Tables is provided in Annex C.

PART I: GDP AND ENERGY

A. GDP GROWTH: A HISTORICAL PERSPECTIVE

World total primary energy requirements and Gross Domestic Product (GDP) over the last 150 years are displayed in Graph I-1. Beyond the small discrepancies due to poor historic data, this graph highlights the fundamental role of GDP as a driver of primary energy demand. However, even in the early days of the Industrial Revolution, this role was more complex than the apparent good correlation which the early period suggests. More recently, the energy price increases of 1973, 1979-80, 1990 and 2000 may partly explain the lower GDP growth and the drop of energy intensities during the two years following each of these events. Conversely, the 1986 'counter-shock' of lower energy prices was followed by two years of faster GDP growth in 1987-88. In short, GDP growth apparently reacts in an opposite way to energy price movements.

Graph I-1 WORLD TPER VERSUS GDP PPP 1850-2002

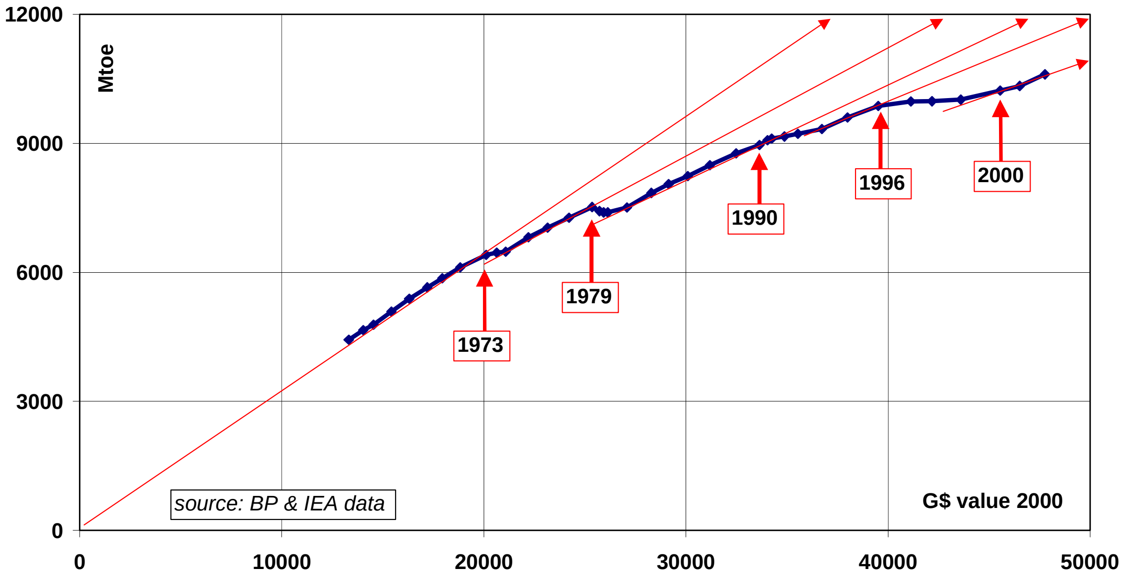


It is worth noting in respect of Graph I-1 that:

- What happened prior to 1850 is of no relevance today. World GDP and TPER were less than 3% of today's figures, and TPER was dominated (more than 85%) by 'traditional' fuels such as biomass;
- Even what happened between 1850 and 1950 (when the yearly series became available) is not very relevant because TPER was less than 20% of today's figures and mostly dominated by coal;
- Up to 1973, TPER was proportional to GDP (an elasticity of one), possibly because of the stable average prices of delivered energy during this period;
- Energy price movements are either small and part of a natural volatility process that does not impact on GDP, or if they are significant across a large part of the energy pool and last for a relatively long time, they may affect GDP growth at least temporarily.

Graph I-2 displays the same data in slightly different form in order to highlight the periods of apparent stability compared with the periods when the trend has changed. Data starts in 1965 to avoid the small discrepancies that existed in the former estimates of Maddison. It shows that the progressive decoupling between energy and GDP is a phenomenon that broadly coincides with the slowing down of GDP growth. Both of these developments started in the early 1970s and might have the same origin, namely, the first oil shock in 1973. This suggests the need to look in more detail at the estimates provided by Maddison (see Table I-A).

GRAPH I-2 WORLD TPER VERSUS GDP PPP 1965-2002



Graph I-3 illustrates the evolution of world GDP over time. It is based on actual national GDP data except for China's, which were revised (see the discussion later in Part I). It shows that average world GDP (PPP) has grown nearly linearly since the first oil shock. If one were to remove the Former Soviet Union (FSU) on the grounds that the collapse of its economy in the 1990s is a non-recurrent phenomenon, the trend would improve a little, yet still remain nearly linear.

Graph I-3 WORLD GDP 1850-2002

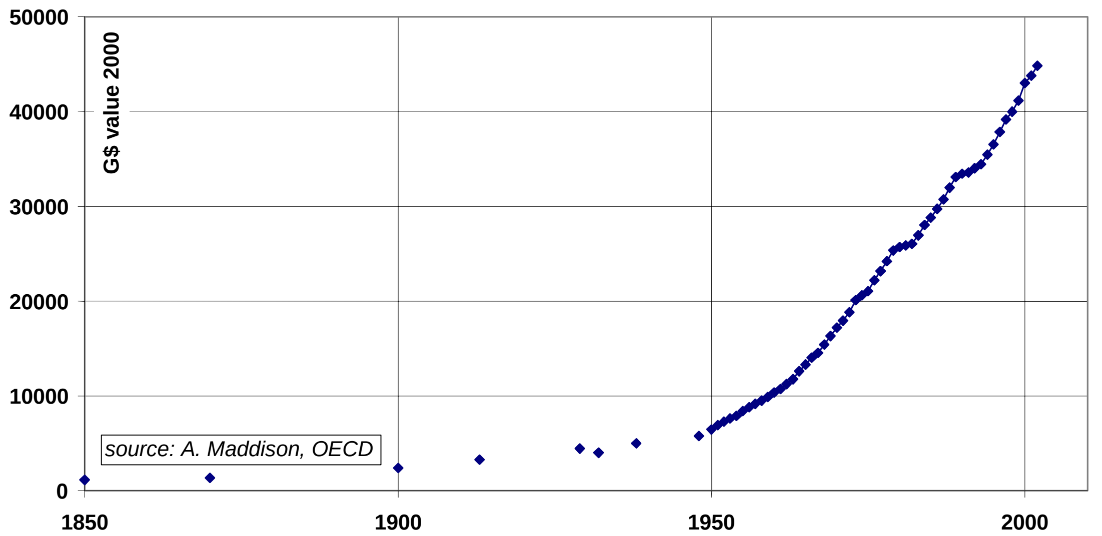


TABLE I-A GDP GROWTH PER CAPITA Average Annual Compound Growth Rates, Per Cent (1820-1998)					
Region	**1820-1870**	**1870-1913**	**1913-1950**	**1950-1973**	**1973-1998**
Western Europe	0.95	1.32	0.76	4.08	1.78
British 'offshoots'*	1.42	1.81	1.55	2.44	1.94
Japan	0.19	1.48	0.89	8.05	2.34
Eastern Europe & FSU	0.64	1.15	1.50	3.49	-1.10
Latin America	0.10	1.81	1.42	2.52	0.99
Asia without Japan	-0.11	0.38	-0.02	2.92	3.54**
Africa	0.12	0.64	1.02	2.07	0.01
World	**0.53**	**1.30**	**0.91**	**2.93**	**1.33**

Source: *The World Economy, A Milennial Perspective*, Maddison, OECD
* What Maddison calls the British offshoots are the USA, Canada, Australia and New Zealand
** Official Chinese GDP figures because Maddison's report was issued before he revised the Chinese data downwards

Table I-A summarises the historic regional developments over the last two centuries. One should note that:

- At the beginning of the Industrial Revolution (1820-1870), growth was concentrated in the 'western' regions of Europe and their 'offshoots';
- During the 1870-1913 period, the Western experience spread everywhere in the world except for Asia, which was thought at the time not to be 'growth prone';
- The lower growth rates of the now developed countries during 1913-1950 resulted from the negative impact of the two World Wars and the Great Depression of the 1930s;
- 1950-1973 was an exceptional period of relative peace and stable institutions. Hence there was a 'catch-up' in most regions thanks to the stock of technical innovations of the 1930s and 1940s;
- 1973-1998 exhibited a significant but progressive economic slow-down that is analysed in more detail later in this report;
- The higher growth during the 1973-1998 period in Asia, excluding Japan, is over-estimated. Maddison puts China growth rates at about 70% of the official figures.

Problems with GDP Methodologies

The choice of consistent GDP methodologies is important because of the need for unbiased comparisons across time, which were highlighted in the above discussion on the slowing down of world GDP, and across regions. Purchasing power parities (PPP) are used to avoid the under-valuation of GDP in developing countries which market exchange rates create (the less developed a country, the higher the perceived risk of maintaining its currency, and therefore, the higher the under-valuation of its national currency).

Once GDP PPP is chosen, the linkage between energy and GDP may be considered a causal relationship because the necessary and sufficient conditions to establish a correlation are met.

The necessary condition is to have an *ex-ante* intuition of the role of GDP (this is the reason a GDP scale was chosen in preference to a calendar scale in the previous graphs), *and* the sufficient condition is to confirm *ex-post* that the raw data (those that are used in all graphs of this study even if individual annual data are not readily visible) follow this intuition. On this basis, one may use GDP data to discuss the reliability of energy data, or conversely, energy data to discuss GDP data, which is done in the following paragraphs.

In general, global GDP levels and primary energy consumption are well correlated, as we have seen. The changes that affect the relationship may be explained and related to external events, such as significant price changes. However, three very large countries display GDP-energy relationships that are partly at odds with the rest of the world, namely the USA, China and the FSU.

The Case of the USA

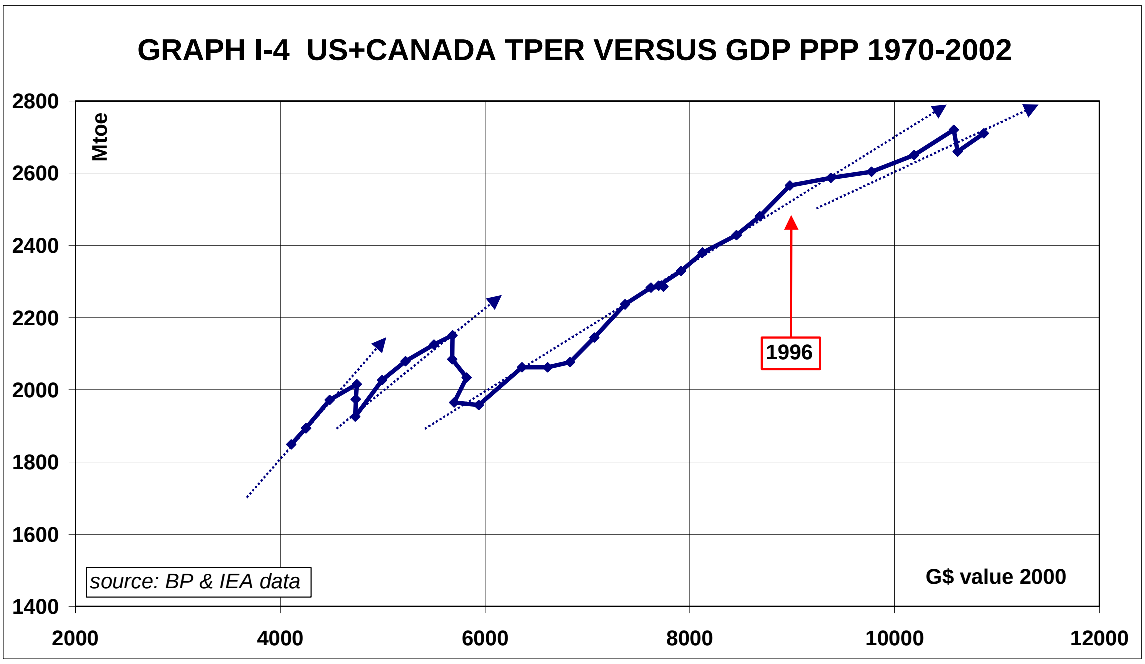
The 1970 break in the USA statistical series on the GDP-energy relationship results from a change of datum because of the need for all IEA countries to provide new consistent data on energy after 1970. However, the downward shift in TPER in the USA and Canada after 1996 cannot be explained by a change of GDP datum as occurred in 1970 or by the oil shocks which occurred in 1973-75 or 1979-82. As it is unlikely to correspond to a saturation of energy demand, there are three explanations that come to mind which may, separately or in combination, explain this downward shift since 1996:

- First, it may have been caused by the very mild winters in 1996-97, 1997-98, 1998-99 and 1999-2000, which were respectively about 4%, 10%, 8%, and 9% warmer than normal winters;
- Second, it might correspond to an artificial inflation of GDP figures, reflecting the way the rapid increase in performance of US-manufactured computers was imputed as ‘hedonic GDP’[1]; and/or,
- Third, it might correspond to an artificially higher GDP and productivity improvement created in the distribution sector thanks to the higher margins made on cheap imports[2].

Graph I-4 (see also the energy services Graph II-10 in Part II of this study) suggests that USA GDP growth between 1996 and 2000 (from the end of the business cycle to the end of the concerns for the Y2K) might be overstated. Whether there is an over-estimate and if so, quantifying it, is beyond the purpose of this study. Suffice it to say that the problem exists, that it could affect the quality of the GDP analysis and therefore the relationship of global GDP and TPER. Future annual data and more detailed studies may bring more consistency to this issue, but for the sake of the analysis of this study, the choice has been made not to modify the actual official USA GDP data.

[1] A computer sold for US$1,000 in 2000 with say three times more power than the US$1,000 computer sold in 1996 was considered to generate a US$3,000 value, therefore resulting in a US$2,000 benefit accounted for in GDP with the ‘hedonic’ methodology. While all historic series were transformed accordingly, the impact was particularly high in the 1996-2000 period because of the huge investment in IT, amplified by the fear of the Y2K during this period. For this reason, GDP growth in the USA might be overstated by 30%. The accounting shift of software spending from expenses to investment has also had an obvious, yet temporary, beneficial effect on USA GDP.

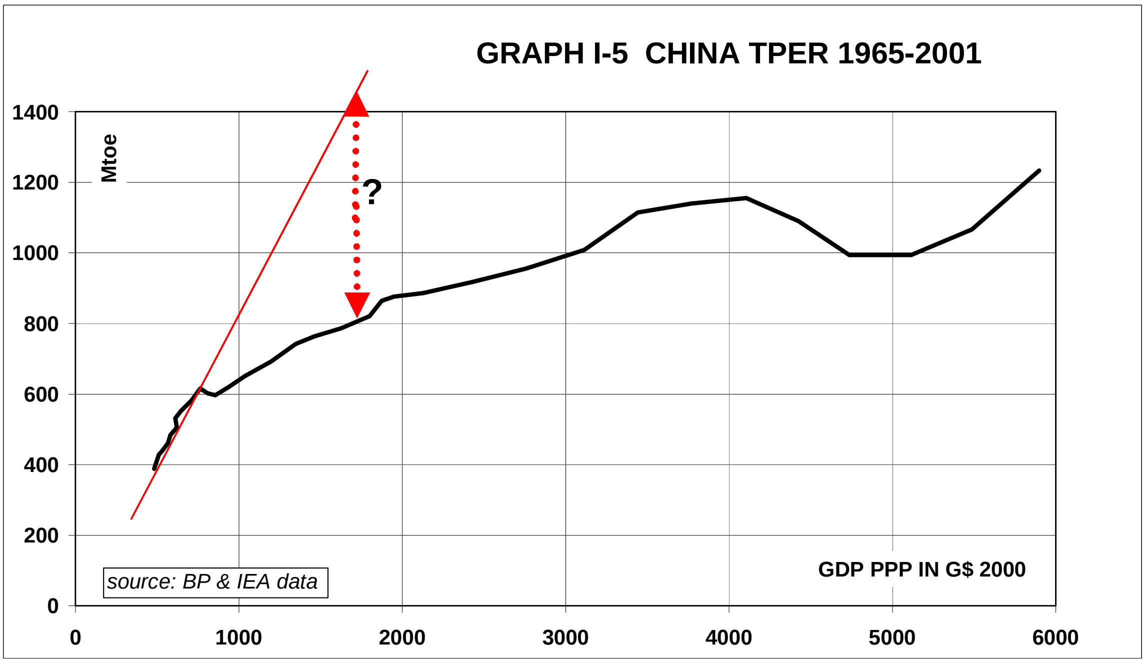
[2] The trade deficit in the USA, now at nearly 500 G$/y, is important.

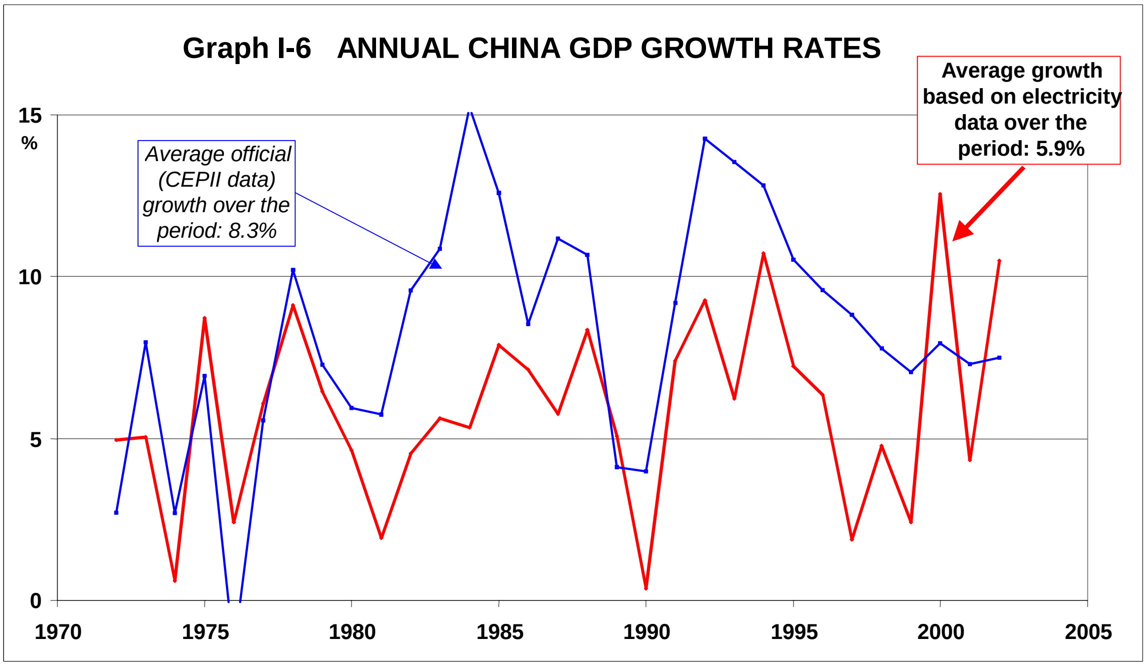


The Case of China

By comparison with other regions, one would expect a linear correlation between Chinese GDP and TPER, similar to that which existed up to 1979. Yet the series breaks at the end of the 1970s and again in 1996-1999, when many village coal mines were closed. Income elasticity of primary energy consumption was about one up to the end of the 1970s, then fell, a situation never observed on a sustained basis in any other region of the world. Some observers have concluded that China is making considerable progress in improving its energy intensity. That is certainly true, because energy prices were increased in the past, e.g., for electricity, and strong efficiency standards exist in many sectors and for many appliances. However, the brutal decoupling since the end of the 1970s not only corresponds to a change of policy (the end of the Cultural Revolution) but also to a break in the energy series. As this decoupling has never happened elsewhere, it seems logical to investigate whether the GDP methodology used in China since the end of the 1970s is comparable to that in market economies. These issues are described in Graphs I-5 and I-6.

As the most consistent linear trend in all market economies is that of electricity, the data for China for the 1965-1980 period have been extrapolated and GDP re-measured along this new trend. On this basis, average annual Chinese growth was 5.9%, a third less than the official 8.3% average. As the new revised GDP annual growth estimates are similar to Maddison's results when he reviewed the Chinese GDP data, they were kept for this study. An additional question is whether, once GDP growth has been revised, the new GDP values for China should be based on recent GDP estimates of the latest years or on those of the earliest years. In the first case, the revised GDP rates of the 1970s are double, whereas in the second case, the revised GDP rates are halved for the most recent years. The choice is not obvious, as we shall see later in this report, and may lie somewhere between the two extremes. In this report, however, WEC has chosen to keep the GDP PPP of the 1970s for China, thus leading to GDP values in the 2000s slightly above 3000 G$, which puts China's GDP below that of Japan.





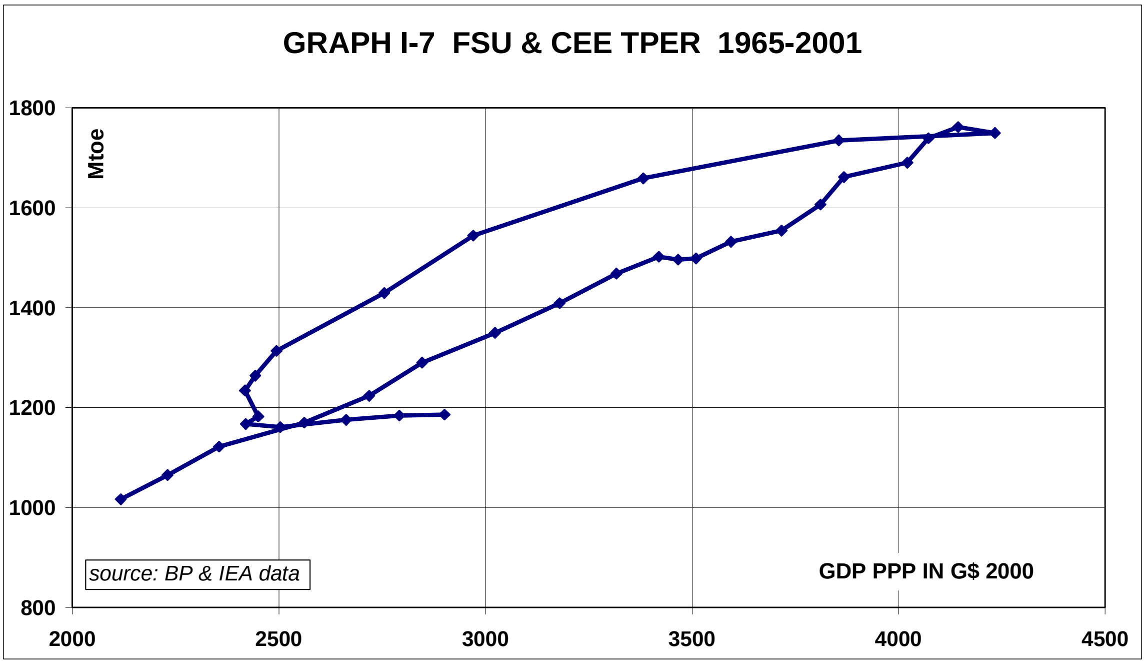
This report is based on the revised data because a number of sources confirm them. Not only are energy data and the revisions proposed by Maddison very much in line, but the former methodology used in China was based on the concept of net material product, a concept that ignores ‘services’ and their lower productivity. The ‘revised’ nearly 6% average growth is already an impressive performance for such a huge country with so many inefficient state-owned enterprises.

The Case of the FSU

In all countries, there is a part of the economic activity that is poorly, i.e., partly or not at all, recorded in the official GDP figures. The problem for the FSU, shown in Graph I-7, is the reverse of the China case; by associating under-estimated GDP figures with correct physical energy consumptions, there is a huge potential for overstating TPER per unit GDP.

This bias is difficult if not impossible to assess when it is more or less constant over time. The only case which clearly shows evidence of the growth of an unofficial 'grey or black' economy in the FSU is that, after 1989, when the GDP declined, energy consumption increased more than the past previous trend would have suggested for the declared GDP.

If one compares the official figures for 1978 (GDP of 2,719 G$ and TPER of 1,505 Mtoe) and 1993 (GDP of 2,234 G$ and TPER of 1,477 Mtoe), one finds that a similar TPER in 1993 corresponds to GDP that is about 400 G$ lower than in 1978. A possible reason is the evolution of an unrecorded economy of the size of this gap. The energy services further confirm this explanation because of the lack of evidence that the price environment of energy services had changed. However, as for the USA, the purpose of the discussion of the FSU case is to raise awareness of inconsistencies which might lead to the wrong conclusions about energy demand or emissions. As in the case of the USA data, it was decided for the purposes of this study not to change the official GDP data for FSU.



GDP Splits Among Different Regions

Table I-B is based on official GDP PPP data for all countries except China, where GDP data are the official data up to 1980 and are revised for the period 1980 until today as discussed above (with an average reduction of the annual growth rates of one third down to 5.9%).

Table I-B highlights three 14-year periods, from the golden 1960s up to the first oil crisis in 1973, from 1974 to 1988 and from 1988 to the present. One may note that:

- The weight of the rich countries has continuously decreased over the period (from 59.4% in 1960 to 54.5% in 2002) but the USA and Canada[3] have increased their share over the last sub-period, whereas Europe and Japan have seen their shares fall for the opposite reason;
- The weight of developing countries has continuously increased over the period (from 24.4% in 1960 to 31.8% in 2002) but with contrasted performances, such as the very dynamic growth in Asia: the Latin American share has hardly grown (from 7.8% in 1960 to 8.7% in 2002), and the Africa-Middle East share has fallen (from 8.7% in 1960 to 8.0% in 2002 after having reached 10% in 1974 thanks to the increase in oil prices the year before);
- The performance of China since the end of the Cultural Revolution is impressive, even if one revises downwards the official GDP growth figures. Its GDP PPP was only 3% of that of the world in 1974 but grew to 7.2% in 2002;
- FSU-CEE displays a chaotic evolution. The weight of its GDP PPP as compared to that of the world goes from 12.5% in 1960 to 13.2% in 1974 and 13% in 1988 before falling to 6.5% in 2002. It should now rise progressively thanks to the market reforms that have been implemented since the rouble crisis in 1998.

TABLE I-B REGIONAL GDP GROWTH RATES

	Annual GDP (G$ 1995)				**Mean annual GDP growth**		
	1960	**1974**	**1988**	**2002**	**60-74**	**74-88**	**88-02**
USA & Canada	2523	4411	6859	10023	4.1	3.2	2.7
Western Europe	2618	4930	6764	9089	4.6	2.3	2.1
Rich Asia-Pacific	582	1709	2867	3668	8.0	3.8	1.8
Rich countries	5724	11050	16491	22780	4.8	2.9	2.3
Latin America	755	1705	2582	3638	6.0	3.0	2.5
Africa/ME	836	1912	2420	3359	6.1	1.7	2.4
Developing Asia	758	1434	3146	6302	4.7	5.8	5.1
Developing countries	2349	5051	8149	13299	5.6	3.5	3.6
FSU/CEE	1208	2531	3859	2699	5.4	3.1	-2.5
China/Hong Kong	363	583	1754	5653	3.4	8.2	8.7
Revised China/Hong Kong	363	569	1283	3028	3.3	6.0	6.3
Economies in Transition (EIT)	1571	3114	5613	8352	5.0	4.3	2.9
Revised EIT	1571	3100	5142	5727	5.0	3.7	0.8
World	9644	19215	30252	44432	5.0	3.3	2.8
Revised World	9644	19201	29781	41807	5.0	3.2	2.5

In short, the world GDP split changed very little during the high world growth period of 1960-1974 but has changed dramatically from 1974 onwards; the share of developing countries has risen.

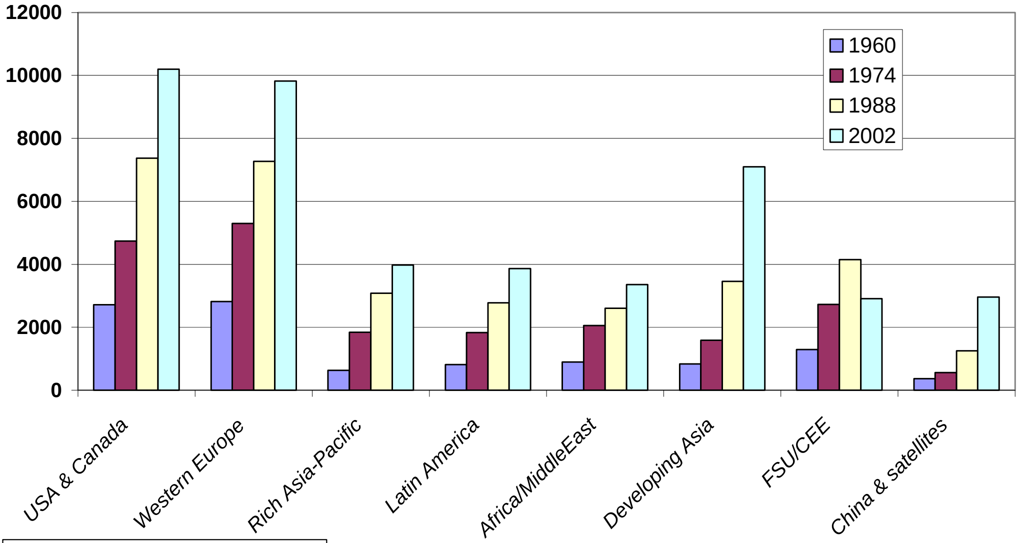
While this increase is impressive, it occurred with a series of crises that have severely impacted the potential growth of developing countries. According to *World Capital Markets – Challenges to the G10*, by Wendy Dobson and Gary Clyde Hufbauer, Institute for

[3] If the USA GDP were corrected to allow the 1997-2000 TPER to remain on the trend prevailing up to 1996, the USA/Canada GDP would only be 9500 G$ instead of 10023 G$ in 2002 and would not have increased its share of the world GDP.

International Economics (2001), banking and currency crises resulted in a loss of 0.6% annual growth rate in the 1980s (mostly concentrated in Latin America, which lost 2.2% per annum) and 0.7% in the 1990s (mostly in Asia, which lost 1.4%, with Latin America losing another 0.7%). Africa-Middle East experienced an even worse outcome because this region never succeeded in really 'taking-off' (no growth per capita on the average).

Economic development has spread to all regions of the world, but as shown in Graph I-8, GDP growth has slowed down since the 'golden 50s and 60s'. This explains why predictions of energy demand made during the past thirty years or so invariably exceeded reality, in some cases by as much as a factor of 2, as was the case with the French AFTP 1970 study forecasting energy demand in 1990. Interestingly, in that case, the 1973 and 1979-80 oil shocks only account for one fifth of the discrepancy, the rest coming from a lower than anticipated economic growth. Similarly, when ETWAN reviewed the former hypotheses of the earlier ETW, it concluded they had turned out to be too optimistic.

GRAPH I-8 GDP PPP IN G$ 2000 FROM 1960 TO 2002 (CORRECTED US & CHINA GDP VALUES)



source: CEPII & WEC estimates

With the spread of economic growth to all regions and the catch-up of some developing economies, the gravity centre of the world economy has shifted. Not only has the weight of developing countries increased from 24% in 1960 to 32% today (28% to 39% if one includes China) but within the world economy, the shares of the regions have also evolved. The Americas have remained stable as one third of the world economy, and Asia-Pacific has grown from 18% to 31% of the world economy at the expense of the decline of the Europe/FSU/Africa/ME regions. Hence the economic centre of gravity of the world economy is shifting from the Atlantic to the Pacific basin, as shown in Table I-C.

TABLE I-C REGIONAL SPLIT OF THE WORLD GDP (%)

	1960	1974	1988	2002
Europe/FSU/Africa/ME	48	49	44	36
Americas	34	32	32	33
Asia/China/Pacific	18	19	24	31

In other words, regions with relative rigidities in their economic and structural reforms have lost ground; those with resilience have maintained their share, while the more dynamic areas have gained share.

B. FACTORS AFFECTING GDP GROWTH

Given that GDP is a key driver of the energy scene, one may wonder what drives GDP itself. No definite answer exists to this question because there is no consensus on the 'endogenous theory of growth' except to say that GDP growth seems mostly to depend on three parameters: population, technical progress and cumulative nature that might be summed up as 'institutional capacity'.

- Population summarises several aspects, not only the number of human beings and their rural/urban groupings, but their age, life expectancy, and the split among the young, those of working age and the elderly.
- Technical progress combines two elements: the stock of innovations that can enter the market and the extent to which psychological/institutional barriers may prevent a rapid entry;
- Institutional capacity covers human knowledge, ethics, public infrastructure and institutional development (property rights, finance, judicial systems, cultural practices, etc.).

In each region or at the world level then, GDP growth reflects a combination of several factors:

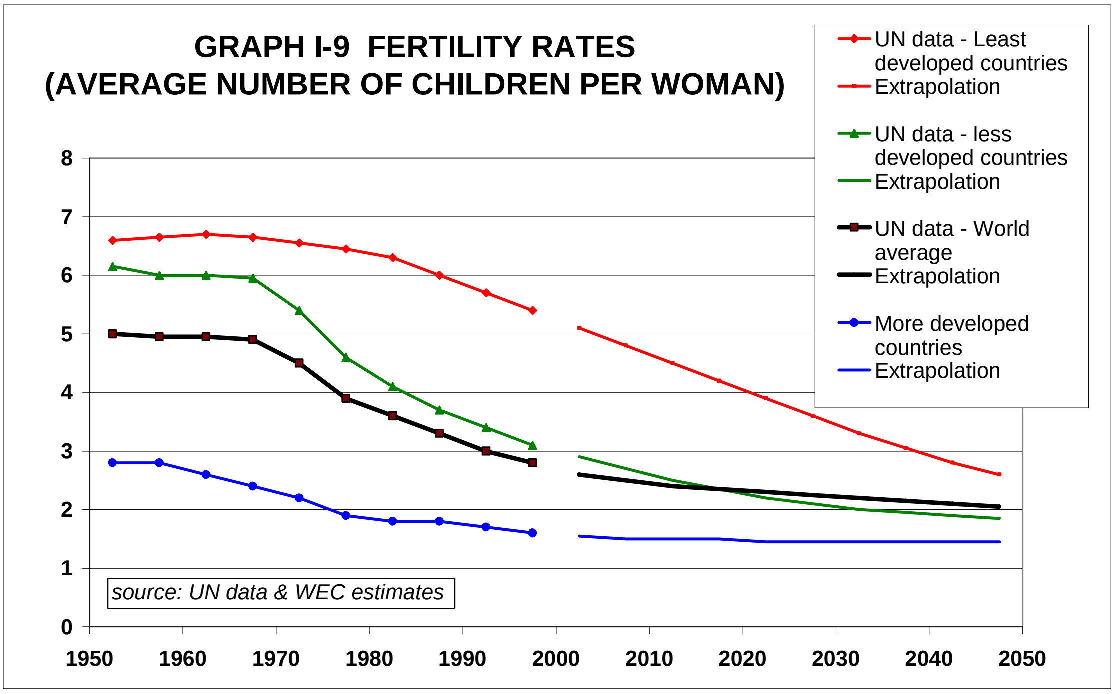
- Demographics that describe the concentration, habitat (urban/rural) and ages of the population;
- Potential technical innovation, which has never been the limiting factor;
- Institutions that allow technology to actually be implemented; and,
- External factors related to energy accessibility, availability and acceptability.

Even if all these factors come into play more or less in all regions, their importance and interaction vary considerably from one region to another. This is particularly true of the institutional factors. As shown by the dramatic FSU example, good institutions at a certain stage of development are not a guarantee of prosperity forever.

Demographics

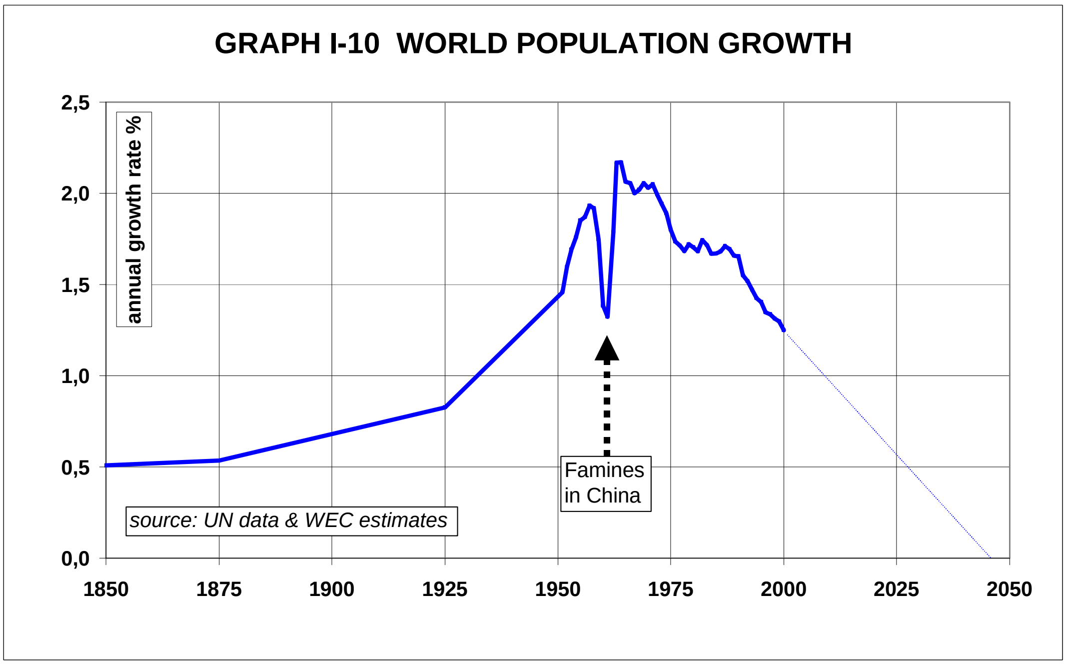
Demographic growth has been slowing down faster than expected, as shown in Graph I-9, with an emerging consensus that by 2050, population growth will either peak before declining or reach a plateau lower and earlier than previous predictions. All population forecasts made over the past four or five years have shown a marked deceleration in the rate of population growth. The consequence is that all regions will have to bear the growing cost of their elderly (not only because of the change of the pyramid of ages but also because of longer human life) and face a less dynamic society.

While the slowing growth rate of population and ageing are not the only problems that humanity will have to face, they will certainly have a strong influence on future economic growth rates. The extrapolation in Graph I-9 is as simple and straightforward as possible; it suggests that the average fertility rate will fall below the threshold for stability (2.1 children per woman) in the 2030s. Other aspects that will also play a role are the acceleration of urbanisation and birth control policy (in practice, often favouring boys) that creates potential imbalances and may accelerate the decline of population.

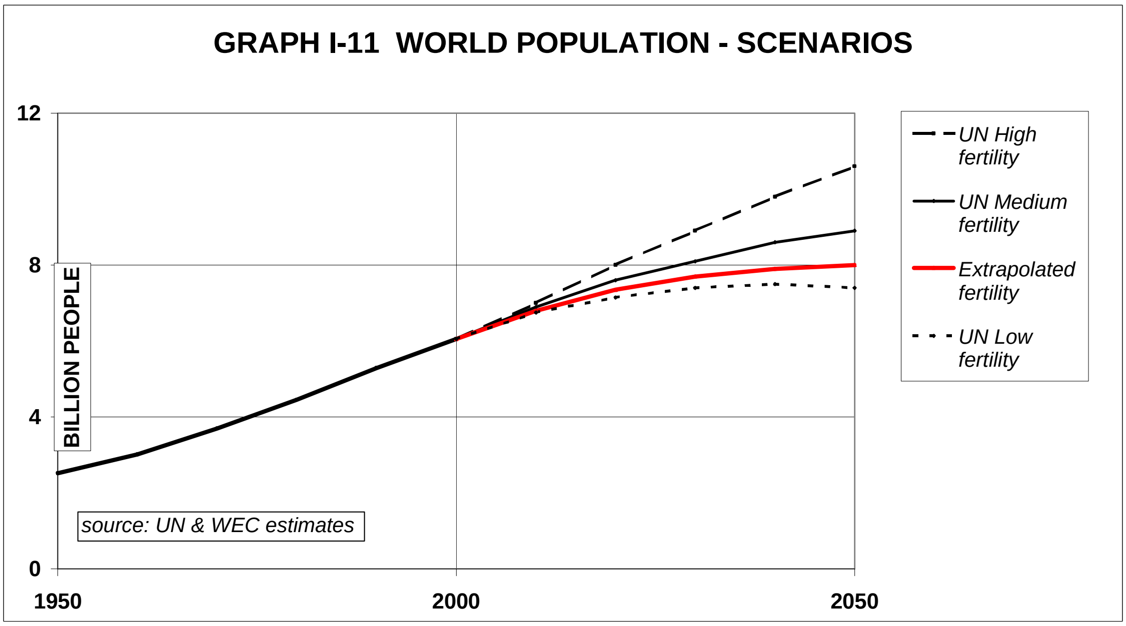


From this perspective, world population growth slows down progressively, resulting in a maximum population around 2040-2050 (2040 if average life expectancy were to remain unchanged, slightly later if it continues to grow as it has in the past), provided there is no distortion in the gender structure - a hypothesis which might not hold in China and India.

Graph I-10 corresponds to the extrapolation of the fertility trends and is compared to the 2000 UN hypotheses. Graph I-11 shows the progressive rise of the world population and the demographic changes that started during World War II. This shift is a result of the availability of antibiotics to reduce infant mortality and of the family-prone laws promulgated in many countries at the end of the 1930s.



Even though one may have slightly different views of regional population growth rates because of the increased migrations toward the rich countries (Western Europe, US and Canada) that provoke temporary rebounds of the fertility in these regions, the overall decline reflects some powerful feedbacks, including a general drop in fertility that adds to the impact of birth control. This is why, whatever the chosen extrapolation, whether that of the fertility trends or that based on annual growth rates, world population may peak around 2040-50. Such an extrapolation represents the most likely and robust vision that historic trends convey in terms of the 'demographic driver'.



Technical Innovation

'Productivity' combines the capacity of man and human society to innovate and to incorporate the innovations at a slow or more rapid rate in the socio-economic fabric of the regions in which they live and work. In the past, the factor limiting the growth of productivity has never been the 'tank' of innovations ready to be used but rather, the existence of an adequate business environment. New technologies, new processes and new management techniques are available, and as discussed below, there are strong grounds to anticipate that the innovation process will continue, making it difficult to imagine that the lack of technological advances could become the limiting factor of economic development in the future.

There are many examples of technical innovations and technological breakthroughs in the energy sector, even in the last 30 years:

- For oil and gas, 3D seismics (the very first concepts such as 'wide-line profiling' were imagined and put in place in the early 1970s), horizontal drilling that leads to lower production costs while reaching new targets (allowing, for instance, tapping of the Troll field's oil ring);
- In power generation, the introduction of reliable gas turbines, thanks to military innovations for jet aircraft and their combination with vapour and combined cycle turbines to increase efficiencies;
- The reduction of costs by 3% and more per year thanks to economies of scale, better designs and technical innovations, for instance, the development of new high-grade steel (for pipelines, natural gas liquefaction processes);

- The generalisation of IT and PCs in exploration, production, process control (for energy processes including the optimisation of the performance of car engines, power plant operations and maintenance, buildings heating and cooling systems), management of technical data, etc;
- Future breakthroughs are expected to increase oil recovery, control or clean accidental pollution, separate carbon and sequestrate it, enhance the safety of nuclear reactors, etc.

However, these breakthroughs have occurred progressively under incremental changes. This will probably continue to be the case over the next fifty years; new viable technologies are likely to penetrate the economic fabric slowly and progressively, although carbon sequestration or synthetic fuels, to name two recent areas of great focus, could have a cumulative impact of considerable importance.

The Importance of Institutional Capacity

The judicial (such as property rights, the rule of law, stability of institutions, democracy, gender equality), physical (such as utilities and information technology) or intangible aspects (such as education systems, insurance, capital markets) are difficult to quantify as a parameter of GDP. Table I-D is a qualitative approach to the screening (demographics, technology, overall political context, finance, energy and basic institutions) that might be used to understand better the economic growth of the different sub-periods which were examined above.

These different factors contribute to the GDP dynamics in several ways:

- Demographic trends have a lot of inertia and may impact entrepreneurship;
- Technology availability and new innovations have never been the limiting factor;
- Globalisation and international trade have favoured economic growth;
- Confidence in financial institutions (central banks, stock exchanges, etc.) is critical to growth;
- Energy availability and the growth of oil have greatly contributed to economic development; and,
- Market reforms and political courage are needed for the dynamic build-up of institutions.

In this context, it is important to remember the linkage between energy accessibility and economic growth prospects. Access to modern energy services is a subset of the institutional conditions that need to be fulfilled for a country to ‘take off’. It is such access, for example, which has made possible China’s impressive growth record; in a population now exceeding 1.3 billion inhabitants, there are only 20 million people without access to electricity.[4]

[4] Comments made by Zhou Dadi, Director General of ERI (Energy Research Institute), National Development and Reform Commission, during his presentation at the ‘Montreux Energy’ Seminar, June 2003, Montreux, Geneva. It is also interesting to note in this regard that the National Development and Reform Commission, formerly known as the State Development Planning Commission, changed its name to put more emphasis on the need for structural reforms to sustain economic development.

TABLE I-D FRAMEWORK CONDITIONS (1820-2050)						
Period	**Demography**	**Technology**	**Context**	**Finance**	**Energy**	**Institutions**
1820-1913	Balanced but slow growth	Steam-engine & railways	Spreading of the 'Western' model	High savings in rich countries	Traditional fuels & coal dominate	Development of property rights
1913-1950	Very slow because of World Wars	Cars in North America, electricity	2 World Wars, depression, spot autarky	Inflation in Europe	Mostly coal, oil develops, gas appears	Consolidation of property rights
1950-1973	Rapid in rich countries (baby boom)	Cars in rich countries, airplanes	Period of relative stability	Gold peg, high savings are invested	Oil growth under coal umbrella	Adequate institutions in rich countries
1973-2003	Rapid in DC, slowing elsewhere	Plastics, IT, electrification, cars everywhere	Fall of iron and bamboo curtains	Variable rates and inflation	Oil price sets a multi-energy scene	Some DC enhance their institutions
2003-??	Slowing & OECD greying, urbanisation	IT, bio- and micro/nano-technologies	Protectionism and anti-globalisation?	Deflation? Mistrust in finance companies	Transition to more non-conventional fuels?	Deficiency of property rights in DC?

How to integrate innovations then? This was relatively easy in the 'modern' era, when the main aim of industry and services was to bring more products on a mass-scale (Ford Model T, standard telephones, refrigerators, cookers). It is much more difficult in the 'post-modern' era when consumers have rapidly changing tastes for tailor-made products and services. Unfortunately, even the institutional framework for a 'modern economy' is still lacking in many developing countries, which do not have adequate property rights, equitable courts accessible to all, safe financial and banking systems, etc. In the rich countries, the situation is also worrying because some have been unable to implement the market reforms that the 'post-modern' era requires. A few countries are committed to such reforms, but in many cases, unwise or delayed decisions have led to a worsening of the present economic situation.

One needs to understand how consumers contemplate their future in terms of the 'economic pie': will it grow, and how will it be shared? The main issue is the degree of confidence of the potential savers in their future and that of their own country. This is illustrated by the situation of savings today. Annual world savings represent $5,000 G of which $1,000 G flow internationally. These $1,000 G create large imbalances in terms of foreign exchange reserves with more than 55% of the foreign exchange reserves being in Asia[5]. Half of these flows ($500 G) go to the USA to finance the current account deficit, supporting the view that USA consumers have such a high degree of confidence in their economy that they do not need to establish high savings rates. On the other hand, one might surmise that consumers in Asian countries have a lower degree of confidence in their own countries than in the USA, since they prefer, for their own future, to invest their savings heavily in the USA.

Many reports on developing countries highlight their structural weaknesses. For instance, in Asia, there are no analyses that foresee that the recent growth in the large regional economies,

[5] Japan owns nearly $450 G of foreign reserves, representing 19.3% of the world total. It is followed by China (11.3%), Taiwan (6.8%), South Korea (5.1%), Hong Kong (4.8%), India (2.6%), Thailand (1.6%), Malaysia (1.4%), Indonesia (1.3%), Philippines (0.6%), etc., making more than 55% of the world total for Asia only.

including China, may continue at the same high rate, even if some of the structural imbalances that sparked the 1987 crisis have now found a solution. In a similar way, reports on Latin America are at best mildly positive when they are not negative. Last but not least, there is no anticipation that the situation in Africa and the Middle East can improve rapidly. This is not to say that analysts are right but to warn against too optimistic forecasts about GDP growth and therefore energy demand.

In developed countries, the long-term outlook for Western Europe and Japan is uncertain because the new world situation calls for market reforms that governments often dare not engage or have much difficulty implementing because of vested interests that favour the status quo. The outlook is brighter for North America because some of the key market reforms were made in the 1980s, but the 'productivity miracle' may not be so great as the official data suggest, and temporary problems (the too-high trade deficit in the USA in particular) may lower the potential of growth at least for a few years.

Exogenous Factors Related to Energy

There are three exogenous factors considered in this report:

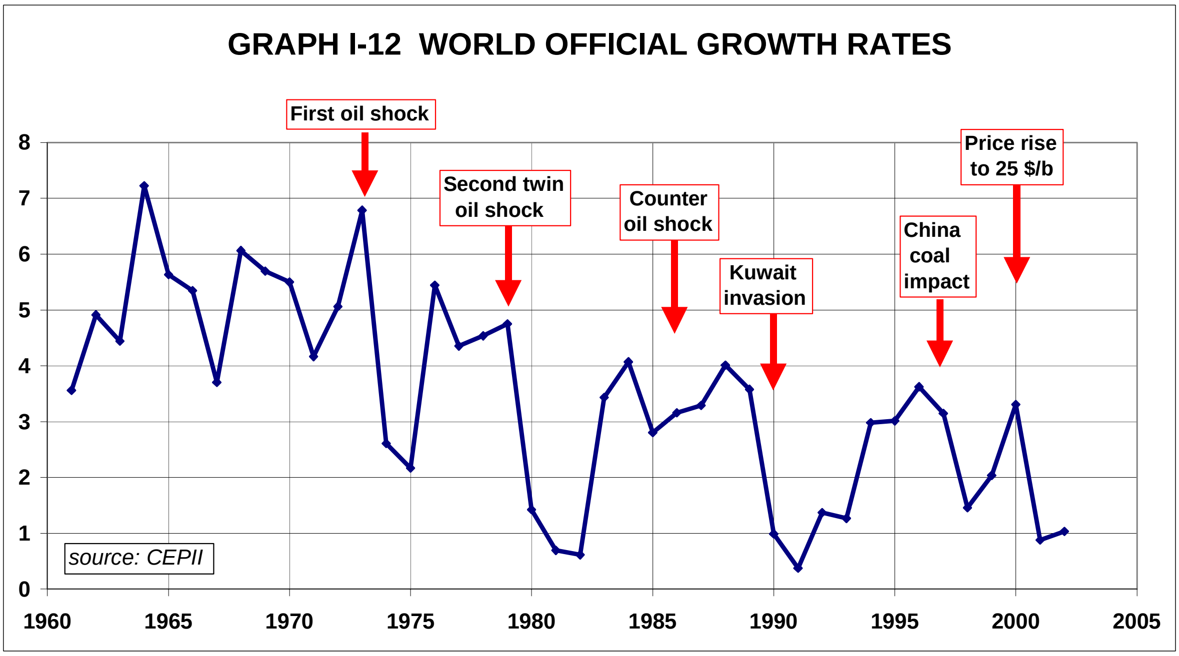
- Lack of energy availability: it has emerged from time to time since 1973 and may do so again;
- Lack of energy accessibility: in addition to its human and social dimension, it contributes to limiting the economic development of the poorest countries;
- Lack of energy acceptability: it is coming to the fore because of global warming and the threat of climate change.

Energy Availability

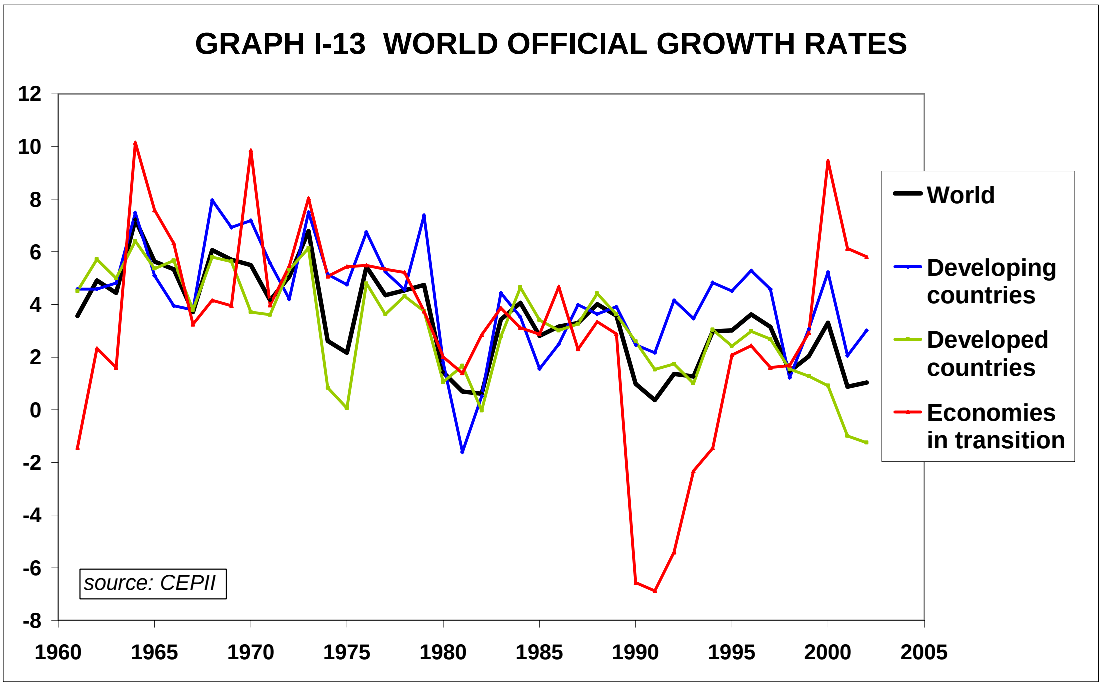
Cheap and stable energy prices have contributed to the exceptional world growth of the 1950s and 60s. This stable environment also explains the rapid growth of the share of the poor receiving modern energy, a factor of social equity that in turn has helped the economic performance of the developing countries. In a similar way, one may note that, after the strong GDP rebound of 1983-84, the world was heading for an economic slow-down in 1985-86, but the halving of oil prices in 1986 transformed it into the high growth of 1987-88.

Conversely, energy imbalances had negative impacts on world GDP growth as shown in Graph I-12:

- A reduction of about 6% (world growth of 2% in 1974 and 1% in and 1975 as compared to a 4.5% trend) in 1974-75 after the 1973 first oil shock;
- A reduction of about 7.5 % (world growth of 2% in 1980, 2% in 1981, and 0.5% in 1982 as compared to a 4% trend) in 1980-82 after the twin 1979 (Iranian revolution) and 1980 (Iran-Iraq war) oil shocks;
- An uncertain impact in 1990 when Kuwait was invaded by Iraq. The world economy was already slowing down because of the end of the business cycle and the coming financial crises, in particular the savings and loan debacle in the USA;
- Again, an uncertain impact in 1997 in China. Revised GDP fell by 8% (growths around 3% in 1997-99 as compared to a 5-6% trend) when coal supply fell by 30%. However, other reforms (reduction of the workforce in some ministries) and the Asian crises also contributed to this slowdown;
- Again, an uncertain impact in 2000 because energy developments (the oil price rise to 25 US$/b and the North American gas crisis) were only part of the story, with the end of the stock exchange market 'bubble' (in particular NASDAQ) also contributing to the end of the business cycle.



The world economy showed less volatility, however, than its three main regional components, as shown in Graph I-13. Volatility of economic growth is 1.1 times that of the world for developed countries, 1.8 times for developing countries, and 3.8 times for the economies in transition. This high figure for the economies in transition cannot be attributed to energy prices because, in this region, prices have not changed much. Conversely, in the market economies, there is a link between economic growth volatility and energy price changes. The recessions of 1974-75 and 1979-82 are mostly attributable to the oil shocks, and the energy sector contributed to worsening the recessions of 1991-92 (oil price increases), 1997-98 (coal supply decline in China) and 2001-03 (oil price increases again).



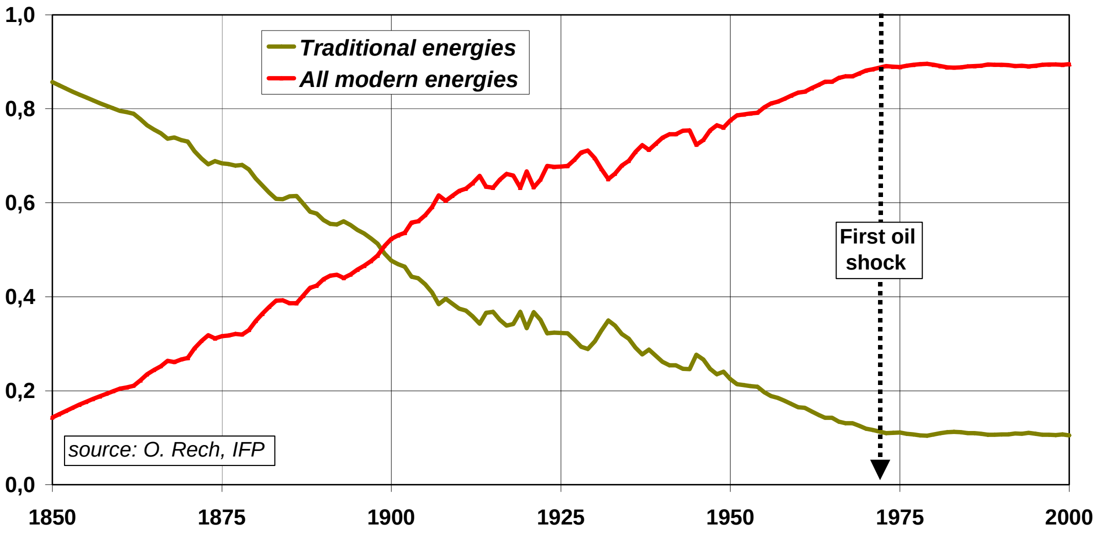
In the view of WEC, this will hold true for the future. If energy supply conditions are steady, allowing energy prices to decline slowly in constant money, this will contribute to higher economic growth. However, if energy availability is undermined from time to time (e.g., by the inadequacy of infrastructure), this could cause, or at least contribute to, temporary slow-downs of world GDP growth. While it is tempting to discount the impact of future energy supply shortfalls on the grounds that energy costs represent a much smaller share of the GDP than in the 1970s and 1980s, the reality may prove to be the opposite, because, other things being equal, the decline in GDP growth to drive the reduction in energy consumption that the supply shortage would require could be higher now that redundancies, flexibilities and room to manoeuvre in the energy sector have been reduced.

Energy Accessibility

Sustainable development depends on a combination of economic growth, social equity and environment factors. There is evidence to show that social equity and economic development are closely linked: unequal societies have lower economic performance than more equal societies. Hence the achievement of social equity has economic and not just moral overtones. This concept has many dimensions, including gender equality, basic education and adequate rural infrastructure (a focus on the latter by the Korean government certainly contributed to the take-off of the country in the 1980s) and is key for sustainable energy development.

For energy, sustainable development involves the provision of modern commercial energy[6] , including both grid (e.g., electricity) and non-grid delivery (e.g., LPG). As shown in Graph I-14, using the trend in dependence on traditional non-commercial energy as a proxy, modern energy accessibility has continuously improved in the world since 1850, when 85% of the total energy consumed was made up of traditional fuels (combustible renewables, i.e., biomass and wastes) up to the second oil shock, when they accounted for 11%. However, since then, the share of traditional fuels has not changed, meaning that the growing population has had to rely on these traditional fuels rather than modern energy services. Most of these people are in developing countries, often in rural or hard to reach areas. This prevents them from full integration in their societies and impacts negatively on their economic development. [7]

Graph I-14 MARKET SHARES OF PRIMARY ENERGIES



---

[6] An excellent description and analysis of this challenge is developed by the IEA in the 2002 *World Energy Outlook* (Chapter 13 – Energy and Poverty)

[7] The contribution of the poor may be direct, thanks to the greater quantity and improved quality of their work, or indirect because they support and spread strong social values that in turn contribute to the economic take-off and industrialisation of the country.

In the same way that market reforms may have a huge impact on economic growth by providing a business environment in which new technologies can develop, market reforms are also part of the ‘access’ agenda. As suggested in ETWAN, it is not inconsistent with market reform that sunk costs might be subsidised as long as commercial tariffs cover the running, maintenance and extension costs for electricity or natural gas grids and are actually paid by the consumer.

An order of magnitude estimate of the costs to provide a minimum of universal access by 2020 to those who have insufficient or no access today was calculated in ETWAN. Providing 500 kWh per person per year to the 0.6 billion lowest consumers of developing countries who only use 340 kWh presently and to the 1.6 billion who have no access would require 900 TWh (about 6% in addition to the 16,000 TWh of world consumption today). This would require 200 GW of additional installed capacity at a total investment cost of about 2,000US$/kW (generation, transmission and distribution), or a total supplementary investment of 400 G$. This amounts to about 20-30 G$/y between now and 2020, with the requirement that these users pay an adequate tariff. In special cases, ETWAN acknowledged that this tariff might require temporary, transparent and targeted consumer subsidies, but it insisted that the tariff reflect the true cost and actually be paid by the customer either on an individual basis or at least on a village or township basis.

Such an analysis links energy access firmly to the economic growth pillar of sustainable development. Not only is there the payoff which commercial energy access brings to the quality of life and productivity of those who gain it, but the utilities delivering the commercial energy will also be healthier enterprises contributing jobs and investment to the country as a whole. As already mentioned, the example of the Asian ‘tigers’, now followed by China, confirms that appropriate reforms leading to increased energy access is a recipe for economic growth.

Energy Acceptability

Among the factors that may affect GDP growth negatively is the question of environment. Setting aside the serious issue of local and regional pollution and their heavy impact on the health of mothers, children and others in developing and transition economies, climate change has become both a political and a scientific issue because of global warming, the phenomenon which occurs when the atmosphere cannot recycle all the anthropogenic GHG emissions. Given that the largest share of these emissions originates from the production and use of energy, principally from the burning of fossil fuels and the direct release of gases such as methane, there is the possibility that national or global emissions targets might result in taxation or regulations which lead to a strong increase in energy prices, possibly as much as, or even more than, those resulting from past oil ‘shocks’.

Despite the large gaps in the Kyoto Protocol (for example, not addressing GHG emissions with truly global targets which cover both developed and developing countries, the additional flexibility that the windfall emissions credits in the FSU or Eastern European countries provide, or the failure to address GHG emissions that occur prior to the delivery of the energy service at the border of the importing developed countries, that is, not measuring them on a life cycle basis), it is unlikely that the Kyoto Protocol objective of an average 5% reduction below the total GHG emissions of 1990 will be achieved.

Some policymakers have put their hopes in fuel switching, that is, moving from coal and oil power generation to a heavy dependence on natural gas. However, marginal gas is hardly better (in terms of life cycle GHG emissions) than marginal oil or coal, given its remote origin and its relatively inefficient use as a mid or peak-load fuel for power generation; the advantages of a shift from coal or oil to natural gas are small and cannot be the basis of policies aimed at drastically reducing GHG emissions. In that respect, it should be kept in mind that, by far, the most significant influence on GHG emissions from fossil fuels is individual end-use behaviour at the industrial, commercial and residential levels.

Others call for a steady or accelerated reduction in the use of fossil fuels in the world energy mix in favour of modern renewables or nuclear power. Reducing the use of fossil fuels calls for a combination of policies to dramatically and arbitrarily increase their prices or to favour non-fossil sources. Such policies are neither likely nor wise in the context of achieving universal energy access and the worldwide trend in demand for transportation fuels and electricity. In any case, price is a difficult instrument because it places too much onus on governments and energy efficiency improvements (a 20% reduction of energy intensity resulting from the two oil shocks of the 1970s, as discussed in Part III, was at a very significant macroeconomic cost). The order of magnitude of price increases to wean the world of its dependence on fossil fuels would be at least equivalent to the two oil shocks of the 1970s every 10 years! Energy efficiency policies have their role but cannot achieve energy acceptability on their own.

A focus on non-fossil fuels really means nuclear power, because, setting aside the burden of the very high costs and constraints that go with the new modern renewables (other than large hydro projects which face considerable local/regional opposition where they are still possible) there is no way at this stage to manage their intermittency beyond a roughly 10% market share. Of course, nuclear power is not an answer for the transportation sector, although the advent of a hydrogen economy based on nuclear power is within the realm of the possible, looking out 30-40 years.

The consequence is that the only long-term means to seriously address the question of energy-related GHG emissions while addressing the problem of universal energy access is to introduce clean fossil fuel technologies, coupled with carbon capture and sequestration, to reduce the GHG emissions from their production, transmission and utilisation. In WEC's view, it is a focus on best practices in power plant performance and cleaner fossil fuel systems which will provide the least cost and most effective reductions in GHG emissions in a reasonable timeframe. WEC has called for the extra costs of such systems and practices to be built into the prices of energy services based on fossil fuels. Today, for example, the estimated costs of carbon sequestration are 150-250 US$/tC, i.e., 3-5 times the cost of delivered coal and twice that of oil. However, if such costs were built into fossil fuel pricing, this would be equivalent to a major energy shock and would reduce world GDP growth by the same percentages discussed above. Obviously, such costs have to be brought down, and least cost carbon mitigation technologies of all sorts need to be judged in a competitive market context.

Thus, while the environment, or energy acceptability, has not been a major driver of the energy scene so far, it could become a key factor in the future, with negative impacts for the GDP growth at least in the order of magnitude of a series of serious energy shocks. The cost of GHG emissions management therefore links directly with the economic growth pillar of sustainable development and could also impact energy availability, at least in terms of affordability. However, perhaps the most serious linkage is with the energy accessibility pillar of sustainable development; if energy services become excessively more expensive because of government policy, regulation or pricing which aim to reduce harmful GHG emissions, this will be good for the environment while making the problem of universal commercial energy more difficult. Ironically, doing so will only prolong the use of traditional fuels by poor people in developing countries, thus exacerbating the global level of GHG emissions.

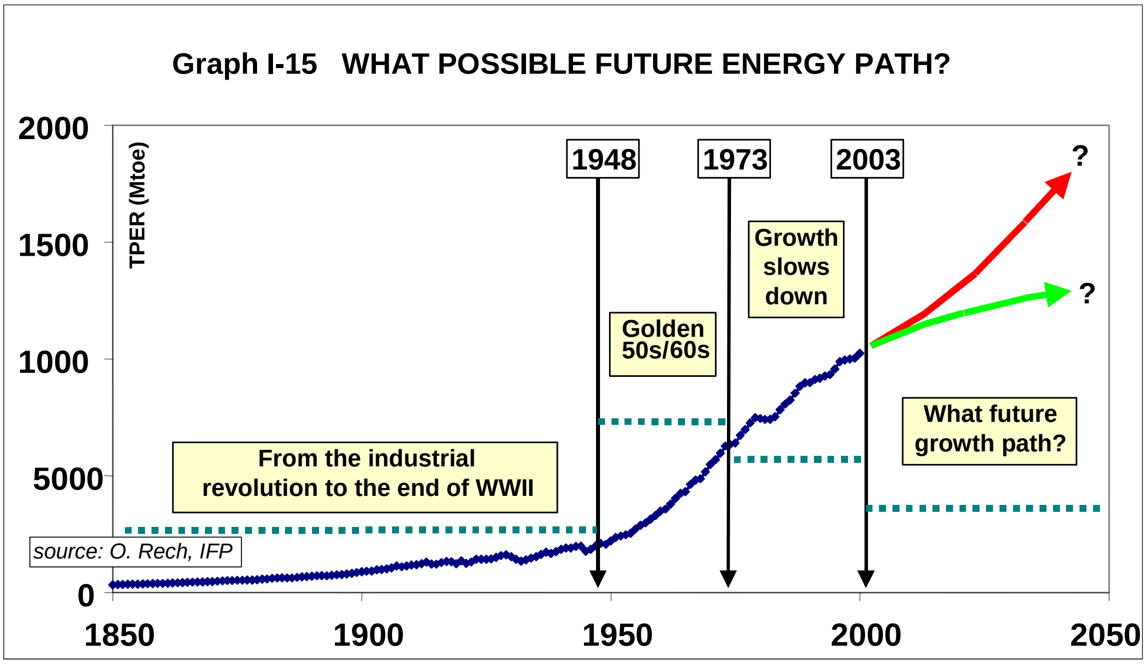
It is for this reason that in addressing energy acceptability, WEC has opted to focus first and foremost on the goal of universal commercial energy access, using the latest, cleanest technologies to simultaneously address harmful local, regional or global emissions. This is a win-win situation and one which this analysis of GDP and total primary energy requirements firmly supports.

C. CONCLUSIONS ABOUT THE 'GDP DRIVER'

The analysis in Part I can be boiled down to one question and one fact. The question is that raised by Graph I-15 in terms of future GDP and the energy path[8]. The fact is that humans - their growing number, particularly in developing countries, their capacity to change and improve things, their wish to compete and climb the social ladder, but also their willingness to work with others - are central to what the future holds for us all.

There were times when man thought that things had to remain as they had always been, with the son ploughing the field that his father ploughed before him. This vision radically changed during the Middle Ages. Man triggered the Renaissance and the first agricultural revolution, followed by the 18th-19th century Industrial Revolution, and further amplified by the spreading of all these new ideas, first from the Mediterranean to the Atlantic, then to the rest of the world. Today, we would more likely speak of a mother running a shop, with her daughter deciding to take a Ph.D.

Such changes would not have happened without a deep evolution of human society, i.e., the manner in which people interact with each other. Customary rights in the limited family or tribal environment of the early stages of development were sufficient but had progressively to be replaced by the formal rights that go with larger and complex human groups. Man remained central, but the institutions and the process of market reforms to continuously adapt them to the new needs that development creates also became central to GDP growth. The way this process will evolve, accelerating, evolving steadily or slowing down in the decades to come, is the key issue for the future of GDP and sustainable energy development.



[8] Most projections or scenarios (IIASA,US-DOE-EIA, IEA/OECD, OPEC, etc.) are optimistic about the future trends, which are generally concave, with exponential rates higher than 3% per annum, whereas a direct extrapolation suggests a convex slow-down.

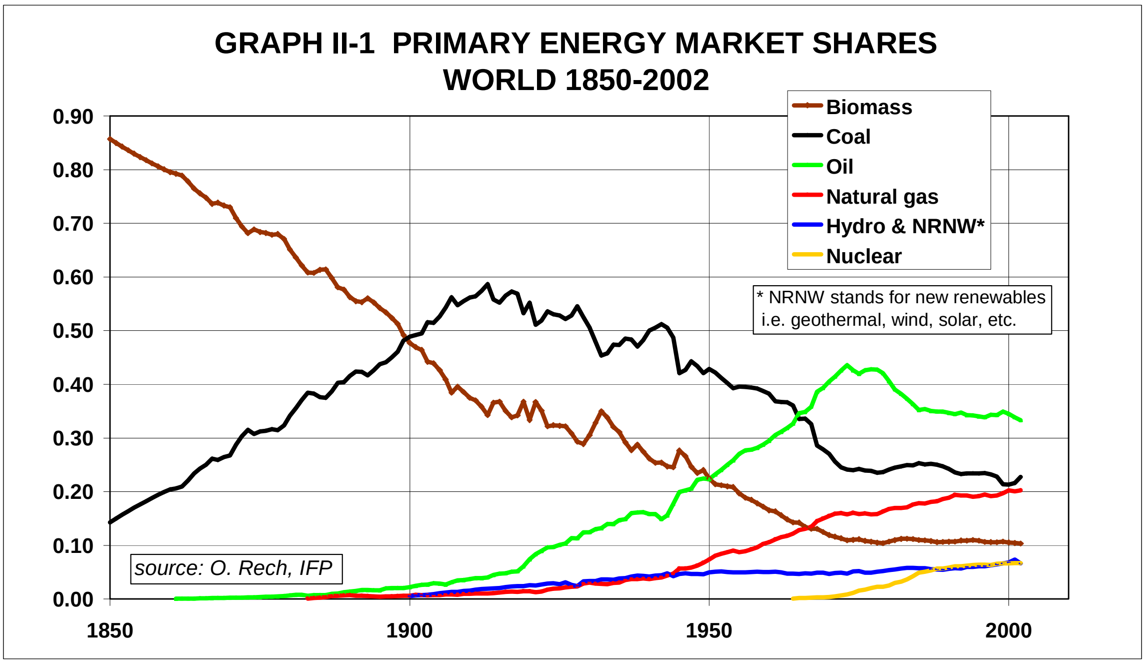
GDP growth does not depend solely on the behaviour of individual stakeholders – they will always draw the best from their business/institutional environment. It partly depends on the unpredictable vagaries of Mother Nature, with temporary energy imbalances which could affect GDP growth negatively. Finally, unless governments have the courage to push market reforms in the form of competition and customer choice or to support national programmes for electrification, including access to modern energy infrastructure, national economic growth will suffer, and average global GDP could decline, with significant implications for total primary energy requirements.

PART II: ENERGY DEMAND

A. THE STRUCTURE OF ENERGY CONSUMPTION

Part I analysed GDP and its linkage with total primary energy requirements at the global level. It provides a 'helicopter view' of how much energy service is needed to generate a given level of GDP and how this relationship changes with significant energy price movements. However, knowing how much energy is needed to support GDP does not tell us what kind of energy is required, the service it provides or how the components of energy services evolve over time, in particular whether each service maintains its proportion of total energy consumption.

The world has undergone significant transformation, both prior to the first oil shock when primary energy consumption was tightly coupled to the evolution of GDP PPP and even more after 1973, when energy requirements and GDP began to de-couple. This deep transformation is reflected by the changes in the world primary energy portfolio set out in Graph II-1.



- Traditional fuels such as biomass lost ground up to the first oil shock and have remained at about 11% ever since. Hence, modern energy access improved rapidly up to 1973 before slowing down considerably;

- Other non-fossil fuels maintain a stable share (as with hydro), have grown rapidly before reaching a significant plateau (as with nuclear), or have expanded rapidly from a very small base to a share which is still quite small (as with new renewables);
- Coal has followed a trajectory similar to that of traditional fuels -- a decline followed by a much lower plateau -- with another drop after 1996 reflecting big changes in the China coal situation;
- Natural gas, after its initial rapid growth of the 1950s and 1960s is now growing more slowly, with the growth of its market share even slower in the 1990s;
- Oil was ‘king’ up to 1973, in the sense of marginal supply and pricing as a substitute for coal, before declining in the face of post-1973 investments in other energies (nuclear, gas and now coal again). However, oil’s share has stabilised recently. This is treated in more detail in Part III.

Energy consumption depends on what consumers want in terms of the value to them of final energy services. There are essentially three elements in this valuation:

- What is fashionable and affordable in society in terms of lifestyle and consumption, for instance a VW beetle or a four-wheel-drive sport utility vehicle, an apartment downtown or a large house in the suburbs;
- The level of personal income, reflected in the trend of GDP PPP, and the way energy services improve their quality and reliability at a given cost thanks to technological advances;
- The final price of energy services, which incorporates the cost of primary energy, the fixed capital, the running costs of these services and the taxes/subsidies which come into play.

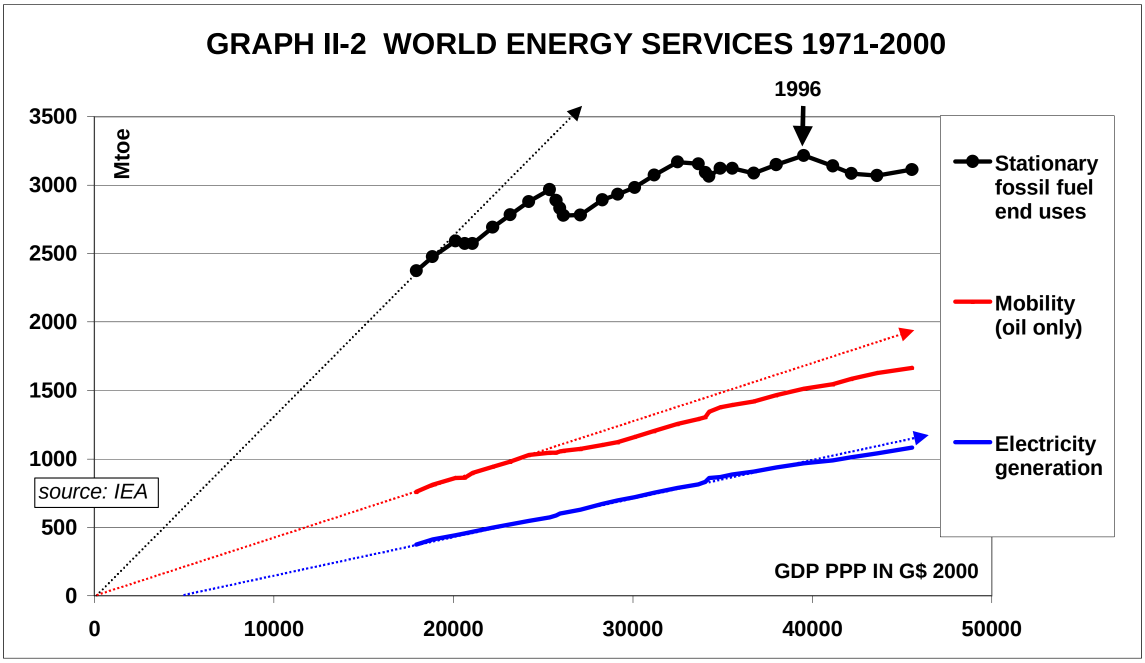
Today, some commentators would add that consumers also value the ‘green’ aspects of energy services, and indeed, some governments base energy policy and taxation on this component. However, there is much evidence that this type of valuation of energy services by consumers is not iterative in nature, nor is it widely held. Consumers in developed markets, where modern energy access is almost universal and payments are metered and collected, act strongly when their overall budget for energy service exceeds an intuitive share of their personal disposable income, while consumers in developing countries capture subsidies for energy access and are hard pressed to give them up or they have no choice but traditional non-commercial energy.

The Concept of Energy-Related Services

In national accounts, energy demand is often split among residential (households), commercial (services, including transportation) and industrial (industries and transformation sector) consumption. This approach has two handicaps:

- It is difficult to make a correct split between services and industry because most industries now sell ‘packages’ that include both a capital goods and a service component; and,
- It makes little sense to aggregate energy services that are not of the same nature, e.g., a warming service, the functioning of an electronic device or the moving of a car.

In fact, very little effort is made to split the mobility function into what is used for leisure, commerce or industry. This suggests that it is preferable to crosscut the traditional sectors and to focus demand on the specific energy-related services that consumers need, namely electricity, mobility and stationary fossil fuel end-uses, and to study the way they evolve over time. Such a categorisation approximates more closely end-user energy services than does the conventional categorisation.



Based on the latter concept, world final energy services consumption is shown in Graph II-2, which breaks out three services measured against world GDP (PPP in dollars 1990). Most regions in the world have experienced distinct and steady development in the three components of energy services since the end of the impact of the second oil shock in 1982, but for some it was more chaotic: the USA since 1996 with its apparent decoupling between GDP and energy consumption; China, where GDP rates need to be revised to reconcile GDP and energy requirements; and the Former Soviet Union and Central & Eastern Europe, where the restructuring since 1989 led to a massive drop in GDP and the emergence of a grey/black economy.

But only focussing on end-use has other problems. It ignores what happens in the transformation sector:

- The power plants to make electricity;
- The combined heat and power plants (CHP);
- The refineries, coking plants, gas-plants, etc.;
- The transportation and logistics to bring energy to end-users.

Even though the efficiency of upstream/midstream sectors of energy use are generally well correlated to that of final end-uses, one cannot ignore their impact on total primary energy requirements because they play an important role in the generation and dispatch of available energies resources into the final energy services demanded by residential, commercial or industrial customers.

Final Electricity

Electricity consumption, i.e., the total produced electricity (including losses as part of the 'consumption'), has a very regular trend, nearly linear, with no apparent impact from the energy events that happened during the period of the oil shocks. This constancy over time has two explanations. First, the electricity market is 'captive' with very little room to switch back to primary sources of energy. Second, real final prices have remained nearly unchanged over a long period of time because:

- Final prices include high fixed costs (capital costs of power plants, transmission grid and distribution systems, and personal costs) but small fuel costs;
- Within the fuel costs, oil and natural gas costs were variable, but the prices of the other primary energies such as hydro, nuclear and coal were more stable;
- Utilities were under public control at the time of the shocks and could not increase their tariffs much within the inflation policies of their government masters.

With deregulation, electricity prices have become more volatile and may affect industrial consumption either because the volatility is perceived as a source of uncertainty and risk or because sustained high prices for a few years may discourage some industrial investments (e.g., aluminium mills) and provoke the 'de-location' of plants (see the discussion later in this Part) that otherwise would have remained in the country. Captive users ignore the volatility because, even with the advent of retail wheeling, their contracts are mostly based on fixed tariffs.

Transportation: Oil for Mobility

The term mobility is used here for autonomous systems that use energy carried with the vehicle (embarked energy). Trains are excluded from this service when they depend on an energy supply that is not on board, as is the case with electrical trains, but are included along with cars, planes, and ships if they depend on their own embarked fuel. For obvious reasons of convenience (concentrated energy, easy to transport, distribute and store), liquid fuels, mostly derived from oil (gasoline, diesel, LPG, kerosene, bunkers), dominate this energy service at 98%, with the remainder accounted for by compressed natural gas, coal and electric batteries.

The trend in consumption of mobility energy services has been nearly as steady as that of electricity for similar reasons. It is a 'captive' sector, and real final gasoline prices have remained nearly unchanged in most regions because high fixed costs (transporting crude oil, refining it and delivering the products) and taxes that account for up to 80% of final prices 'cushioned' the impact of any increases in oil price. Indeed, the impact of real oil price increases, if any, has been more than 'covered' by general inflationary pressure in most markets. A major exception to the steady trend in mobility energy demand against GDP PPP is the USA market, precisely because of its much smaller taxes. Changes in USA mobility energy consumption are the origin of the slight change one may observe in the global trend in mobility end-use.

Stationary Fossil Fuel End-Use

Most fossil fuels used for this energy service are for heating/cooking in buildings and for industrial processes, but they are also used as raw materials ('non-energy' uses such as petrochemical feedstock, lubricants, asphalt, etc.). The data do not include secondary heat (because this heat would be counted twice, first as heat and, then through the primary energies used to generate it, thus hiding the improved energy efficiency achieved by CHP), nor do the data include biomass and wastes (a small part of the consumption of the industrialised countries but a large to very large share in developing countries).

The trend in stationary fossil fuel end-use consumption is totally different from those in electricity and mobility. It is broken several times, with each break associated with a fall in demand and a downturn of the slope of the trend thanks to increased efficiency. Four break episodes can be identified on the graph:

- The first oil shock, with the 1973-75 drop;
- The second twin oil shock, with the 1979-82 drop;
- The beginning of the FSU restructuring and the 1990 shock, with the 1990-92 drop;
- The decline of Chinese coal production and the change in the USA trend from 1996 onwards.

The 1986 counter-shock (price decrease) did not modify the trend because price changes have asymmetrical effects on energy consumption (there is nearly no impact if price falls, whereas a sustained price increase triggers the purchase of new, more efficient equipment). The impact of the 2000 oil price increase will only be reflected in new data for 2001 and beyond.

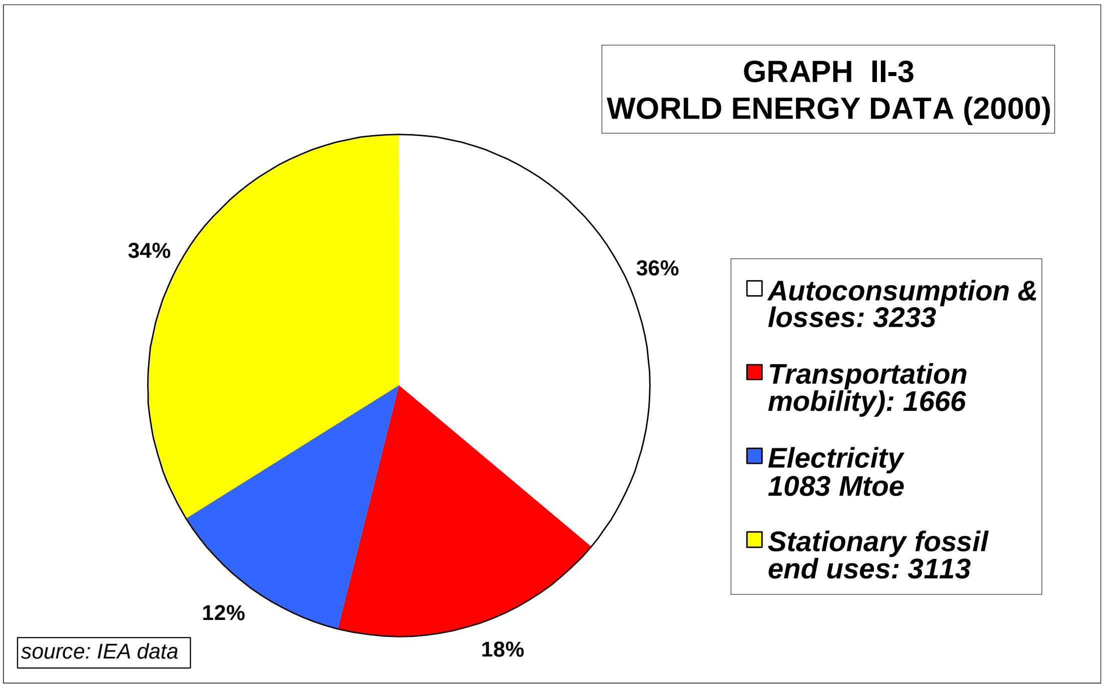
It should be noted that traditional energies such as biomass and animal waste are not reflected in the analysis of this service because of the poor reliability of the corresponding data (for instance, BP chooses not to mention them in its annual Statistical Review). However, it is acknowledged that in some countries, traditional energies do play a significant role in heating and industrial processes.

Intermediate Energy Consumption: Transformation and Logistics

The term intermediate energy consumption refers mostly to the losses when modern primary energies are transformed into electricity, final oil products or usable natural gas and coal, and transported to final users. Such losses could reach ~65% for electricity, ~25% for oil products, and ~15% for natural gas and coal.

This intermediate energy consumption accounts for the largest share of the total primary energy demand. The figures for the year 2000 shown in Graph II-3 are: TPER = 9.1 Gtoe (excluding traditional energy), with electricity = 1.1 Gtoe, mobility = 1.7 Gtoe, stationary fossil fuel end-uses = 3.1 Gtoe and all losses = 3.2 Gtoe. If one were to allocate the intermediate consumption or losses to final consumption, the ranking of the three energy services would be very different.

- Electricity would appear as the fastest growing (income elasticity close to 1) and largest energy service, at about 39% of TPER (~ 3.6 Gtoe/year);
- Mobility would appear as the second fastest growing (income elasticity of about 0.8) but smallest energy service, at about 23% of TPER (~ 2.1 Gtoe/year);
- Stationary fossil fuel end-use would appear as the slowest growing (recent income elasticity of 0.2) but the second largest energy service, at about 38% of TPER (~ 3.4 Gtoe/year).



Another important issue related to the intermediate sector, in particular for electricity generation and GHG emissions, is what primary energies are used. It needs to be stressed that:

- The different fossil fuels have, at the margin, similar GHG emissions on a life cycle analysis (LCA) basis; and,
- Non-fossil fuel sources (nuclear, hydro and other modern renewables) do not directly emit GHG (even though the flooding of some areas or the back up of intermittent renewables could result in additional GHG emissions).

One of the contributing factors to the impact of the first oil shock in 1973 was the heavy reliance on fuel oil in power plants. Yet ten years later, many countries had replaced fuel oil with either coal or nuclear without any significant impact on the long-term price of electricity. In other words, the unchanged electricity trend tells us little about the primary energies used for power generation. Should the political or scientific concern for climate change lead to policies or regulations which discourage the use of fossil fuels, a similar change might happen with large impacts in terms of primary energy prices and little in terms of final electricity prices and demand.

Thus, while there might be indications, for a variety of reasons, that the world is leaving an era of cheap primary energy prices, this would not necessarily translate into higher final electricity prices. The disaggregated energy services approach used in *Drivers of the Energy Scene* suggests that, when it comes to electricity generation, there is scope for fuel switching based on reliability, technical issues and life cycle emissions. This sheds further light on the discussion in Part I on whether the goal of energy acceptability is compatible with energy availability or energy accessibility. It is WEC's view that the three WEC goals for sustainable energy development are linked and could be achieved together over time.

On the other hand, the scope for fuel switching for mobility and stationary fossil fuel end-uses is very limited or non-existent at the present time. For mobility as it is defined here, i.e., that using embarked fuels, the energy service essentially relies on oil products and is likely to continue for many decades. While there are some signs of cooperation between the automotive and petroleum sectors on more efficient hybrid vehicles (WEC welcomes this), even the most optimistic scenarios could well require significant supplies of reformed gasoline or synthetic fuels based on biomass, natural gas or coal; furthermore, in the aviation sector, which until recently was one of the fastest growing components of mobility demand, there is no real alternative to kerosene.

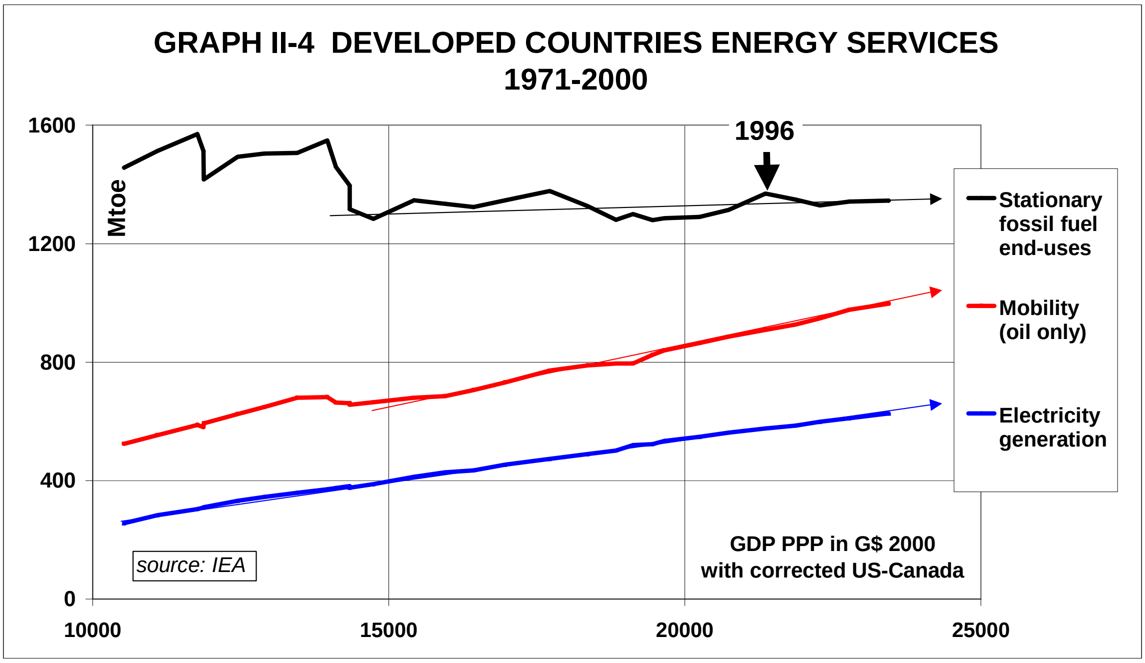
The fossil fuels used for final stationary end-use are not only similar in terms of GHG emissions on an LCA basis, but there are no purely environmental incentives to change consumption patterns, since the coal share is on a declining trend and gas, when available, is priced in a way that makes it systematically preferred to oil products.

B. WHAT DO REGIONAL TRENDS TELL US?

World trends say nothing about the regional dynamics of demand. There are important differences worth noting.

Developed Market Economies

As shown in Part I, the first oil shock nearly halted the economic growth in 1974 and 1975 in developed countries but had a smaller impact on their energy consumption than the second oil shock. One reason is that the USA energy market was insulated from international price movements prior to the first oil shock. Another reason is the time lag, perhaps five years or more, before new investments triggered by the 1973 oil shock came on-stream. A breakdown of the feedbacks on energy services over the last decades of the 20th century is shown in Graph II-4.



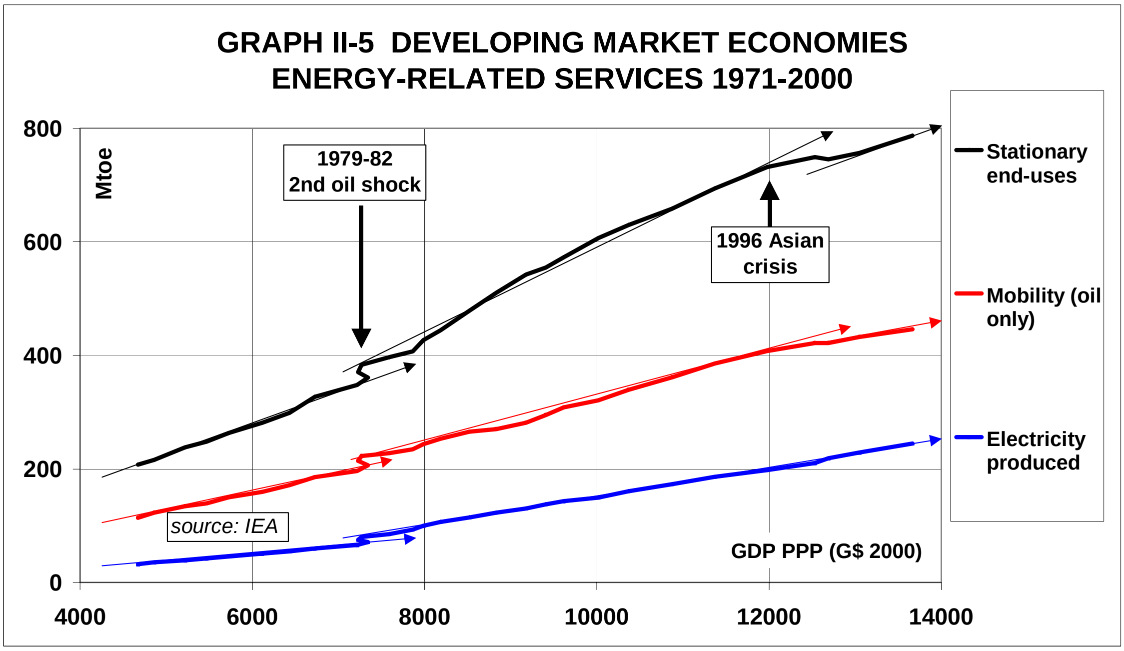
This time lag cannot be ignored because of its considerable consequences. After 1973, the new wealth of the oil-producing countries was recycled as 'petrodollars' that developing countries borrowed to build new industrial plants. These plants were built in the 1970s but came on-stream at the end of the decade or early in the 1980s, at the time of the second oil shock. Being new, and having good logistics, these plants were more competitive than the old OECD plants, which were generally uncompetitive in a context of high energy prices and redundant because of the world recession. Hence the apparent stronger impact of the second oil shock combined its own direct effects and the lagged consequences of the first oil shock in terms of industry 'de-location' and changes in the primary energies used for power generation.

The word 'de-location' should not be seen as the physical transfer of factories from the developed to the developing regions. Even if the opening of new plants in developing countries appears to be the consequence of the closure of those in OECD countries, the reality is the opposite: the opening of new competitive plants in developing countries with lower labour costs at a time of over-capacities caused the closure of the OECD plants. In terms of energy, the corresponding energy demand fell in OECD and increased in the developing countries.

Developing Market Economies

'De-location' is today an ongoing process, yet more regular and less intense than what happened in 1979-82 when the new plants came on-stream in developing countries. This explains why these countries now react to 'shocks' in a similar way rather than contrary to the reaction of rich countries as occurred in 1979-82 (see for instance the impact of the 1996 price rise in Asia due to the decline of their local currencies).

The first oil shock in 1973 had no direct impact on the GDP of developing countries and their energy requirements, possibly because they used little oil, mostly subsidised, at the time. Graph II-5 displays the impacts on energy services in developing market economies since 1971. Even without any direct impact, the first shock temporarily eased the financial constraints on those developing countries with exportable oil and gave rise to the recycling of 'petrodollars'. It is in this perspective that the apparent paradox between a GDP that did not grow from 1979 to 1982 and an energy consumption that increased (industrial 're-location', symmetric with the 'de-location' in developed countries) should be viewed and reconciled.

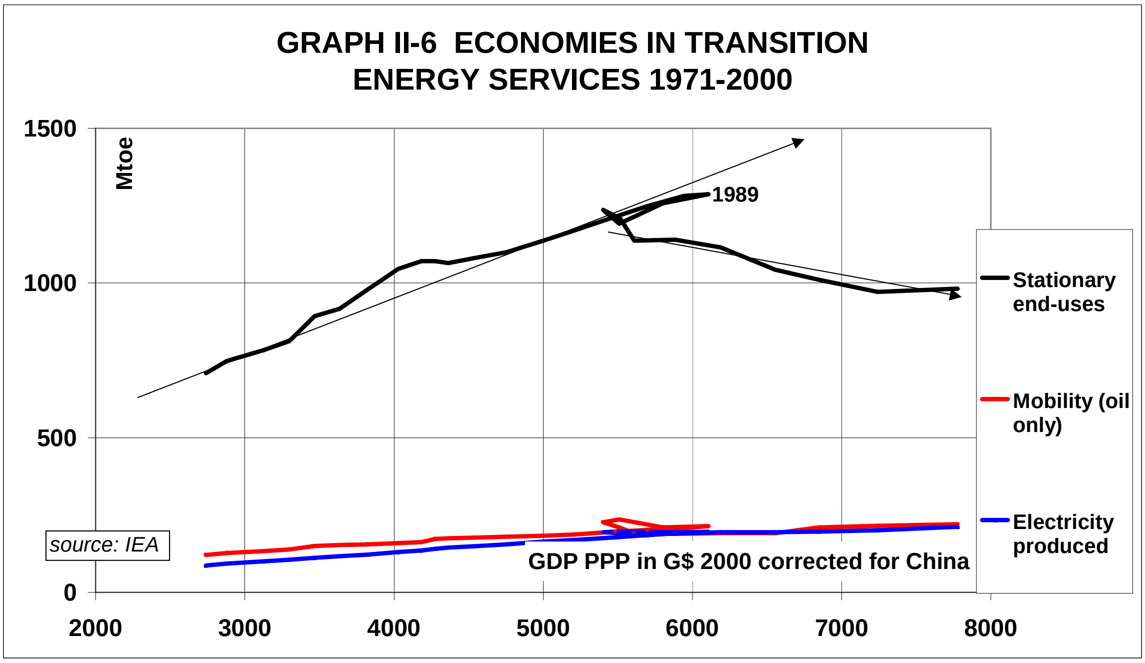


The most significant patterns in energy services that are common to the developed and developing countries are:

- For stationary fossil fuel end-uses, the high price sensitivity of this service because fossil fuels, especially for industrial use, are not (or only slightly) taxed. Demand for such services has now reached a plateau in developed countries and may soon decline due to higher taxes or charges as stricter environmental policies are introduced. In developing countries these services continue to grow strongly, but were slowed down by the Asian crisis of 1997-98;
- For mobility, the strong inertia of the trends, hardly broken although shifted downwards at the time of the second oil shock in the developed countries or at the time of the Asian crisis in 1997 (when local gasoline prices shot up as the result of the fall of the local currencies and policies aimed at reducing hard currency imports), with no evidence of saturation;
- For electricity, the even stronger inertia of demand shown by the constancy of trends over time, with the only exception being the USA where the trend has been moving downwards since 1996, a remarkable phenomenon that remains unexplained at this stage (unless one accepts that USA GDP estimates since then are too high, as discussed in Part I). In developing countries, the upward shift in electricity demand at the time of the second oil shock, is due to the 'de-location' of some industries, e.g., aluminium production in Venezuela and Qatar or pulp and paper in Indonesia.

Economies in Transition

In the economies in transition, the impacts on energy services are displayed in Graph II-6. Similar remarks can be made on the stability of mobility and electricity trends and the fall of stationary fossil fuel end-uses as compared to the trend before 1989. Because of the closed nature of these economies, Western oil shocks did not impact them. For political reasons, individual mobility was either prevented or not favoured and is much lower than in other regions of the world. On the other hand, the development of electricity has been more rapid because it was considered a priority symbolising 'modernism' and economic expansion.



Comparisons across Regions

Economies in transition are very different from market economies in other respects as well. First, as Table II-A shows, their energy intensities are higher than one would expect, possibly because the present GDP PPP estimates still under-value their true GDP. Second, the intensity of stationary fossil fuel end-uses in transition economies is very high because of the presence of heavy industries and unmetered or unpaid district heating. Thirdly, mobility and electricity have the same intensities, suggesting that electricity intensity is higher than one would expect, while the opposite is the case for mobility.

Among the developed countries, the USA has the highest electricity and mobility intensities, followed by Japan-Pacific and Western Europe. While this seems to be correlated with the economic ranking of the three regions, the principal reason is the different price environments in these regions. This also explains in particular the exceptionally high mobility intensity in North America. On the other hand, the similar and relatively low intensities in stationary fossil fuel end-uses of the three developed regions characterises the trend towards a declining share in the post-industrial age.

In the developing countries, the most interesting feature is the relatively low intensity of Latin America in terms of stationary fossil fuel end-uses. The reason is that coal is not plentiful in the region and where it exists, it is developed for export purposes; in Latin America there has also been a significant reliance on large hydro to produce cheap electricity. Another interesting feature of Latin America is the high mobility intensity because gasoline and diesel are subsidised in some large countries of the region.

Generally speaking, the ratio between mobility and electricity energy intensities is close to 2 in the developing countries, higher than in the developed countries (1.7 in North America, 1.5 in Europe and 1.3 in Asia-Pacific), and could probably be lowered with adequate pricing policies.

TABLE II-A
Regional Energy Intensities by Energy Service (2000) – toe/M$

Region	Electricity (total production)	Mobility (with embarked fuels)	Stationary fossil fuel end-uses
Developed regions	**26**	**42**	**56**
US & Canada	32	55	62
Western Europe	20	31	57
Japan-Pacific	25	33	51
Developing regions	**18**	**33**	**58**
Latin America	19	38	44
Africa & Middle East	20	36	79
Developing Asia	17	28	55
All market economies	**23**	**38**	**57**
Economies in transition	**39**	**40**	**179**
FSU & CEE	46	55	214
China/Hong Kong	32	26	145
WORLD	**25**	**39**	**73**

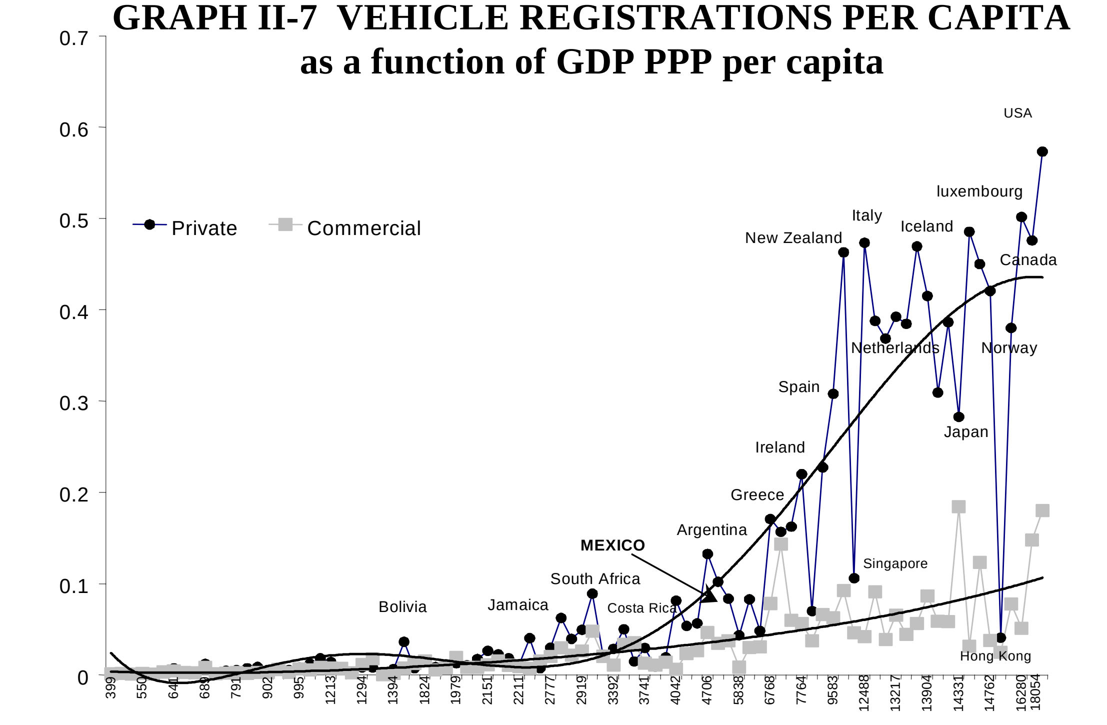
C. POSSIBLE TAKE-OFFS OR SATURATION OF ENERGY DEMAND

The Case of Transportation

The linearity of the consumption of mobility energy services as a function of GDP contrasts with actual vehicle registrations, which do not evolve in a linear fashion. As shown in Graph II-7, the number of cars per capita is very low up to a GDP PPP per capita of about US$3,000 (1985) or about US$5,000 in 2000 dollars, after which it takes off quickly before tapering off at GDP PPP per capita of about US$15,000 (1985) or about US$25,000 in 2000 dollars. Among developing countries, for example, Mexico seems to be on the threshold of a huge vehicle growth in the coming years, and it could be followed by large markets like China or India.

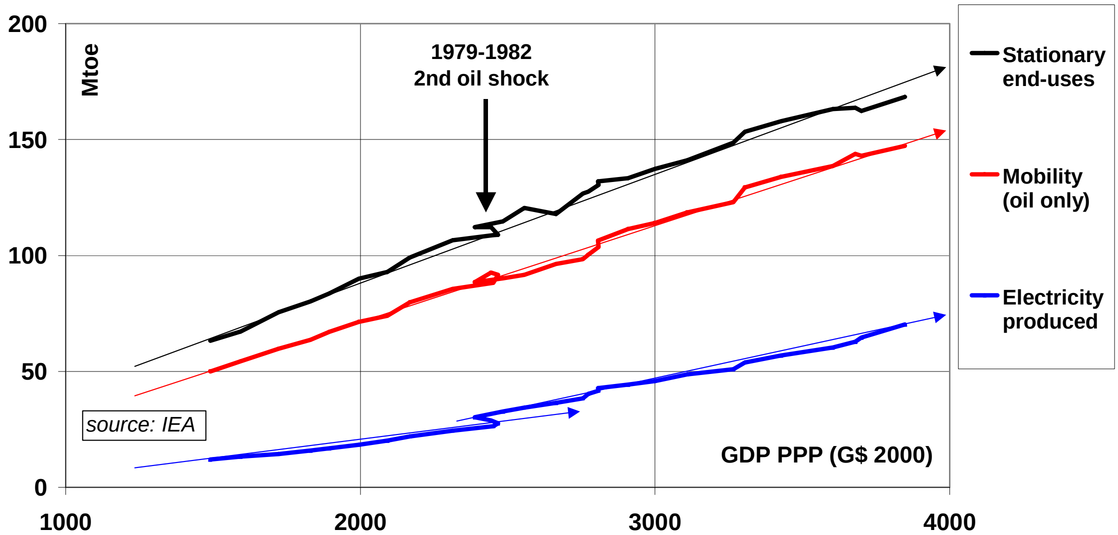
However, it is interesting to note in Graph II-8 that Latin American energy consumption in the transport sector as a function of total GDP PPP does not show any evidence of a take-off, nor does Graph II-2 for world energy services show such a take-off even though GDP per capita rose from less than US$4,000 per capita in 1971 to about US$6,000 in 2000. The growth in mobility energy services in developing countries is steady, probably because buses are used when few cars are available and/or because the individual consumption of new users is very low.

GRAPH II-7 VEHICLE REGISTRATIONS PER CAPITA as a function of GDP PPP per capita



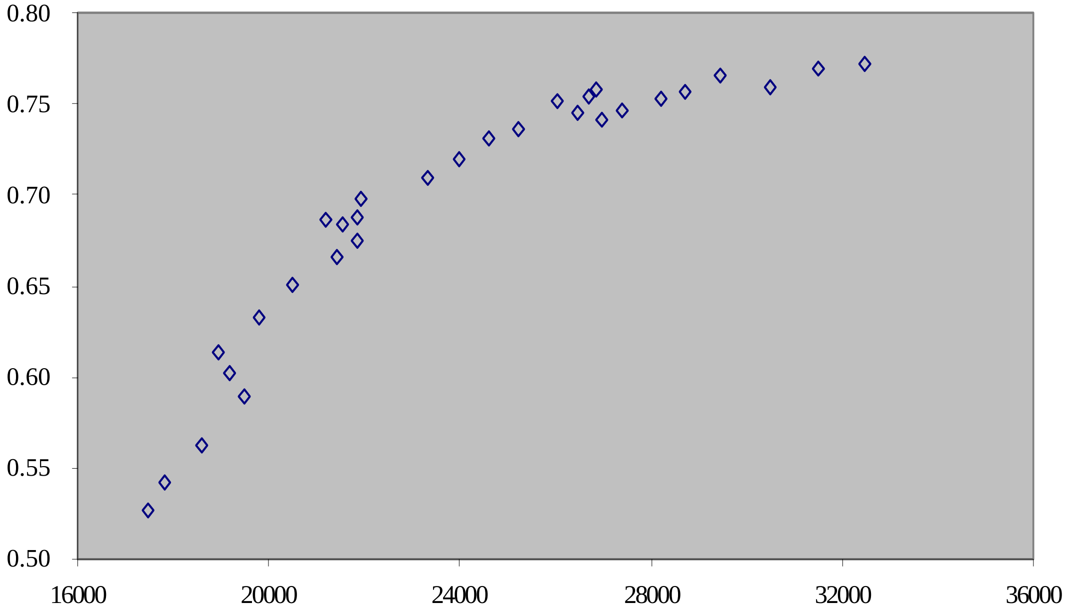
Source: M. Bauer, Mexican Petroleum Institute, based on AAMA database supplied by K.B. Medlock III

GRAPH II-8 LATIN AMERICA INCLUDING MEXICO ENERGY-RELATED SERVICES 1971-2000



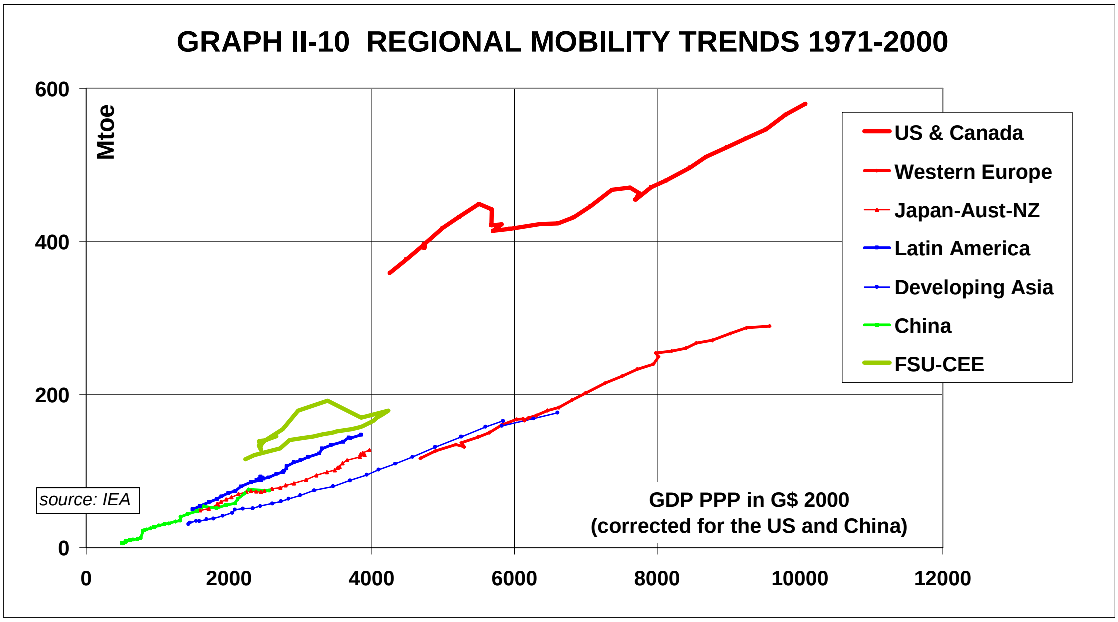
Graph II-9 shows vehicle registrations in the USA. It complements Graph II-7 for the high GDP PPP values per capita and confirms that the number of cars per capita slows down towards a saturation level beyond GDP PPP per capita of roughly US$20,000 (1995 dollars) or about US$24,000 in 2000 dollars. For the USA, this saturation is about 0.8 cars per capita, but it is safe to say that different saturation levels exist in each country as a function of national circumstances (mostly depending on final fuel prices, the level of taxes and, to a lesser extent, the density of the population). Japan, for example, has a much lower saturation level than the USA.

GRAPH II-9 USA VEHICLE REGISTRATION (vehicle per capita versus GDP PPP per capita)



Source: A. Shihab-Eldin, OPEC Secretariat

Graph II-10 compares mobility service trends in several regions of the world. The USA-Canada trend that was jarred somewhat by the price increase of the second oil shock has remained linear even for GDP PPP per capita now exceeding US$30,000 (2000 dollars) in spite of the progressive saturation in the number of vehicles per person in the USA. The continuous increase of consumption suggests that individuals in the USA and Canada may, with higher incomes, switch to larger and less efficient vehicles (for example, sport utility vehicles) or use vehicles in a wider range of activities. One may also observe that, in similar fuel price environments, there is a linear continuity from low to high income, for instance, with the trends of developing Asia and Western Europe.



There seems to be no evidence of mobility saturation in developed countries as a whole. If one believes that 'consumers will use as much energy as they can afford', this simply means that while one cannot drive two cars at the same time, a person might choose a bigger car and run it more miles. Up to now, and possibly for some time in the future, physical limitations to mobility - ownership, number of miles travelled, congestion – will be offset by the size/power of the cars and their use on the outskirts of the cities where transportation is the adjustment variable of low urbanisation.

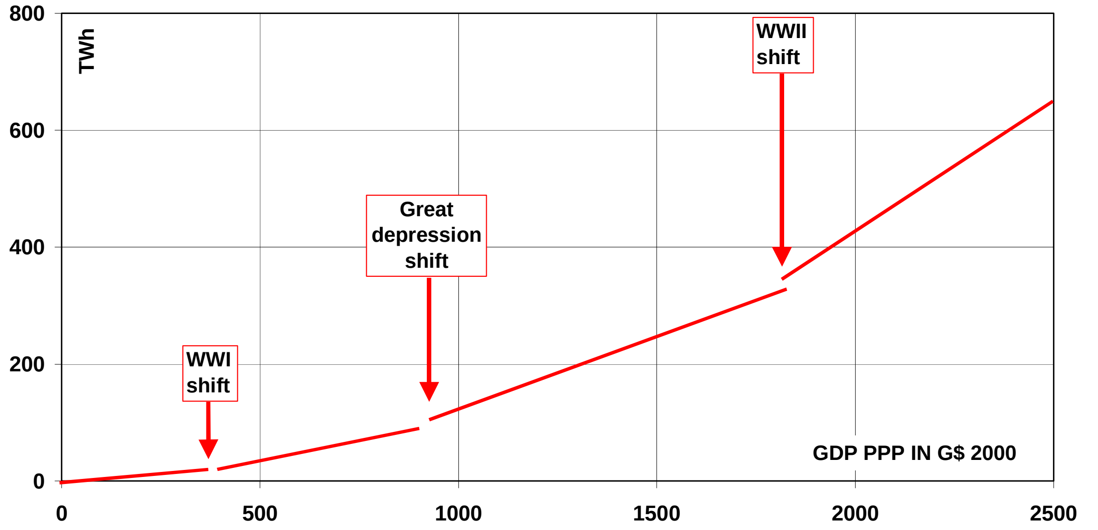
The case of China has been highlighted many times in this report, so it is worth pondering the future effect of current government policy to encourage private car ownership. According to Lin Gan in a recent energy policy publication, China puts emphasis on increased private car ownership as a means of stimulating personal consumption and economic growth through automotive sector growth and infrastructure development. Thus Chinese vehicle stocks almost quadrupled from 1985 to 1995, with an average annual growth of over 14%. According to Dongquan He and Michael Wang of the Center for Transportation Research at Argonne National Laboratory, by 2030 total Chinese motor fuel consumption and CO_2 emissions could reach the current USA levels.

The Case of Electricity

Whatever the increased performance of appliances such as refrigerators, the same basic rule still seems to apply to electricity, namely that 'consumers will use as much energy as we can afford'. In fact, with the sole exception of the USA (as already mentioned), electricity trends against GDP display a linear relationship. Electricity consumption goes hand-in-hand with technical innovation because many new appliances need an electricity supply, in particular all the developments centered on information technologies.

Very large technology breakthroughs and major innovations shift the electricity trend upwards, as if suddenly, electricity were offered new markets to penetrate. This is highlighted in Graph II-11. One may wonder whether the IT revolution might continue to provoke such a break in the future. Should that happen, the phenomenon would first affect the USA, the most advanced and flexible economy in the world. However, the higher US productivity growth since 1996 happened in the context of a downward shift in electricity demand, with electricity consumption lagging the earlier linear trend of consumption.

GRAPH II-11 ELECTRICITY TRENDS IN THE US & CANADA
(Indicative - after Chauncey Starr & Milton Searl, EPRI 1985)



The conclusion is that electricity demand growth below or above the past trends seems unlikely. The only country that shows a new and lower trend is the USA, but this apparent change of trend since 1996 requires further scrutiny because it runs counter to what the new IT revolution would normally have generated.

Recent events have shown that competitive electricity markets do not always perform as well as expected. The fragility of the electricity grid was highlighted in Canada with the ice storm of 1998 and in France with the high winds of 1999, with serious economic consequences. However, capacity problems and technical losses leading to blackouts and brown-outs, which market reforms are meant to address, have been a common occurrence in a number of developing countries; indeed, in the United Kingdom the number of failures in the system has declined by 10% in the last decade, and their duration has fallen dramatically. However, there are now questions about whether something of a more fundamental nature is afoot which could impact GDP and therefore energy demand. The first signal occurred in the USA market with the California crisis in 2000, followed by the experience in Brazil in 2001. In one case, there was a lack of investment in new generation capacity, which could not be combined with shorter hydro and gas-based supplies from neighbouring markets, while in the latter, there was a lack of transmission infrastructure between the two main hydro basins coupled with a serious drought in a large part of the country. In 2002, the cold spell in Norway and Sweden could have triggered a major supply crisis if hydro had not been 20% higher than normal. More recently, during 2003, the major blackout in eastern North America, the partial London blackout and the blackout in eastern Denmark and Sweden are under serious technical and economic scrutiny to determine their longer-term implications.

The Case of Stationary Fossil Fuel End-use

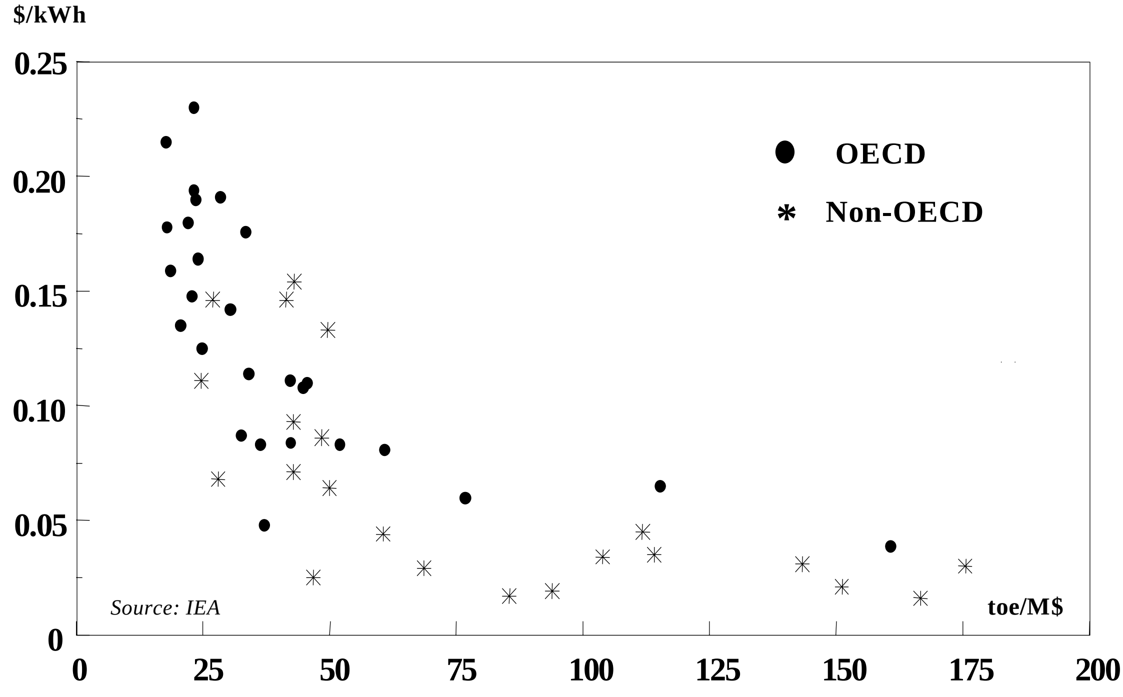
The increased growth of electricity is associated with income elasticities higher than one and even much higher -- up to two -- during the early stages of growth of the developing countries. This growth occurs at the expense of stationary fossil fuel end-uses, and it is not surprising to find that this service was already growing more slowly than GDP before the first oil shock, nor that this growth has slowed even more because of the impacts of energy price increases since then. Stationary fossil fuel end-uses are hardly growing in the developed countries, but even in the developing countries, the rate of increase has started to slow down.

D. THE ROLE OF FINAL ENERGY PRICES

Whatever the energy-related service or sub-service, one systematically obtains the same kind of hyperbolic relationship, with energy intensities being roughly inversely proportional to final prices (-1 price elasticity). Such final price elasticities may look large, but in the case of electricity, and to a lesser extent mobility, they apply to final prices that include many cost elements: the capital cost of power generation, the costs of transmission and distribution and the taxes or shadow costs associated with political constraints (environment, security of supply, universal service, burden of subsidies, etc).

The cost of primary energy fuels is only a small share of the final price, and within that pool, the share of oil and gas is even smaller. The consequence is that electricity prices are not very sensitive to the prices of the most volatile fuels, namely oil and gas, because the large fixed costs cushion their impact. Graph II-12 compares the electricity/GDP trends for the different regions of the world.

GRAPH II-12 ELECTRICITY INTENSITY OF THE GDP VERSUS PRICES IN THE RESIDENTIAL SECTOR



Graph II-13 displays:

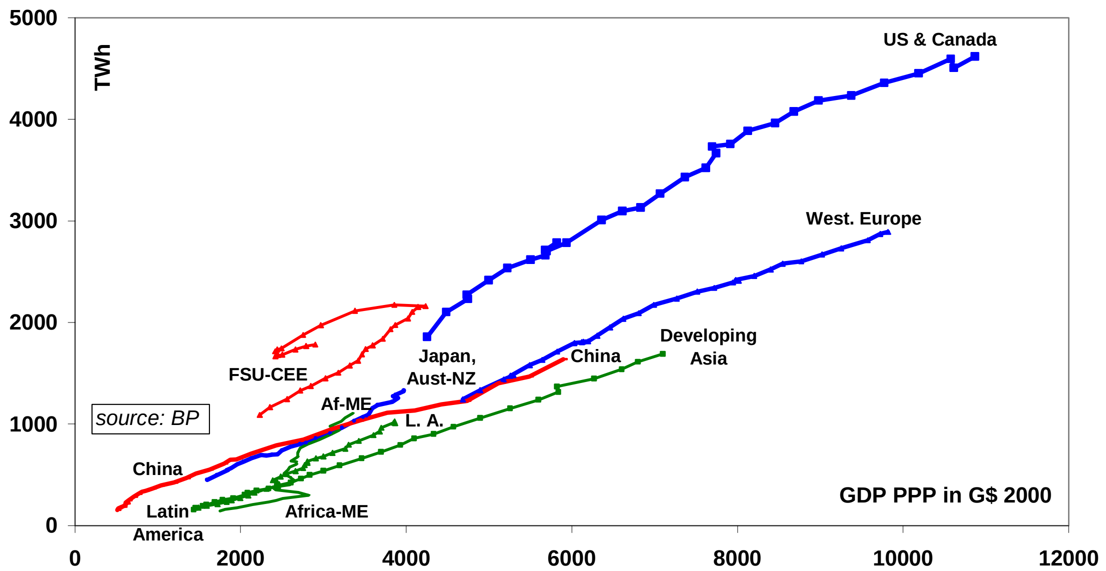
- Three developed regions (USA-Canada, Western Europe and Japan-Pacific);
- Three developing regions (Latin America, Asia excluding China, Africa & Middle East); and,
- Two regions with economies in transition (FSU & CEE and China).

One finds linear trends with slopes that inversely reflect the average electricity price:

- Low prices and high intensities for the economies in transition (one may note that the trend in China was consistent with that of FSU & CEE up to the end of the 1970s);

- Low prices and high intensities in the USA versus higher prices and lower intensities in Europe and Japan-Pacific (Japan's high costs are slightly weighed down by Australia/New Zealand prices);
- Different prices in developing countries (not directly comparable to those of the other regions) ranking from the highest in Africa, then developing Asia, Latin America, and Middle East.

GRAPH II-13 REGIONAL ELECTRICITY TRENDS 1971-2002



Factors Influencing Prices

As mentioned earlier, final energy service prices depend on primary fuel costs and on fixed costs, such as capital costs of energy infrastructure and political taxes and constraints. The share of fixed costs added to the primary energy component varies. Hence the influence of primary energy prices also varies:

- It is large for industrial final fossil fuel uses;
- It is medium for residential/commercial final fossil fuel uses, power generation and mobility in regions with small fixed costs (low taxes as in the USA, Latin America or Africa/Middle East);
- It is small for electricity used in industry; and,
- It is very small for oil mobility in most other regions or final residential/commercial electricity use.

The three factors that may contribute to changing final prices are:

- Energy imbalances that affect the primary energy component;
- Market reforms that may influence both fixed and fuel costs;
- Environmental constraints that influence the fixed costs and the choice of primary energy.

Energy imbalances are discussed in the third part of this report, which is devoted to 'supply'. They trigger price increases, and the experience of the first two oil shocks shows that the price rise needs to be high enough to slow down GDP in order to readjust energy demand at the level of the available production capacities. The smaller the share of captive uses that have a high price elasticity (unfortunately, more the case today as compared to the time of the oil shocks), the higher the price rise and the decline in GDP that will be needed for the readjustment of demand to supply.

For the sake of simplicity, with respect to oil, let us take refinery losses, building and mobility as price-inelastic uses whose consumption is not sensitive to the price of crude and power plants and industry as the only price-sensitive uses. Based on Table II-B, the share of oil demand sensitive to price has shrunk from 34% (first and second oil shocks, i.e., before the structural changes that began only after 1979 because of the long lead times for new investments) to 26% today (a 30% shrinkage). As the share of price-sensitive sectors has declined, the needed price rise to get the same kind of reduction of oil demand as for the previous shocks is probably higher than the tripling of prices which occurred during the former shocks. Thus, other things being equal, if an imbalance were to appear on the oil market, a four-fold increase up to 100US$/b might be needed to achieve the necessary 'correction' in demand. Fortunately, the build-up of the strategic reserves of IEA countries would dampen, at least on a short-term basis if they were wisely used, such a potential price rise.

TABLE II-B ELASTIC AND INELASTIC OIL USES (MTOE)

	Total world consumption	Refinery losses	Power generation	Industry	Buildings	Transport (incl. bunkers)
1973	2753	165	392	557	666	973
1979	3105	160	412	616	747	1170
2000	3519	183	360	570	643	1763

Market reforms lead to increased competition and volatility of prices, and for electricity, to increased sensitivity to oil and natural gas prices. Formerly, electricity prices were under the control of the state authorities and therefore based on an averaging of all the costs in which oil products and natural fuel costs were only a small part; these prices were barely susceptible to change. Now, in a competitive market, prices are set at the margin, i.e., by the last plants in the merit order, which are those using either oil products or natural gas. In addition, fixed costs may contribute to the volatility if they are not paid in periods of excess capacity and are recovered by price spikes in periods of scarcity.

It is likely that most of the increased volatility of electricity prices under market reform results from imbalances between demand and supply. Some of these imbalances result from inappropriate market reforms (aimed at short-term price reductions at the expense of long-term investment). Some would have occurred whatever the institutional framework (e.g., the fall of the domestic gas supply in North America and Europe). In the long run, it is the view of WEC that the combination of competition and customer choice under market reform, coupled with appropriate regulation that also addresses infrastructure and long-term capacity issues in an investor-friendly manner, will allow price signals to generate adequate investment, although it may be expected that the new market will be better integrated and therefore less volatile.

GHG emissions may become such a concern because of the threat of climate change that they lead to strong policies in favour of carbon abatement. The energy sector, being the largest contributor to anthropogenic GHG emissions, will be the first to be affected. Once the easy reductions (for example, emissions trades, fuel switching, reducing natural gas flaring) have been achieved to meet government-imposed targets, the next stage might be much more difficult, with taxes or charges which could approach the significance of earlier oil shocks.

However, even though all scenarios published so far envisage high and growing GHG emissions and a strong focus on energy accessibility, this should not be taken absolutely for granted. As shown in this study, one may also envisage market dynamics with lesser economic growth and increased energy-economy decoupling that result in GHG emissions peaking around 2050 before declining. Should this kind of scenario happen, GHG concentrations would then remain below 550 ppm, or roughly a doubling of the pre-industrial concentration in the atmosphere. This would allow the focus of energy policy and international negotiation to remain on poverty eradication and least cost carbon mitigation in the achievement of universal and affordable energy access and availability.

Possible Impacts of Price Increases

Table II-C is indicative and qualitative. It is an attempt to summarise the possible impact of a higher real price for oil and natural gas.

TABLE II-C
REGIONAL AND SECTORAL IMPACTS OF HIGHER REAL OIL AND GAS PRICES

	Mobility	Electricity in industry	Electricity for others	Stationary fossil fuel end-uses in industry	Stationary fossil fuel end-uses for others
USA	Strong	Average	Very small	Strong	Small
Other rich countries	Small	Small	Very small	Strong	Small
Developing countries	Medium	Small	Small	Medium	Small
FSU-CEE	None	Medium	Small	Very strong	Very strong
China	Medium	Small	None	Very strong	Medium
World	**Small**	**Small**	**Very small**	**Strong**	**Medium**

It is impossible to anticipate to what extent the three factors of energy imbalances, market reforms, or GHG emissions will influence future energy prices in net terms. However, if one were to assume a world of higher real oil and natural gas prices, this will impact the regions where transportation is still not (or only slightly) taxed: North America, Latin America and Africa/Middle East. One could also imagine that the price of electricity will rise only a little thanks to the cushion of fixed costs which serve to absorb the increase in fuel costs, especially for the residential/commercial users.

Furthermore, it is likely that the decline of stationary fossil fuel end-uses will continue, thanks to better insulation, heat recovery in CHP systems and better efficiencies, but higher oil and natural gas prices could lead to a faster decline in energy use in industry processes as opposed to residential/commercial sectors, which bear higher fixed costs (distribution and taxes).

Mobility might offer more of an opportunity for significant change. Table II-D lists a variety of radically different technology options. However, the economic costs in comparison with oil products are either equivalent (natural gas), higher (synthetic liquid fuels) or much higher (hydrogen). Environmental benefits, if they were conducted on a life cycle analysis basis, would be unconvincing except for hydrogen made from nuclear power. In addition, there are huge technical barriers, such as the conversion of the fleet, the adequacy of infrastructure, etc.

Another radical yet simple option for changing mobility energy patterns is to use more electrical trains which rely on fixed infrastructure and electricity that can be produced without harmful emissions. These are the most energy-efficient and the most energy-flexible means of transportation the world will ever have. Whereas cars can only achieve 25 to 50 gross ton miles per gallon, airliners 60 to 65 gross ton miles per gallon, buses 110 to 120 gross ton miles per gallon and trucks 120 to 200 gross ton miles per gallon, electric trains can achieve 750 gross ton miles per gallon.

TABLE II-D
EMISSIONS OF CO_2 ACCORDING TO DIFFERENT ENGINE/FUELS FOR ROAD TRANSPORTATION

Energy	Origin	Engine	$C0_2$ g/kWh	Efficiency kWh/km	CO_2 g/km	$C0_2$ g/km comparison
Diesel	Oil	Diesel	308	0.54	166	1.00
Diesel GTL	Natural gas	Diesel	376	0.54	203	1.22
Dimethyl ester	Biomass	Diesel	201	0.54	110	0.60
Gasoline	Oil	Spark ignited	327	0.66	216	1.30
ETBE	Corn, beets + oil	Spark ignited	278	0.66	183	1.10
Ethanol	Corn, beets	Spark ignited	169	0.66	111	0.70
Natural gas	Natural gas	Spark ignited	224	0.54	121	0.73
LPG	Oil, natural gas	Spark ignited	276	0.66	183	1.10
Comp. H2	Nuclear+electricity	Fuel cell	151	0.40	60	0.36
Comp. H2	Gas + electricity	Fuel cell	388	0.40	155	0.93
Liquid H2	Gas + electricity	Fuel cell	627	0.40	251	1.51

Source: French Petroleum Institute

The evolution from cars, trucks and possibly short-haul airliners to trains may seem obvious, but the past reveals the opposite with a decline of train market share in favour of other means: cars for individual mobility and trucks for moving goods. Technology can do a lot but is disarmed if the price signals are wrong. Given their importance and the need to reflect the full costs borne by society, governments have a key role to play. Even if some habits are so deeply entrenched that they seem impossible to modify, there is room for change, especially at the very time when external events, for instance, an energy price rise, may act as a trigger.

E. ENERGY EFFICIENCY AND PRICE CHANGES

If final prices had remained stable in each region, one might imagine that final energy-related services would have evolved regularly with rapid growth of electricity (it fulfils new needs and replaces fossil fuels), stable growth of mobility and a fossil fuel end-uses trend reflecting the substitution of traditional fuels by fossil fuels, and fossil fuels by electricity.

This evolution follows that of the whole economy, from industry to services, and has existed since the Industrial Revolution, even though it is not apparent in the one-to-one relationship between TPER and GDP up to 1973 and is not driven by prices but by technical changes and a general drift towards a more efficient economy.

However, the price changes associated with the shocks discussed in this report (oil hikes or regulatory reforms, such as those related to the closing of the village coal mines in China) have changed this pattern.

The largest impact is on industrial fossil fuel end-uses (low taxes or fixed costs to soften the impact of higher energy prices), further exacerbated by the closure of a number of old industrial plants that had became uncompetitive versus recently built competitors in developing countries, such as Brazil and Korea. Price changes also had an impact – although a smaller one -- on the buildings sector because higher taxes and fixed costs ‘cushioned’ the primary energy cost rise. On the other hand, mobility final prices and trends have changed little and electricity not at all.

Between the major shocks, when prices were stable, the established trends have been linear. They neither came back to their former shape, as if the efficiency improvement were locked into the economy, nor continued to move downwards because of efficiency policies.

Energy efficiency has improved considerably over the last 30 years with, for instance, the average consumption of a refrigerator or a washing machine being halved and the average fuel efficiency of cars being improved nearly as much. Yet the overall consumption in the two sectors has apparently evolved independently of these technological advances. Similarly, better building codes have had no apparent permanent impact on the trend in energy use in this sector. One finds similar results for heating, electricity and mobility. In other words, energy efficiency improvements appear to have been 'captured' by consumers to increase their well-being but not to reduce their energy consumption, as if consumers were keeping their energy budgets as a constant share of their spending, whatever the final energy price. These questions are of sufficient importance to WEC that a special study on *Energy Technologies for the 21st Century*, covering mobility, buildings, industrial processes and cross-cutting technologies, will be completed in 2004.

Lifestyle impacts were mentioned earlier as one of the elements of the demand for energy services. However, there is a lack of evidence that lifestyles are a discriminating factor across regions at the present time. With the exception of the economies in transition prior to 1989, which at the time were 'closed economies' emphasising electricity growth and limited mobility, all other regions of the world follow the same basic pattern as if lifestyle were 'standardised'. Moreover, several consistent approaches, including both empirical data and economic theory, support the view that there is no sustainable way of rapidly and cheaply lowering energy intensity merely on the basis of standards or technological advances.

The constancy of energy service trends over time in a context of stable final prices confirms first, that consumers behave rationally (some may 'over-consume' or 'under-consume' energy, but their aggregated behaviour closely tracks the level of final prices), and second, that 'energy efficiency' policies have had little, if any, impact on energy consumption (as long as they have not affected final energy prices, either directly through taxes or indirectly through binding regulations).

Theory tells us that, for an economy in equilibrium, all economic inputs (capital, labour, energy) have the same marginal economic productivity. That means that the welfare benefit drawn from the spending of one extra unit of money is the same whatever the input (or economic factor) on which it is spent. Given this obvious rule (nobody would expect to have much larger benefits in spending an additional dollar on, say, energy than on other inputs and not act accordingly), if the price of energy is high, one will use a mix of inputs with more capital and other inputs and less energy. Conversely, a low energy price will lead to higher demand for energy services at the expense of other inputs.

The negative impact of a price rise or the positive impact of a price decrease on energy demand should not lead to the conclusion that it is better to have low energy prices. On a steady state basis, economic growth can exist either with low or high energy prices as long as inputs may be substituted for each other and create an optimum mix. However, on a transitional basis, an energy price rise will lead to adjustments that lower the productivity and GDP levels as compared to the former steady state (as occurred in 1973 and again in 1979-80) in the same way that an energy price drop will increase the productivity of the factors and lead to higher GDP (as happened in 1987-88 after the 1986 oil price decrease).

The adjustment mechanism to a price rise is the following:

- An energy price increase reduces the marginal economic productivity of energy;
- It is then worthwhile to use less costly energy to limit the decline in productivity, and
- To use cheaper capital and labour (i.e., to invest in energy efficiency); but conversely,
- The additional capital and labour will be associated with lower productivity up to a stage when
- Marginal productivities for all inputs come back into balance, that is, at a lower level of GDP.

To complete this model, one also needs to take into account the non-symmetrical effects, i.e. the adjustment costs that occur whatever the price change. If energy prices rise, these costs are those of the new, more efficient equipment and the loss corresponding to the shorter life of the former stock of capital. If energy prices fall, the adjustment cost comes from continued use of equipment that is 'too efficient', i.e., that costs more than what would be necessary in the energy price environment.

F. CONCLUSIONS ABOUT THE 'ENERGY DEMAND DRIVER'

Energy demand is made up of services for electricity, mobility and 'heating' (a word to summarise the stationary fossil fuel end-uses even if this sector also includes some 'non-energy' consumption). Among these services, there are those for which existing or new technologies could become more active in the future.

Put simply, the world will use as much energy as people or industries can afford. It depends on the purchasing power of users, hence on an aggregated basis, on the GDP of the region considered or on global GDP. But it also depends on final prices, because the higher the price to the user, the smaller the amount of energy he can afford. It also depends on the efficiency with which the energy is used or transformed, because the better the efficiency, the greater the benefit the same amount of energy provides.

Many factors, such as market reform, technological breakthroughs, environmental constraints and other policies will have an important influence on primary energy pricing and on the cost of final energy services to consumers. The demand for mobility and for electricity is at an early stage in most developing countries and is expected to increase in the coming years, depending on their economic progress; however, efforts to provide modern energy services to the one third of the people in the world who do not now have such access will also impact overall global demand and stimulate GDP growth.

Stationary fossil fuel end-use services are already declining thanks to the penetration of electricity and the use of more efficient combined heat and power systems. When it comes to electricity, we have discovered that different fuels could be considered for reasons other than cost, as we shall discuss in Part III.

Technology shocks are also important, and while reference has been made to some of them, it is often hard to separate the technology driver from price impacts. Is it new technology which has driven demand, or is it cheap energy availability which has driven technology? In any case, WEC is completing a separate study in 2004 on important end-use technologies for the 21st century that will complement its earlier work on generation technologies.

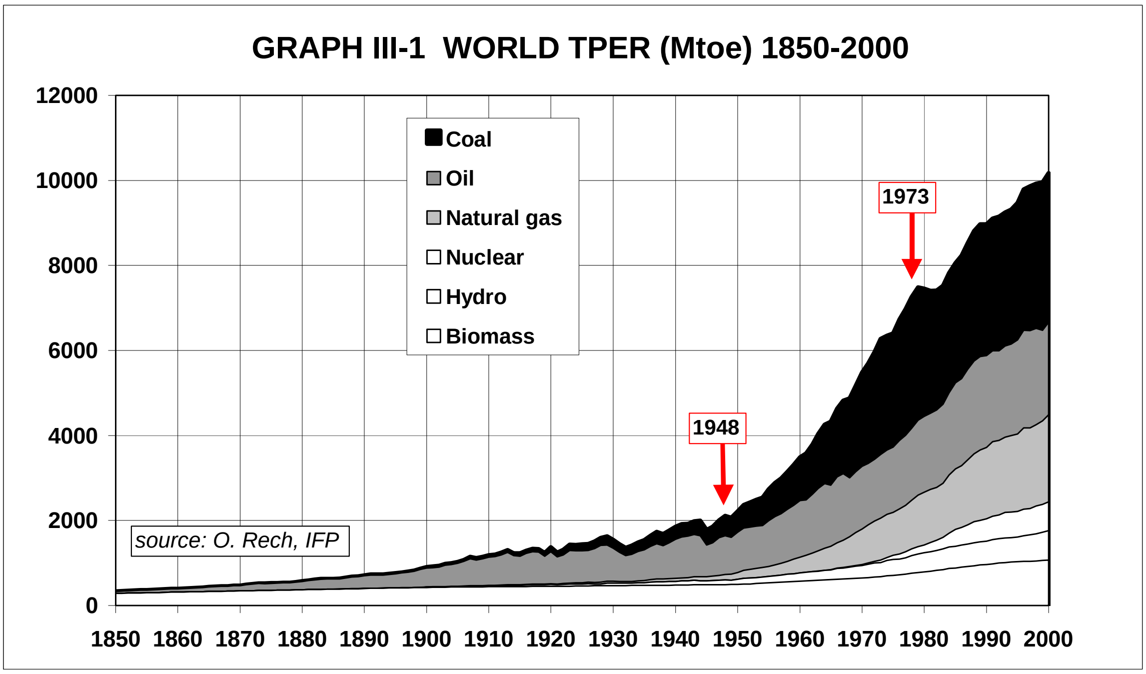
PART III: PRIMARY ENERGY SUPPLY AND THE ROLE OF OIL PRICES

A. HISTORICAL TRENDS IN WORLD ENERGY SUPPLY

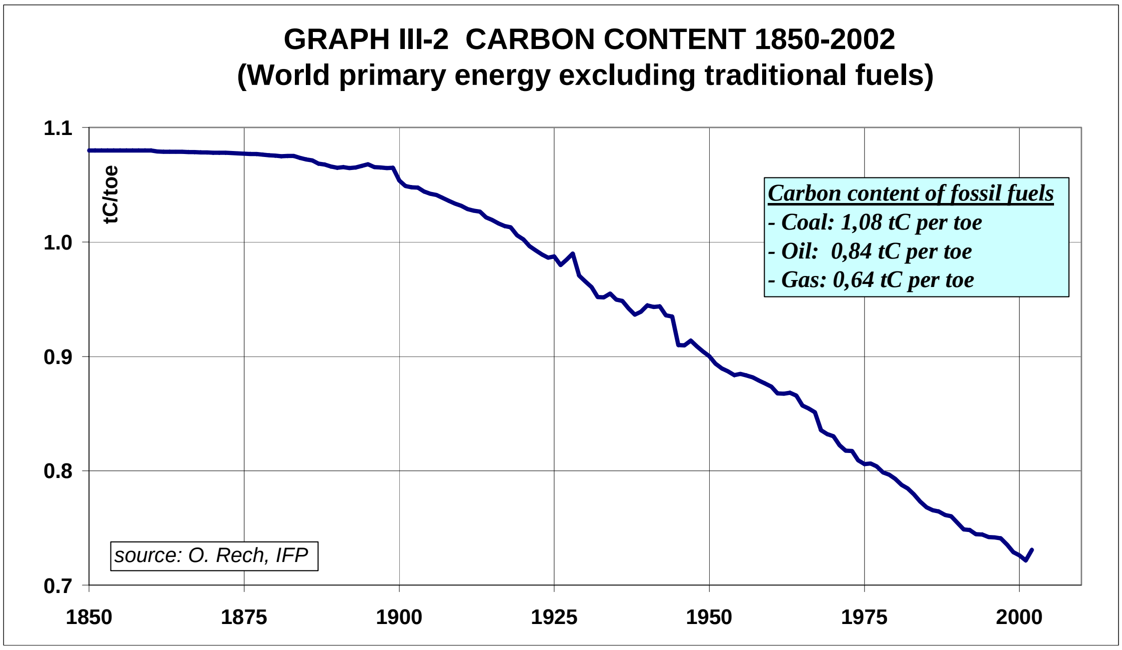
The so-called energy crises of today are not a signal of an absolute scarcity of energy, but rather, point to a temporary imbalance between demand and production capacities, usually on a regional basis because of infrastructure bottlenecks, Mother Nature or political factors. The problem is not the size of the 'tank' (i.e., the amount of 'reserves', and even less, that of 'resources') but the size of the 'tap'.

Throughout this report, WEC uses the term 'shock' to describe a dramatic, rapid and sustained increase in oil prices, but it is acknowledged that, for oil producers in the Middle East and other developing countries with oil, it is just as much of a shock to their economies to experience a rapid downward adjustment in the price of oil such as they have experienced at certain times, for example, in 1986 and especially in the late 1990s.

Graph III-1 shows total world primary energy requirements (TPER) with primary energies stacked according to their fossil carbon content, i.e., from renewables (combustible biomass and wastes, i.e., traditional fuels) to hydro and other modern renewables, to nuclear, natural gas, oil and coal.



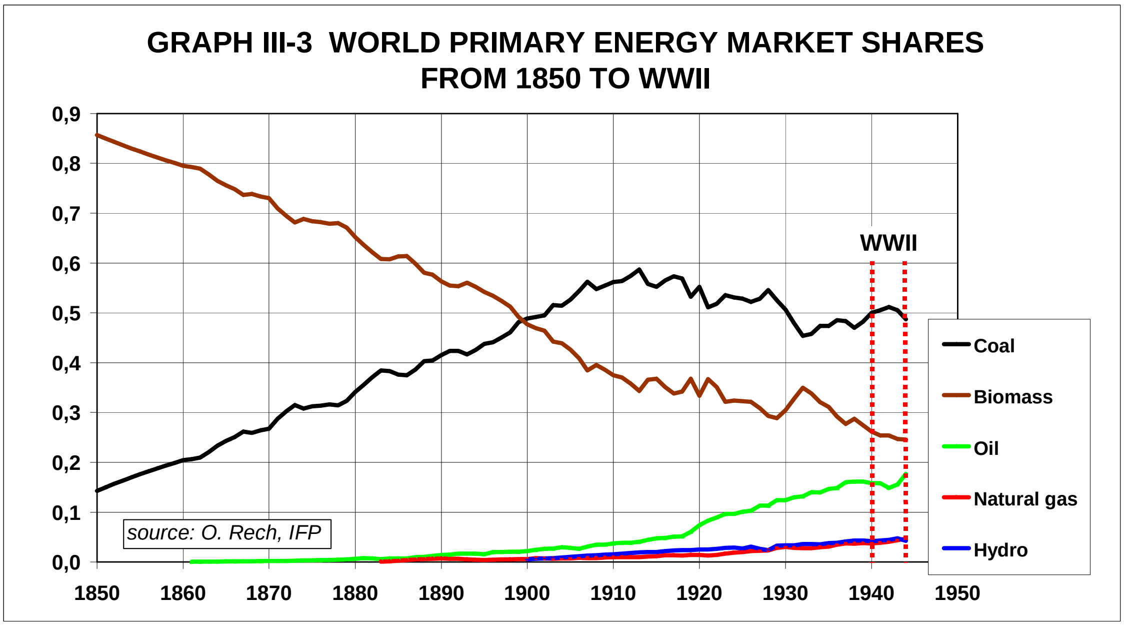
As shown in Graph III-2, the evolution of the energy supply has shown a progressive reduction of the carbon content thanks to the introduction of hydro, nuclear and now natural gas. Modern renewables are growing fast, but their market share is so small that they have no practical influence yet on the carbon content per tonne of oil equivalent of supply.



Ranking of Primary Energies and the New Role of Oil

Up To WWII

Graph III-3 shows that, up to the Industrial Revolution, just as the world was dominated by traditional fuels such as biomass, with a very small contribution of other energies (coal, wind or water mills), the world of the 19th and early 20th centuries was dominated by coal, even though oil, hydro and natural gas appear during this period. One might call the early 20th century the era of modern energy, based on coal with other energy sources supplying small niche markets.



During this first period of ‘modern energy’, traditional fuels (biomass and combustible wastes) continued to be used by the poor even though their market share decreased progressively. Hydropower filled a niche market because its energy could not be transported. Oil appeared first for lighting use before beginning to dominate the nascent transportation sector (mostly in the USA). Natural gas spread progressively, also in the USA, thanks to the development of pipelines. It competed with coal and fuel oil and was therefore priced to find outlets.

Hence the early modern energy market was dominated by coal and the price of coal. As coal has relatively small capital costs but large variable costs, mostly labour costs, its price evolved steadily over the period, with the technical benefits of the economies of scale and new technologies offset by the progressive rise in labour costs. Coal prices helped stabilise the world average energy price and this in turn allowed the one-to-one relationship between GDP growth and energy consumption growth during the period.

From WWII to 1973

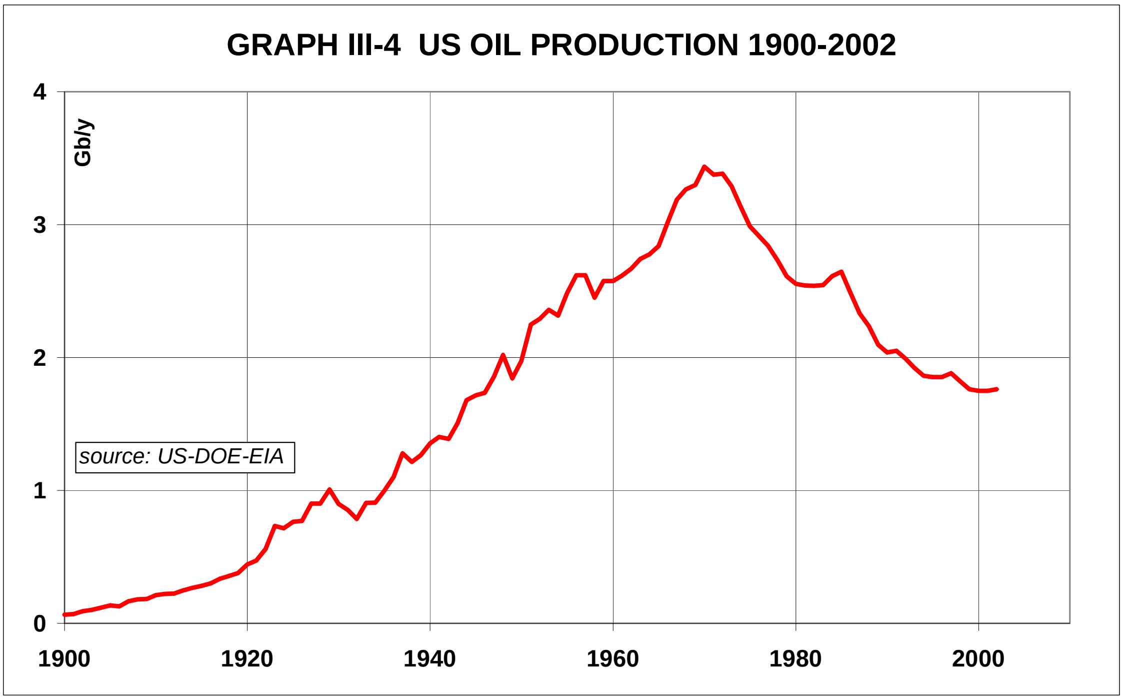
At the beginning of WWII in 1939, oil and gas only accounted for 20% of the world supply (coal 48%, hydro 4%, traditional fuels 28%). In 1948, the share of oil and gas had grown to 28%, and that of coal had dropped to 43% of world supply. This rapid evolution continued up to the first oil shock, and in 1973, the respective market shares were: oil and gas 60% (44% for oil and 16% for gas), coal 24%, others 16%. Rapid oil penetration of the energy market against coal was the result of the increased demand for mobility and the competitive advantage of oil products against coal in most markets (industry, power generation, residential/commercial).

The growth in demand for oil and natural gas (priced to remain attractive against oil products) was certainly facilitated by the low stable oil price during this period. As coal prices were dominated by labour costs, it was attractive to make long-term decisions in favour of oil products to replace coal.

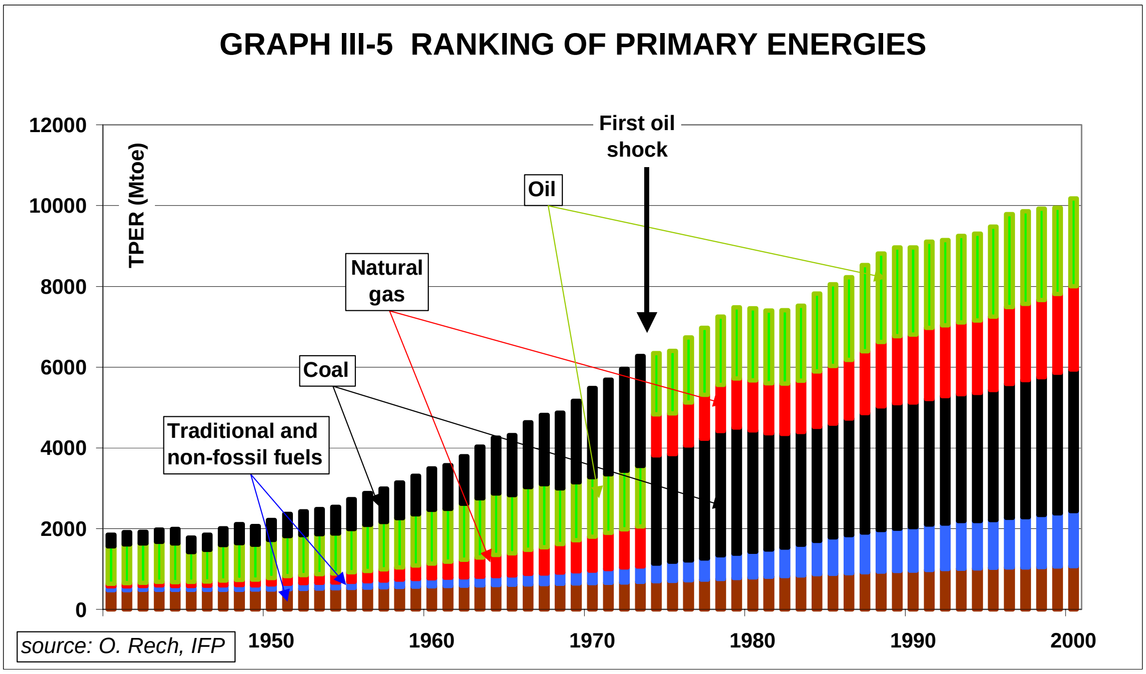
The 1973-74 Shift in the Ranking of Primary Energies

Graph III-4 shows the change in USA oil production over the last century. Between 1948, when the USA became a net importer of crude oil, and 1970, USA oil production continued to increase, and the Middle East became the marginal world oil supplier, with the reference price of oil moving from the Gulf of Mexico to the Arab-Persian Gulf coast. The average annual growth rate in the USA reached 0.4 Mb/d at the end of the period. It then declined symmetrically by 0.4 Mb/d per year, thus opening a supply gap of 0.8 Mb/d each year and absorbing much of the available over-capacities within OPEC supplying countries. The first oil price shock in 1973 was triggered by the reduction of world oil supply (with the downturn in USA domestic oil production that peaked in 1970 contributing strongly to this decline).

The world then faced a situation in which the supply of low-priced oil was no longer able to fulfil the demand. There was a need for additional supply to fill the growing USA gap, and therefore, a need for higher oil prices. Given the long lead times needed to develop new supplies, the oil price increases that began to appear in 1970 and continued up to 1973 were not sufficient. The oil price rose dramatically in October, 1973, triggered, but not caused by, the Arab-Israeli war.



While in terms of known exploitable resources oil was still extremely abundant in 1973 -- a fact confirmed by the experience of the next 30 years and the spectacular growth of non-OPEC production -- the impact of the first oil shock was enormous. It created a dramatic change, now permanent, in the ranking of oil versus coal and in the price setting of the energy market as shown in Graph III-5.



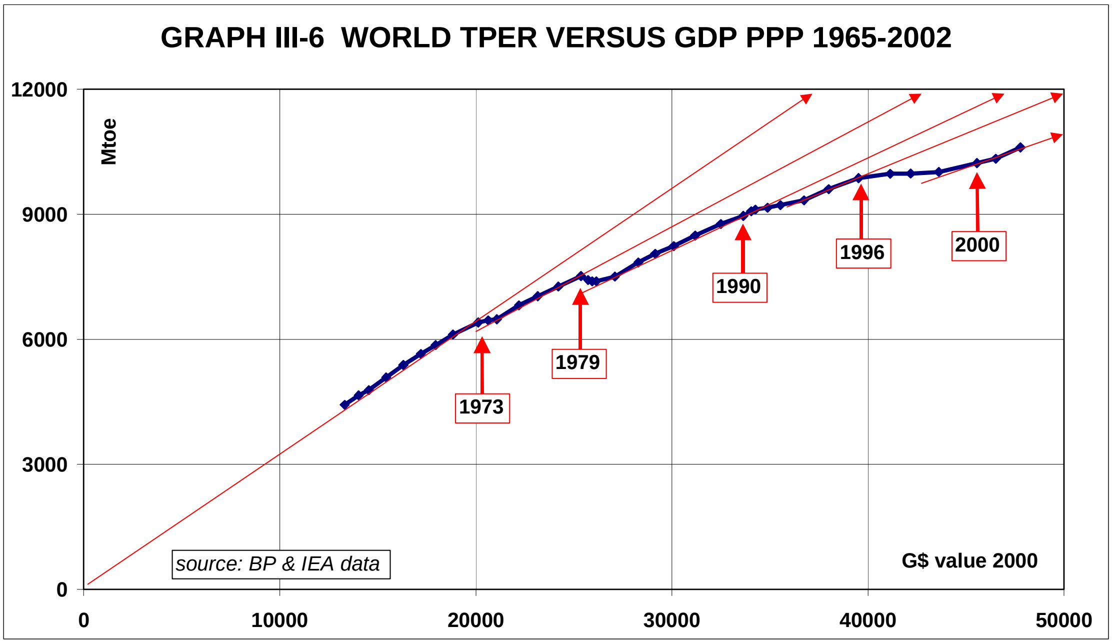
Up to the first oil shock, oil was less expensive than coal, thereby replacing it progressively while leaving coal as a marginal supplier. This role 'at the margin' is indicated by the significant swings in coal supply during WWII and in the late 1960s, whereas the oil supply data exhibited a uniform pattern. Conversely, after 1973, oil prices remained higher than coal prices (except for a few weeks in the USA during the summer of 1986). Hence oil became the 'swing' energy, filling the unmet demand, whereas coal was used to the maximum extent of the existing capacities, thus exhibiting a regular supply pattern compared with wide swings in oil supply. It is in this sense that WEC calls oil the 'king of energy supply'.

Graph III-5 highlights the change in economic ranking of the three fossil fuels. Before the first oil shock, gas was used first with its price set against oil products by the gas monopolies of the time, followed by oil and coal at the top; the latter was the swing supplier with a market share equal to what is left by the other primary energies. After the first oil shock, coal moved into the first position among fossil fuels because it was now cheaper than both gas and oil. It was followed by natural gas, with oil at the top of the series as the marginal supply, with a market share equal to what was left by the other primary energies.

The Energy-GDP Decoupling after 1974

The first oil shock and the change of price-setting mechanisms created another fundamental difference before, during and after 1973-74, namely the transition from a strong GDP-energy coupling before this period to a progressive decoupling afterwards:

- Up to 1973, oil prices had no influence on the world energy price because in the early days (say up to the 1920s), the oil market share was very small, and because after the 1920s and up to 1973, oil prices were lower than coal prices. Hence, during the whole pre-1974 period, the price of energy was determined by the price of coal, resulting in a very stable price that reinforced the one-to-one coupling between energy demand and GDP;
- After 1973, oil became the marginal energy and price-setter for all energy markets. As a price-setter, oil's role was to balance the overall energy supply with demand. Sustained oil price hikes signal the need for additional supplies of energy, be they oil or other primary energies, but they also create incentives to use less energy and more of other inputs, such as labour and capital. Oil price increases initiated and then reinforced the progressive decoupling between primary energy consumption and GDP. This is shown in Graph III-6.



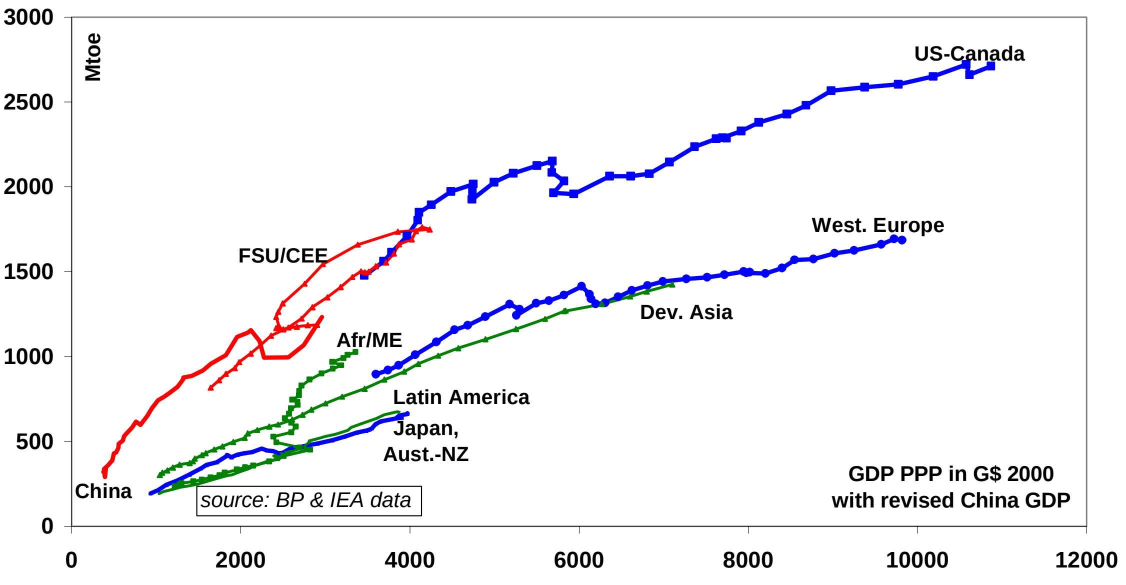
Being the energy price-setter, the oil price can be considered as the marginal cost of supply of all energies. However, in terms of oil pricing, 'marginal' oil is not the readily available oil of OPEC Middle East, which has by far the lowest production costs, but rather, the higher priced unconventional, deepwater, Arctic, or oil from non-OPEC Middle East, which involves much higher production costs. This disconnection between the marginal price of oil today and the full production cost in the Middle East is also a break with the experience which prevailed before the first oil shock.

An analysis of the different regions of the world in Graph III-7 displays the same discontinuity with a coupling between energy and GDP prior to 1973-74 (the breaks in USA and European series prior to the first oil shock are statistical flaws either because of the change of datum in 1970 in the USA discussed in Part I or the incorporation of RDA values for Western Europe after 1970) and a growing decoupling after the first oil shock.

The consistency of the trends is remarkable. The higher the slope, the lower the price (e.g., the USA, FSU-CEE and China up to the early 1980s). There are two diverging trends: the Africa and Middle East region after the first oil shock because their GDP is very much linked to the ups and downs of oil exports, and China after 1978-80 due to the questionable estimates of GDP discussed in Part I.

One might note that all trends prior to the first oil shock, or prior to 1980 for China and 1989 for FSU-CEE, converge towards the origin of the axes, consistent with a one to one energy-GDP relationship (income elasticity of one). After the shocks, trends turned downwards except for Africa and the Middle East, where energy demand increased in the new refineries, petrochemical plants and other energy-intensive industries that relocated to the region because of the cheaper energy prices.

GRAPH III-7 1965-2002 TPER OF MAIN WORLD REGIONS



B. ENERGY PRICE DYNAMICS

Sustained primary energy price increases have three different impacts:

- They change the behaviour of consumers to the extent the change in primary energy prices is more or less reflected in the final price of the energy services on which they depend. This was examined in Part II. As shown there, assumptions about the impact of primary energy price changes on final end-use prices need to be made with care;

- They trigger new investments because a higher price will make some additional supplies for each primary energy (coal, nuclear, renewables, natural gas and oil) competitive. However, most new supplies will only come after 6-10 years, because of the necessary lead times for new major infrastructures;
- They impact negatively on economic growth with two years of slower world growth following the price increase. This delay apparently corresponds to the time that is needed for the marginal economic productivities of all inputs (energy, labour, capital, etc.) to re-adjust to a new equilibrium where they are all equal, as discussed earlier.

In terms of energy price dynamics, the energy scene was long dominated by coal, which still remains important today in the power generation sector along with nuclear, natural gas and large hydro. With the exception of the unstable period at the end of the 1970s and early 1980s when the demand for coal increased substantially because of the coming back on-stream of the former coal-fired power plants that had been converted to oil in the 1960s prior to the first oil shock, coal prices have been stable thanks to the large and predictable component of labour costs. This has played a positive role in economic development in many countries without creating ‘macroeconomic pain’ because of sudden variations in energy prices. Similarly, hydropower contributed to solid growth during this period even though its cost structure is different from coal (very large upfront costs and small variable costs).

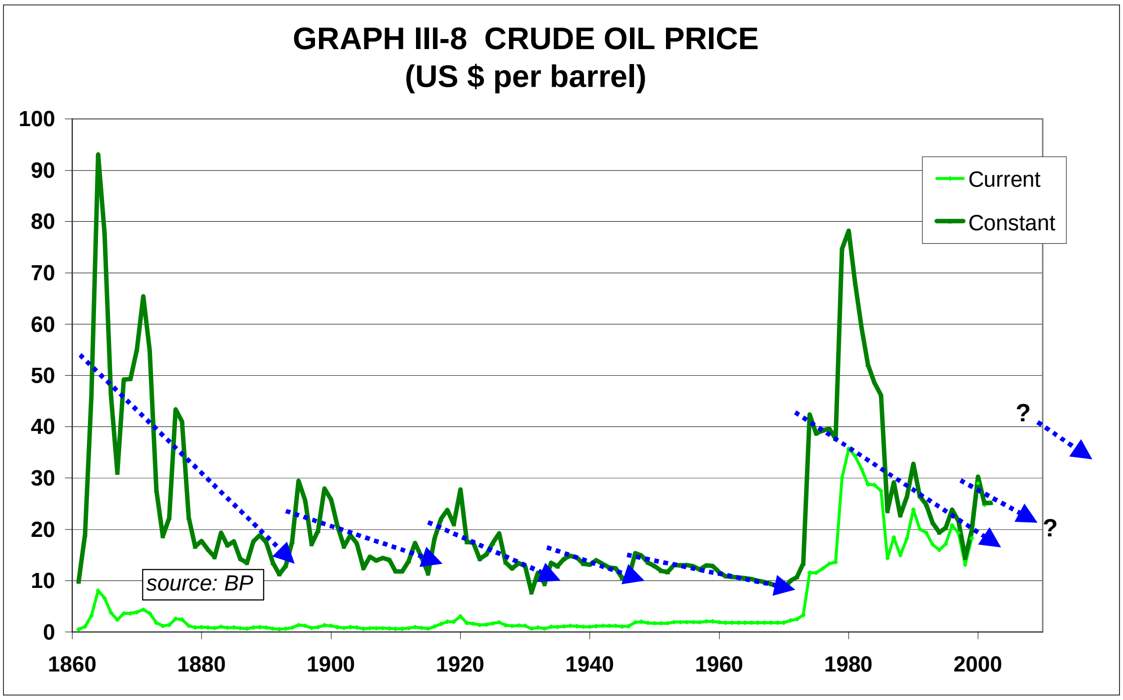
From 1974, worldwide energy price fluctuations have been determined by the oil price and its twin, natural gas, the price of which generally followed that of oil because they compete in the same power generation or heating markets. In terms of impact on energy markets, as discussed below, what is of importance is not only the price variations of oil and natural gas taken together but also the volume of these two energies in the overall market.

Historic Oil Prices

World oil production was negligible up to the 1859 Drake discovery in Pennsylvania but increased quickly afterwards from 6000 b in 1859 to more than 0.5 Mb in 1860, 2Mb in 1861, 10 Mb in 1878 and 100 Mb in 1903. This happened in a context of major price fluctuations, starting as early as 1860 and continuing long after, as shown in Graph III-8. There is a fundamental relationship between the high fixed and low variable costs of oil production (high costs call for high prices to launch new investments and for full capacity use once they are on-stream, while low variable costs push prices down as long as over-capacity exists) and how this leads to enormous volatility in unmanaged markets.

As shown in Graph III-8:

- Volatility in oil prices has always existed but to different degrees: very high up to the end of the 1870s, high in the 1910-20s, very low in 1947-73 and medium since 1973;
- When no supply constraint exists, real oil prices have tended to decline about 3% per annum (constant money). This reflects the technological progress and economies of scale in oil exploration and production;
- When a supply constraint appears, oil prices surge to signal the shortage and call for new additional, yet more expensive, supplies that will complement the existing pool;
- Hence the story is one of more or less volatility in oil prices depending on the degree of control of a dominant actor, and they exhibit an asymmetrical price pattern with rapid rises and slow declines.



To cope with the volatility in oil prices, which has widely different impacts depending on whether a country is a producer of oil or has alternatives, especially in power generation, the chosen tools were:

- Either market instruments (spot markets based on 'pipeline certificates' appeared in Titusville in 1871 and Oil City in 1873 and were followed by as many as 20 others in adjacent states, from Illinois (Chicago) to New York (where the Petroleum Exchange opened in 1877). Market instruments were also used after 1911 up to 1928 and again from the late 1970s until now;
- Or market control by a dominant actor, e.g., from the late 1870s to 1911 by Standard Oil, the Texas Railroad Commission from 1928 to 1941, the USA government from 1942-1947, TRC again from 1948-1959 and OPEC since its founding in 1960, which is discussed in more detail below.

In summary, major oil price increases are not new, but the early ones up to WWII did not impact the energy-GDP link because oil was a minor component of the world energy portfolio in terms of quantities (dedicated to a few end-uses such as lighting or transportation) and the geographical concentration of demand was centred in the USA. The early price increases signalled local scarcities (for example, in the 1890s and 1910s) that proved to be temporary and insignificant in terms of global resource availability. This is confirmed by the average overall decline in the price trend in constant money between 1860 and 1970.

A Zoom on Oil Prices since 1948

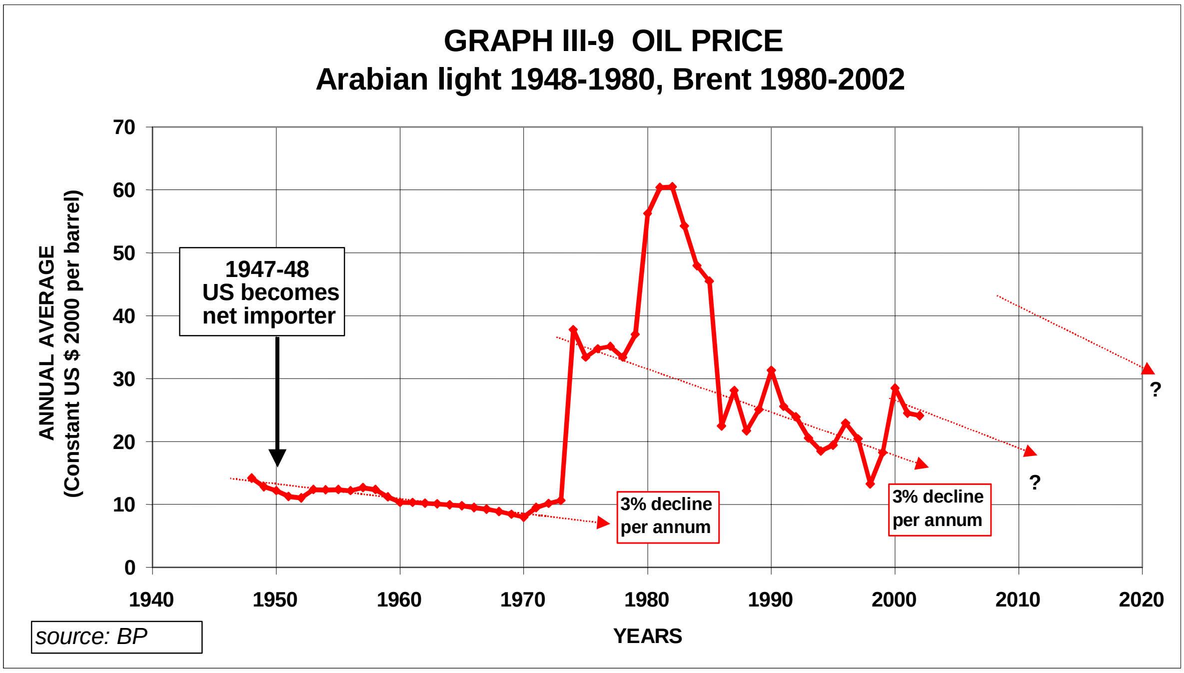
In 1948, as discussed earlier, the USA became a net oil importer, and the global price-setting moved from the Gulf of Mexico to the Arab-Persian Gulf, with a jump from 1.40US$ to 2.40US$/b because of the corresponding additional sea transportation cost of 1US$/b. Yet again, there was no scarcity because oil became even more abundant at the world level thanks to enormous discoveries made in the rest of the world during the 1950s and 60s.

In 1959, the USA administration of President Eisenhower created the mandatory oil quota that resulted in the de facto closing of the USA oil market. That closure meant that TRC's former role as the dominant actor in price-setting was no longer needed in the USA (in the closed market, national oil companies could produce and sell as much oil as they were able) and became unavailable to the rest of the world. Hence the world market was left without a dominant actor. The creation of OPEC in 1960 may therefore be viewed, in this context, as a response to this vacuum, with the major exporters becoming the new dominant actors in the world oil market.

From 1960 to 1973, OPEC was 'assisted' by three special features of the oil market:

- The vertical integration of the market, in the sense that to produce oil profitably it was necessary to have the guaranteed corresponding downstream outlets;
- The dominance of the majors, also called the 'seven sisters' (Esso, Mobil, Chevron, Texaco, Gulf, Shell, BP), which were associated through an agreement on market shares first made among them in Achnacarry, Scotland, in 1928;
- The capacity to dump residual oil in power generation, thus contributing to the growth dynamics that were key to the stability of the market and to its remarkably low volatility.

As with previous major price increases, the 1973 first oil shock did not signal an absolute oil scarcity but a rapidly growing imbalance in availability calling for new primary supplies, be they oil or other energies. Yet there is a fundamental difference between what happened in the past and 1973: before 1973, either the oil market share was small (the case up to WWII), or when it grew (the case since WWII), oil prices remained stable. The first oil shock opened a new era in which the oil (and gas) share in the energy mix was large and oil prices were volatile and prone to significant shifts as shown in Graph III-9. This combination explains the new importance of oil and gas after 1973, which, compared with earlier managed contract schemes, was heralded by the freeing up of oil markets, an increase in spot and contract flexibility and the beginning of more robust and varied financing avenues.



When OPEC emerged by 1974 as the sole 'dominant actor', the role of oil in the energy mix also changed. Oil became the energy 'at the margin', and an inevitable uncertainty appeared. Oil had to fill a market that was not known in advance because it was the gap between an uncertain demand depending on an uncertain economic growth and a rigid supply of energy other than Middle East oil depending on investment decisions made 6 to 10 years earlier. To evaluate this gap and address it correctly in real time has been difficult for OPEC; it often seems to have missed the mark in balancing supply and demand, but a deeper analysis of its performance is worthwhile.

Since 1974, oil price volatility has returned because the two smoothing factors, vertical integration and growth dynamics, have disappeared. Yet the influence of OPEC is evident because, beyond the learning process of trial and error in the early years of its existence, the consistency of the real price trajectory over 1974-1999 is remarkable. The 1979-1985 period was part of this trial and error learning process; it was triggered by political events – the Iranian revolution and Iraq-Iran war, which upset the oil fundamentals[9] and stopped when OPEC returned to a price regime consistent with the fundamentals of the energy market in 1986.

The last element of the oil price series examined here is the increase in oil prices that occurred in 2000. This development is recent and happened in a context of high volatility, making it difficult to analyse. Yet, three features may be identified:

- First, the average price trend was about 17US$/b prior to 2000, while since then, it is about 25US$/b, the middle of the new price band targeted by OPEC and 50% higher than the former trend;
- Second, the timing seems excellent because there was a need for new supplies[10], in particular, LNG in North America, that would not have been assured at the former oil price; and,
- Third, the consistency of this pricing over the last 3-4 years, with average annual prices similar in 2000, 2001, 2002 and the first few months of 2003.

Towards New Primary Energy Price Increases?

The oil price corresponds to an *energy* supply/demand equilibrium in which potential demand evolves with GDP but supply can lag the demand. Hence there is a need to focus on the supply side and the constraints it places on all primary energies because, ultimately, any shrinkage in non-oil supply will impact the marginal OPEC Middle East oil supply and by doing so, impose a new equilibrium oil price; if it were too high, it would trigger too much new supply, and if it were too low, it would not trigger enough new supply.

Given these mechanics of oil pricing when new marginal energy supplies are needed to satisfy demand, as in the clear-cut example of the growing gap in 1973-74 created by the decline of USA production, one might wonder whether similar situations may arise again in the future. To answer this question, it is useful to examine all primary energy sources in greater detail.

There is no certainty that OPEC will be able to achieve a balance in energy supply and demand over the long run thanks to well-managed oil price increases such as those of 2000. Such a strategy, to be successful, would have to address the possibility that the supply of one key energy might fall unexpectedly (with long lead times that are needed to bring new large investments on-stream long before demand is actually known). There is also the folly of

[9] The oil fundamentals were heading for a reduction of global oil demand, first, because of the coming on-stream of investments launched after 1973 to switch away from oil, such as the nuclear programme in Europe or the coal-fired plants in North America, and second, because of the increase of non-OPEC production. Both of these developments suggested an erosion of oil prices, not a 'shock'.

[10] Other factors contributing to this changed need for new supplies were the limited idle capacities left in the Middle East, the flattening of European domestic gas production and the small growth of non-OPEC supply of the previous years.

Man, which can disrupt the best-laid plans and outdate or undermine any analysis of OPEC and non-OPEC supplies.
One might wonder whether, in spite of the downward pressure on real oil prices of about 3% per annum from technological developments as noted earlier, the post 1973 era (not only the past 30 years but also for some decades to come) will not exhibit an average upward real price trend similar in magnitude to the average decline over the 1859-1948 period. The 1950s and 60s could, in this context, be remembered as the lowest energy price period between two symmetrical periods of changing prices, declining from the 19th century to WWII and rising from the 1970s to possibly 2030-2050. Certainly if the OPEC target of 25US$/b were achieved and sustained for a period of time, the trend in the real price of oil would move upwards, more than compensating for the downward impact of technology.

Again, there is no certainty, because the average price trend will depend on the intensity of future oil price increases and on the length of time between these price hikes during which prices would normally decline thanks to technological progress and economies of scale. There are two features to consider:

- *Ceteris paribus*, future oil price increases may be more significant than those of 1973 because oil demand is now concentrated in highly inelastic sectors where the required energy demand reductions in response to price signals will call for major GDP decreases, whereas it was relatively easy to cut the consumption of heavy fuel oil in the power and industrial plants during the 1970s;
- In addition, the stable or declining price episodes may be shorter than the one from 1974 to 1999 (25 years) because the world relies heavily on oil for mobility, and oil supply may soon face a tight situation, when non-Middle East oil starts to decline, especially if this decline is too fast to be filled by the marginal capacities in the Middle East.

To conclude, as long as oil remains the ‘swing energy’, its price will be a central indicator for the energy market. Even though the recent record of OPEC is good, it was unable to prevent the 1973 crisis, the second oil shock in 1979-80, or the high volatility of 1990-91 and that of the last five years. Hence whatever the efforts and accumulated experience of OPEC as today’s dominant actor in oil and gas pricing, one cannot take for granted a smooth evolution of prices in the future.

A Possible New Price-Setter in the Future?

Given the far-reaching consequences of the change in the marginal energy supply, coal prior to the first oil shock and oil since that shock, one might wonder whether similar dramatic changes may appear in the foreseeable future or whether oil is to remain forever the marginal fuel. Oil is liquid and concentrated, which is not the case (without intervention) for natural gas; oil is easy to store and easy to transport, thus making it the ideal fuel for transportation (excluding electrical trains that rely on a fixed electricity infrastructure, but including cars, trucks, diesel trains, airplanes and ships). Oil could be useful in unforeseen ways in terms of new technology and new services.

If the hydrogen economy were to replace the oil economy some day, it would have to be produced from other primary energies. The coming of the ‘hydrogen age’ would need to overcome three technical challenges:

- First, and above all, the capacity to produce hydrogen cheaply from nuclear, renewables or fossil fuels for which the carbon would be sequestrated;

- Second, the development of a totally new infrastructure to store, transport and deliver hydrogen, although there is some scope for using natural gas pipelines for transmission; and,
- Third, the availability of fuel cells at a competitive cost compared with the stroke engine.

These might appear to be an unlikely combination, especially if one believes that Mother Nature can still deliver plenty of oil in the future. Another possibility, still close to the 'hydrogen' concept, but with the addition of a small amount of carbon, is to make synthetic liquids from existing solid or gaseous primary energy sources that will add to the pool of existing liquid fuels and rely on the same infrastructures and the same devices as those of today (turbines, heaters, stroke engines). In fact, the trend to more 'synthetic' fuels is already in evidence today. It is possible, for example, that synthetic liquid fuels produced by a Fisher-Tropsch-type process based on coal/gas/biomass would become the new price-setter of liquids.

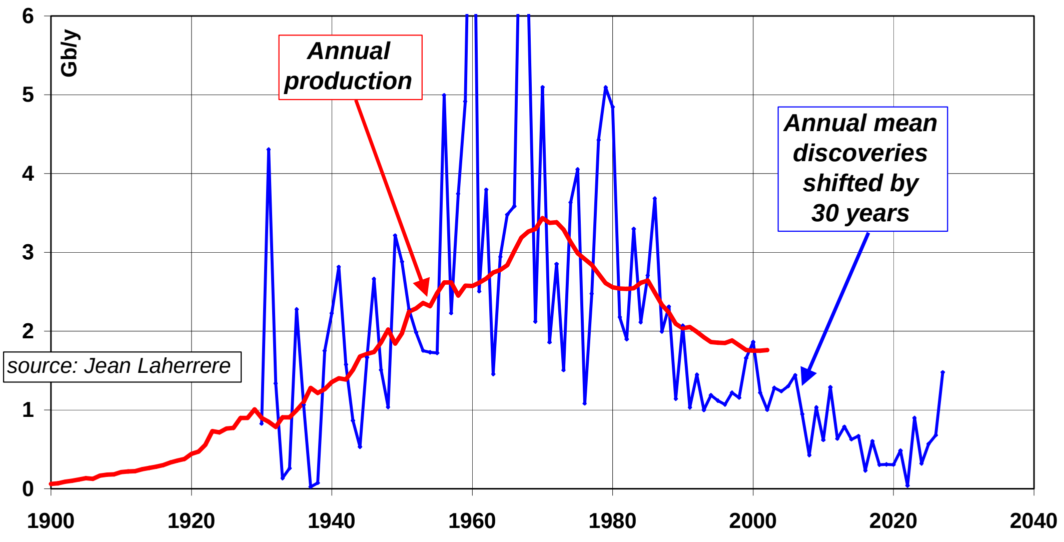
If the next price-setter were the synthetic liquid fuels made out of coal, natural gas or biomass thanks to the Fisher-Tropsch-like processes, the role of oil as 'king of energy' could change along with the role of OPEC as the dominant actor it is today. This would certainly bring a new stability to the world energy market, which would then enter a long period of primary energy price decline. However, between now and the hypothetical arrival of this 'synthetic liquid fuels age', many bifurcations may appear thanks to breakthrough technologies on both the production and end-use sides which could put the world on quite a different trajectory.

C. POSSIBLE FUTURE ENERGY SUPPLY IMBALANCES

The Case of Oil

Graph III-10 shows that the decline of US oil production was foreseeable. In fact, it was actually foreseen by some geologists (in particular, Hubbert) on the basis of discoveries data. Today, there is no dispute among experts that the evolution of discoveries in well explored areas is a precursor of the shape of the production profile, but there is no agreement to go further, for example, to determine that the production curve should be bell-shaped and symmetrical and used to estimate the ultimate reserves.

GRAPH III-10 US OIL PRODUCTION MIMIC DISCOVERIES
(with discoveries shifted by 30 years)



Oil Supply Outside OPEC Middle East

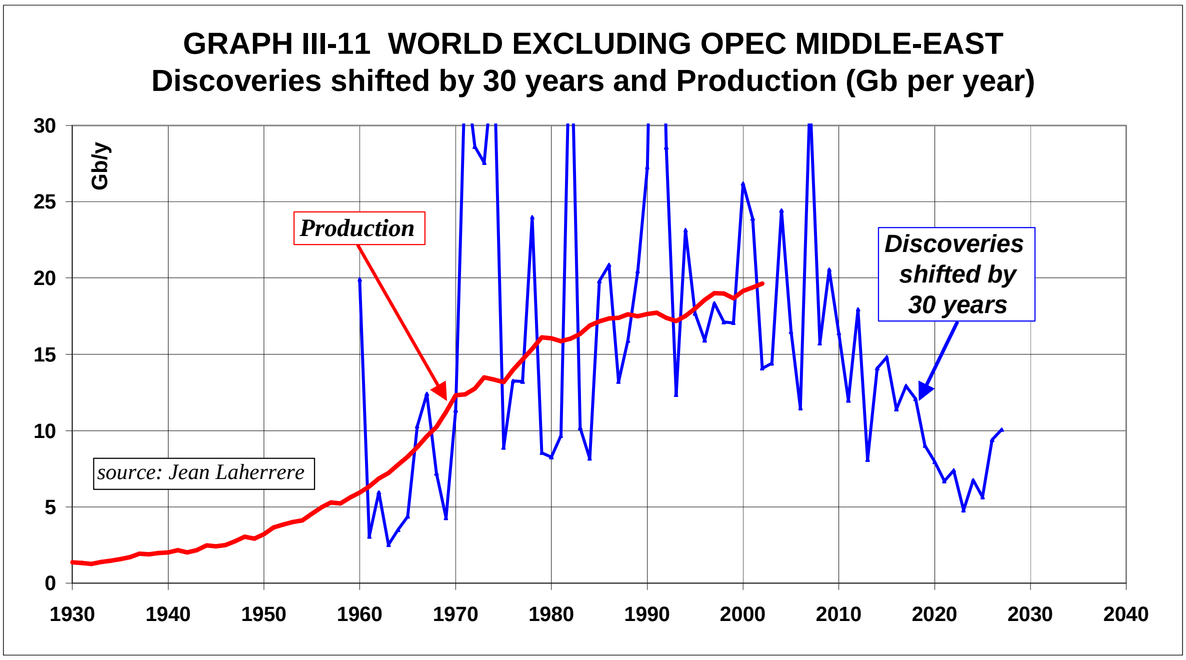
The same kinds of fundamentals are shown in Graph III-11. According to the past discovery profile, oil supply outside OPEC Middle East should more or less plateau between 1985 and 2010. However, past discoveries can only provide a qualitative indication and not a precise prediction. The reality is different, and oil production has suddenly risen since 1995 because of what might be called 'new technological oil', mostly from the FSU and deepwater. It is worth noting here that:

- The introduction of modern technologies in Russia has increased the productivity of existing fields as compared to what their profile would have been in the Soviet era;
- Western technology has also permitted production of the high-sulphur, high-pressure Caspian reserves and discovery additional fields, e.g., Kashagan;
- Deepwater oil production is a new costly frontier. Economics are good if oil is produced very quickly, and some of the discoveries of the late 1980s and 1990s are already producing significant oil.

While there is no doubt that these new contributions will have a growing impact up to at least 2010, one may wonder whether they will be sufficient after that date to prevent the decline that the profile of former discoveries suggests. In fact, two elements suggest that the decline might be rapid:

- New FSU discoveries (mostly in the Caspian region) and deepwater production may only represent 100Gb;
- Technology is a two-edged sword: it first accelerates oil production, then also accelerates the decline.

In *Energy Strategy for Russia until 2020*, published by the government in August, 2003, Russian oil is expected to decline for a variety of reasons, dropping from 75 million tonnes in 2002 to 30-50 million tonnes in 2020.



Should the decline be as strong as the rate of discoveries suggest, there would then be a need for another oil price increase to generate investment in new primary energy supplies.

Unconventional Oil and OPEC Middle East

Unconventional oil is unlikely to fill the gap. Although the resource base is large, and technological progress has been able to bring costs down to competitive levels, the dynamics do not suggest a rapid increase in this supply but, rather, a long and slow growth over several decades. Two examples are worth citing:

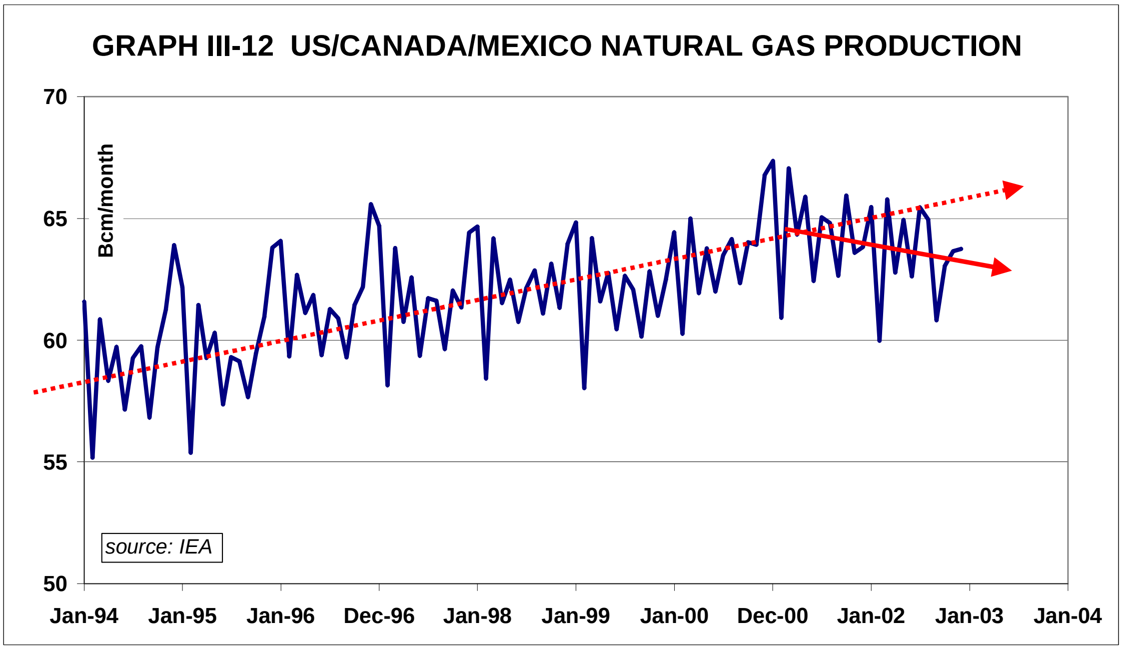
- In Orinoco, Venezuela, with a favourable geological setting, TOTAL expects an 8% recovery over 30 years in its contract area. Should this value be averaged for less good settings and extrapolated to the whole Orinoco belt, overall reserves today would only be ~60 Gb over 30 years, allowing at best 6 Mb/d of production in 2030 if the entire area were put into production;
- Canada's oil sands are now officially announced as a 170 Gb reserve base, but the development of these reserves has been plagued by difficulties which it will take time to address – cost overrun, water needs, cost of natural gas for process heat. Current estimates put the additional production of Canada as compared to 2000 (2.12 Mb/d) at less than 2 Mb/d in 2015-2025[11].

Oil producing fields in OPEC Middle East are more than 50 years old (the number of years since production started weighted by the present production). Whatever their ultimate reserves, they will eventually begin to decline one day. When? There is no consensus, and it is a sensitive matter given the importance of oil to both the producing and consuming countries, something which the new International Energy Forum based in Riyadh will surely address. Suffice it to say that even if this region can continue to produce for decades, one cannot take for granted that these old fields will be able to 'surge' their production to the levels required to fill the gap resulting from a possible decline in oil production in the rest of the world.

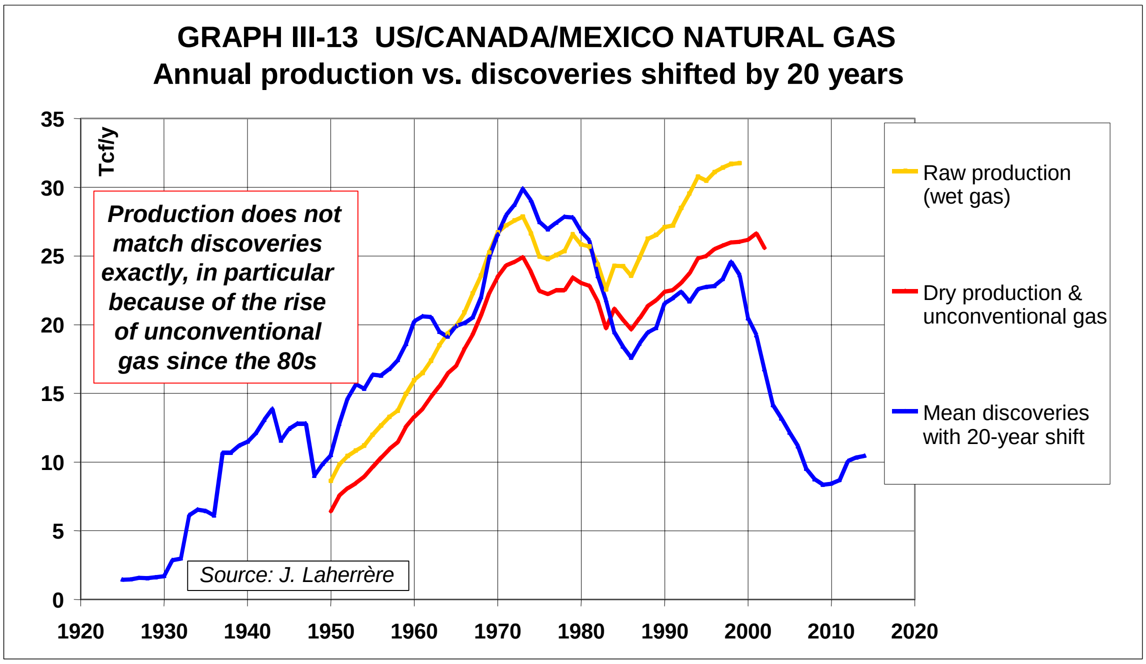
The Case of North American Natural Gas

Today, North American gas represents about 7% of the world energy supply. After increasing annually by about 1.3%, production has now started to decline symmetrically as shown in Graph III-12. By comparison, US oil in the early 1970s represented 8% of the world energy supply and was increasing at 4% per annum before declining symmetrically. Hence, the gap to fill was 3-4 times larger than that of North American gas today.

[11] In October, 2002, Credit Suisse First Boston estimated additional production of 1.38 Mb/d by 2010, increasing to 1.71 million b/d by 2015. In February, 2003, the National Energy Board of Canada (NEB) suggested that additional production could rise in the best scenario ('Supply push') to 1.83 Mb/d in 2013 before declining to 1.65 Mb/d in 2025, and that the figures would be 0.4-0.5 Mb/d less in the other ('Techno green') scenario.



As shown in Graph III-13 if one broadens the above short-term perspective and shows the role of the 'gas fundamentals', this decline was foreseeable because of the relationship between the past discoveries and the production profile. Extrapolating this relationship on the basis of the decline of discoveries 20 years ago suggests a turning point in North American gas supply in 2000, which is what actually happened.



The striking point is that the North American gas production profile broadly reflects the earlier discovery pattern. But the closer the value of discovered reserves to their expected ultimate value, the better the fit. The concept of 'expected ultimate reserve value', or the 'mean reserves', is related to the process of reserve assessment of a discovery.

Reserves are declared on the basis of judgments that depend on the available information and reported according to financial disclosure rules designed to protect shareholders. The result of this process is that declared reserves:

- Are very conservative at the time of discovery (uncertainty is then very large);
- 'Grow' when additional information on the field becomes progressively available; and,
- Are only known for certain at the end of the field life and then equal to cumulative production over time.

If one averages this progressive learning and the corresponding growth of reserves over time for all past known fields, one gets an average growth function that can be applied to newly discovered fields. The result is an estimate of the 'expected' or 'mean' reserve value, i.e., what one expects in terms of cumulative production over the entire field life.

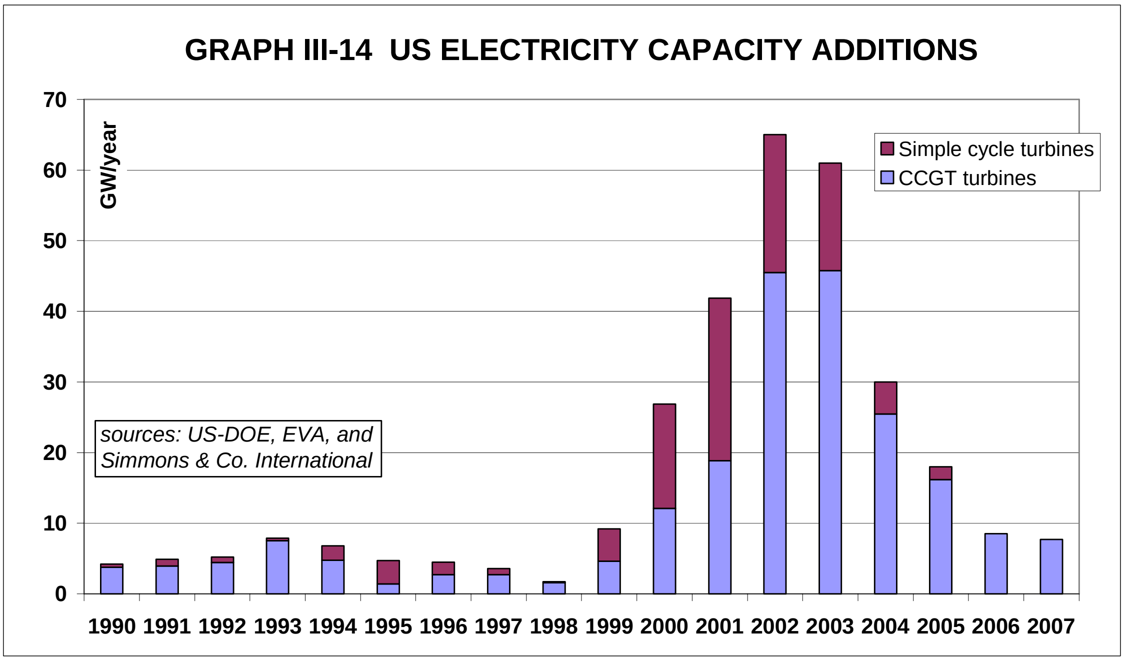
The 20-year shift is supported by the quality of the correlation. Since the same methodology applied separately to the three sub-regions -- US, Canada and Mexico -- reveals the same 20-year lag for each of them, this confirms that the correlation is robust, at least in qualitative terms. Going further and using the extrapolation as a true prediction could be misleading because individual lead times and decline rates have changed over time thanks to improved technology. For instance, unconventional gas today represents five Tcf/year that are not recorded as 'discoveries', and deepwater gas which was discovered since the end of the 1980s is already under production.

The North American problem is the squeeze that develops between a shrinking domestic supply and the emergence of new demand in the power sector. Given the possible cancellations in power plant construction in North America, the final number of new plants may be closer to 200-250 GW than the 300 GW expectation reflected in Graph III-14. Yet as these capacities are mostly gas-fired, the potential gas demand is still very large.

Electricity demand in North America is expected to grow by about 2.5% per annum, thus requiring an additional 100 TWh per year supplied by at most 50 TWh through an improved load factor of coal-fired plants and by roughly 50 TWh in natural gas. For an average efficiency of 50% (i.e., a heat rate of 6,800 Btu per kWh, a high figure for mid/peak load plants, but it is assumed that some old plants will be shut down and replaced by the new, more efficient ones), the 50+TWh from natural gas requires 1 Bcf/d per annum of new natural gas supply.

Such a figure is on the conservative side compared to recent historic figures. Gas demand in the USA for electricity (utility and non-utility[12], i.e., industrial CHP) was respectively 5.75, 6.33 and 6.67 Bcf/d in 1999, 2000 and 2001, or an increase of about 1.6 Bcf/d the first year and 0.9 Bcf/d per annum thereafter. In addition, what is true for the USA is also true for Mexico and north-eastern Canada which also have a need for summer air conditioning. Thus the actual gas supply to meet the increase in electricity consumption in North America in the near term might need to be increased by 1.5 Bcf/d per annum.

[12] US data are slightly confusing because of the existence of two sectors, utilities and non-utilities:
- Non-utility plants provide a base load supply because industry's electricity and heat needs are more or less constant throughout the year. This demand trend is slightly up but can vary quickly if some industrial sectors become uncompetitive (e.g., for aluminium smelters);
- Utility plants provide a mid/peak load during summer when residential and commercial demands are low. This demand has grown rapidly recently and is expected to continue to grow strongly.



Combining the decline of domestic production of 1 Bcf/d with the 1.5 Bcf/d of additional demand in the power generation sector suggests a 2.5 Bcf/d annual gap in supply. Up to at least 2010, when Arctic gas from Prudhoe Bay and the Mackenzie delta may become available, the only source for this gas is LNG imports, in particular from Africa and the Middle East, although Bolivia and some other countries are also eyeing this market gap. However, as it is unlikely that LNG can grow at such a rate, equivalent to two new LNG terminals per year, a potential deficit will remain and will push prices up in order to limit demand, in particular in the industrial sector.

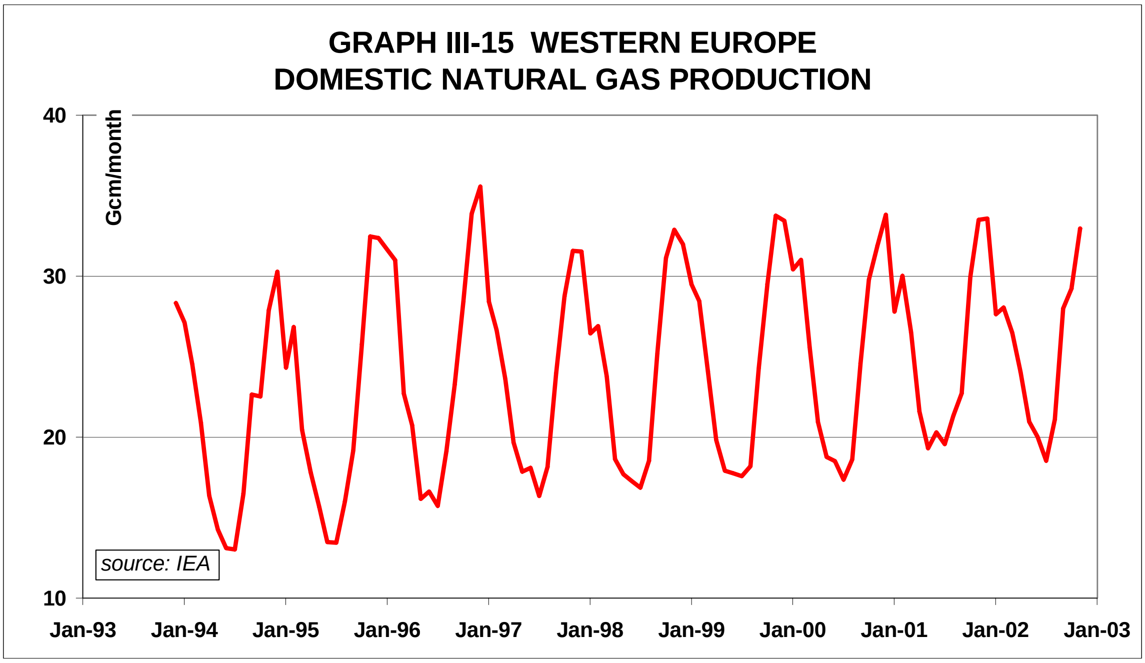
In turn, the growing importance of LNG in North America on a regular basis triggers a fundamental change in the LNG world:

- Until now, LNG has been dominated by Europe and Asia, vertically integrated and based on long-term contracts with price and flexibility agreed and fixed in advance. Prices in Europe were around 2.5US$/MBtu (in line with the then 17US$/b oil price);
- The new LNG world incorporates the huge North American market that is deep, competitive, flexible, spot-based and well endowed with storage capacities. With a new 25US$/MBtu oil price, floor spot gas prices are high enough to attract large LNG supply. North America is thus poised to become the balancing market for the world LNG market.

Whereas in the former vertically integrated LNG world before 1999-2000, there was no need for spot arbitrages except those resulting from a better than planned output of the LNG chains, the new gas era will be characterised by the vertical disintegration of LNG chains and progressive dominance of short-term arbitrages. This evolution will be accelerated by the European market reforms that open access to the infrastructure and favour gas to gas competition. This is confirmed by the increase of spot and swap LNG transactions from about 2 Mt/y up to 1998 to respectively 4.7, 7.6, and 11.4 Mt in the years 1999 to 2001. This is a dramatic change, comparable to the change from a vertically integrated to a spot-dominated oil market that occurred after 1973.

The Case of OECD Europe Natural Gas

The North Sea is a mature region, and natural gas production in the main Western European producing countries is poised to decline, rapidly for Germany, slowly now for the UK, beginning soon for the Netherlands and Denmark and likely during the next decade for Norway. Overall, as shown by Graph III-15, winter European domestic production may have peaked in 2001-2002, nearly at the same time as North America (2000). Annual production is still increasing because, paradoxically, the maturity of the fields no longer allows them to swing between winter and summer as much as they did in the 1990s, therefore holding summer production high.



Even though the supply situation is not a cause for alarm in the short run because demand is not growing much either (present overcapacities in the power sector do not call for massive new gas as in North America – the only exception being the Mediterranean countries, in particular Spain), the question of new external supplies is of relevance for the future of European prices. The importance of the exporting countries to Europe, in particular the FSU, was recently stressed in the Green Paper on Energy by the European Commission. Similarly, in its recent White Paper on Energy, the UK government is concerned about its shift to net energy import status around 2006 while at the same time, it has set itself an ambitious target for GHG emission reductions.

New supply for Western Europe will come from Africa (for example, Algeria, Egypt, Libya and Nigeria), but at the margin, the main choice will be between Russia and the Middle East.

<u>Future Gas Exports from Russia to Europe</u>

Russia has been a major and reliable supplier of natural gas in Europe, but the restructuring of the economy and the collapse of energy consumption, including that of natural gas, have somewhat hidden the supply situation of this region. The huge size of the official natural gas reserves was seen as a guarantee in terms of the abundance of cheap supply, but Russia now faces a number of problems.

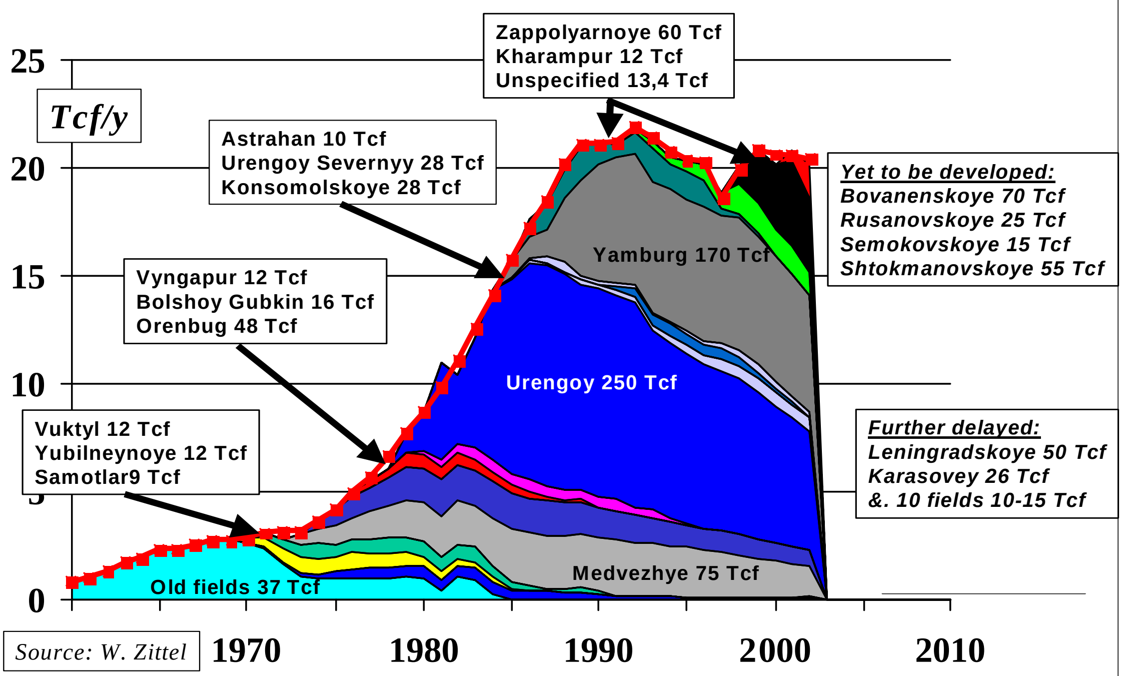
First, there is a huge need for new private investment in the Russian natural gas infrastructure. In *Energy Strategy for Russia until 2020*, cited earlier, exports are expected to grow from 185 billion cubic metres per annum in 2002 to 275 billion cubic metres in 2020. To achieve such an increase, an estimated US$200 billion will have to be invested in infrastrucutre and gas fields in Siberia, the Far East and Yamal.

Second, domestic consumption is larger in Russia than it ought to be, thus using resources that could be exported, because domestic prices are too low and fail to reflect the cost of supply and the marginal competition that should normally exist between internal use and export. The Russian government is aware of the problem but has chosen to limit the price increases in order to limit the inflationary pressures in the Russian economy.

Today's wholesale gas price[13] in Russia is six times less than in the USA and Europe, and domestic consumption is about 370-380 Bcm/y. Low prices also have an impact on what Russia could draw from the Caspian republics. They call for tariffs in line with export prices, whereas Gazprom can only offer netback prices based on the weighted average between its exports and its domestic market.

Third, there is also concern about the decline of the large fields that fed the growth of the supply during the Soviet era. As reflected in Graph III-16, the major fields of Medvezhye, Urengoy and Yamburg are depleted by 78%, 67% and 46% and now decline at a rate of 30-40 billion cubic meters per year. Today, 80% of Gazprom investments are to maintain the current level of gas production. Zappolyarnoye in Western Siberia is the latest gas field to come on-stream (2002) and should reach its full capacity of 100 Bcm/y in 2004, thus contributing to offset the declines of the aging Urengoy, Yamburg, Medvezhye and Orenbug fields.

GRAPH III-16 RUSSIAN GAS PRODUCTION



Source: W. Zittel

Following the development of Zappolyarnoye and its satellites comes the development of super-giant gas fields of the Yamal Peninsula (Bovanenkovskoye, Novoportovskoye and Kharassavey) and the building of a new pipeline between Yamal and Kassel, Germany, where it will tie into the European gas grid. The project's major pipelines will eventually require

[13] The 2001 price was only 0.40-0.45 $/MBtu. The government approved a 15% hike only from July 1, 2002, onward for both industrial and residential tariffs. This is too small an increase to reduce the internal demand for gas and to allow Gazprom to rely on domestic revenues to finance some of its mega- projects. And while consumer debt to gas companies has almost halved in the past two years, Russian users still owe 44.9 billion rubles (1.44 G$) for past deliveries; moreover, only 29 of the 89 regions in the Russian Federation are up-to-date with their gas bill payments.

around 10,900 km of 56-inch pipe designed to the unprecedented operating pressures of 83 bars. Of the project's five major sections, only the Belarus and Polish legs have been completed so far (and are being used to carry non-Yamal Russian gas westward). While building the German section will not pose a big problem, the main 3000 km Russian route will prove a major challenge, especially its northern portion from Yamal to Ukhta (some 1220 km), much of which overlies permafrost. Total investment cost for the Yamal-Europe project is estimated at US$45-50 billion for an ultimate network design capacity of 67 Bcm/y. Such cost estimates explain why the most often quoted estimates of natural gas prices delivered to Europe from this project are greater than 4 or 5 US$/MBtu.

The outlook for the Northern Barents Sea may not be any better. First, Gazprom will have to await adequate production-sharing agreements (PSA) legislation because the current Russian law suffers from ‘organic incompatibility’ with PSA, and foreign oil and gas companies naturally insist on having a clear-cut deal before getting into a project's execution phase. Secondly, even on paper, the cost of developing the super-giant Shtokmanovskoye is great, pushing the planned delivered price in Europe above 4 $/MBtu.

To conclude, if and when a supply gap for natural gas develops in Western Europe, Gazprom’s stated goal is to keep its production plateau at around 530 Bcm/y for the next 2 decades, a goal that already appears very ambitious. And the new USA/Russia energy partnership as well as Russian interest in natural gas markets in Asia may alter the dynamics of Western Europe-Russian negotiations on future projects.

Future Gas Exports from Middle East to Europe

Middle East gas could come to Europe either as LNG, which has already started, or by pipelines. The LNG delivered cost to Europe is 3$/MBtu or less, which, given current European prices, is competitive but suffers from two limitations: the growth of LNG availability and the need to share it with North America, where prices are already attractive, and receiving capacities could grow quickly.

The building of pipelines along a possible southern route – from the Middle East to Turkey, Bulgaria and then directly, or through Yugoslavia, to Greece and Italy – faces two kinds of constraints: the need to have many trans-boundary agreements (a problem that the Energy Charter treaty should ease) and the Turkish situation, where the economic crisis and slower than anticipated growth of gas demand has led to the decision to interrupt supplies from Iran or from Russia, in particular from the newly built deepwater Blue Stream pipeline. This decision will have an impact on the potential suppliers and will slow down the projects for extending the present pipelines westwards.

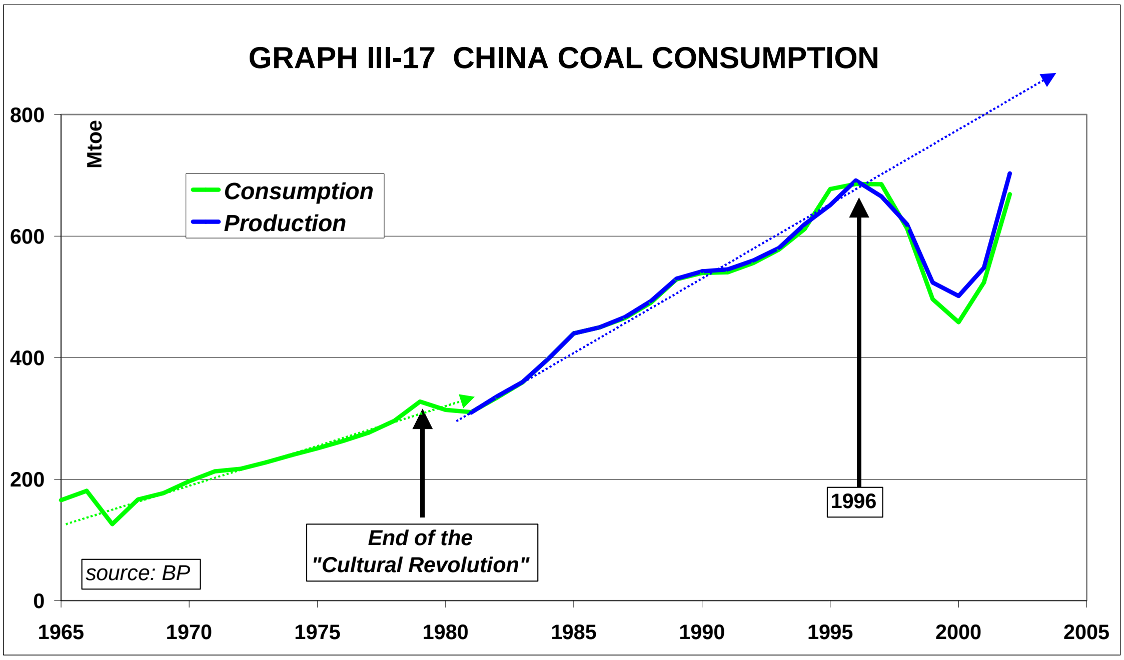
The positive stance of Turkey, which looks favourably on this project as a means in the future to avoid the over-supply they are now experiencing and to get cheaper gas (a lower netback price based on the gas delivered to Europe), may not suffice to convince the suppliers that the extension towards Europe makes economic sense.

Other Energy Sources

The analysis of energy supply has concentrated principally on the oil and natural gas markets and the way in which oil continues to impact most energy policy and business decisions. However, there are other important energy sources, some of which are in plentiful supply and compete in base load power generation. The following analysis is not a systematic review but a brief description of a few supply drivers which might play a role in the future.

Coal

Coal is so significant in so many markets that WEC has undertaken a special global coal study, which will be released at the Sydney World Energy Congress in September, 2004. Coal use is increasing everywhere except in the FSU and China (where both production and consumption fell after 1996 because of the severe restructuring that took place). Graph III-17 presents data from the *BP Statistical Review of World Energy* (2003).



The messages that emerge about China coal are the following:

- Coal production and consumption were very similar up to 1996, when a significant decline began up to 2000 (with production 30% lower than in 1996);
- From 1996 to 2000, coal production outstripped consumption, resulting in a large build-up of storage (100-200 Mt in 1996);
- Improved logistics of transportation by railways has allowed the shipment of part of these supplies to the export market. China's coal exports increased from 32 Mt in 1998 to more than 90 Mt in 2001. Exports in 2002 were around 84 Mt;
- Production and consumption of coal in China appear to have rebounded vigorously since 2001 and kept in step, but as noted below, it is not entirely clear if this will be sustained.

The Chinese government was concerned by the growth of cheap but unsafe village mines that were 'creaming' the coal deposits, spoiling the economics of the untapped reserves and competing with the official state mines; hence the government introduced tough regulations and closed many village mines (31,000 mines in 1998 and 1999 resulting in 1,044 Mt produced in 1999, i.e., 280 Mt or 24% less than in 1996), with a planned production of 890 Mt in 2000 (Graph III-18).

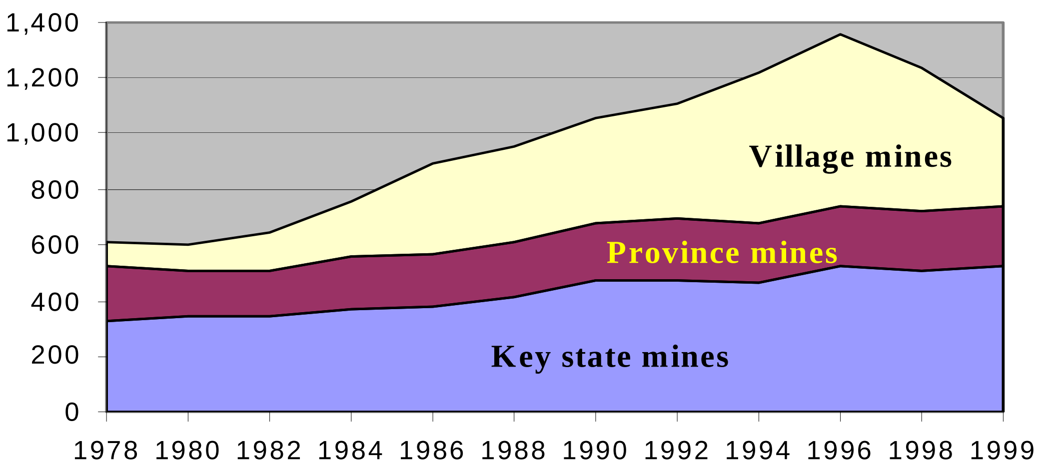
Data on China coal are not entirely reliable, and interpretations often focus on only a few aspects:

- ABARE (Australian Bureau of Agricultural Resources and Energy), in its report *China's Changing Coal Industry – Implications and Outlook*, concentrates on the potential of China to increase its coal exports at the expense of Australian coal. According to ABARE: "The relatively sudden and large fall in coal consumption in 1996 was the result of several factors. A key driver has been China's economy-wide economic reforms, including the closure or merger of some large and inefficient state owned enterprises and the closure of small plants in key industry sectors. These reforms have resulted in notable energy efficiency improvements in major coal using industries, including a 16 per cent fall in coal use per tonne of pig iron production between 1996 and 2000";

- JETRO (Japan External Trade Organisation) examined the mining sector in China in detail and confirms the key role played by the closure of many village mines (see Graph III-18). Many of these mines were opened without licenses and had very low levels of safety and reserve management. Their closure (at least officially) is therefore part of the broad reforms engaged in by the Chinese government and coincided with the need to strengthen the economy at the time when the Asia crisis was developing and pushing Chinese exports down;

- Last but not least, different messages emerge from China concerning future coal availability. While the China Academy of Geological Sciences released a report in March, 2003, declaring that there are vast and largely undiscovered coal reserves, some Chinese officials publicly raise doubts about the long-term capacity of Chinese coal to provide the necessary supply. A coal industry report issued at the tenth session of the National People's Congress in November, 2003, declared that, with demand increasing at a rate of about 20 Mt a year, the gap between supply and demand for coal could reach 200 Mt by 2005, when exploitable coal reserves would stand at 25.6 Gt instead of the 55 Gt needed.

GRAPH III-18 CHINA COAL PRODUCTION (Mtoe)



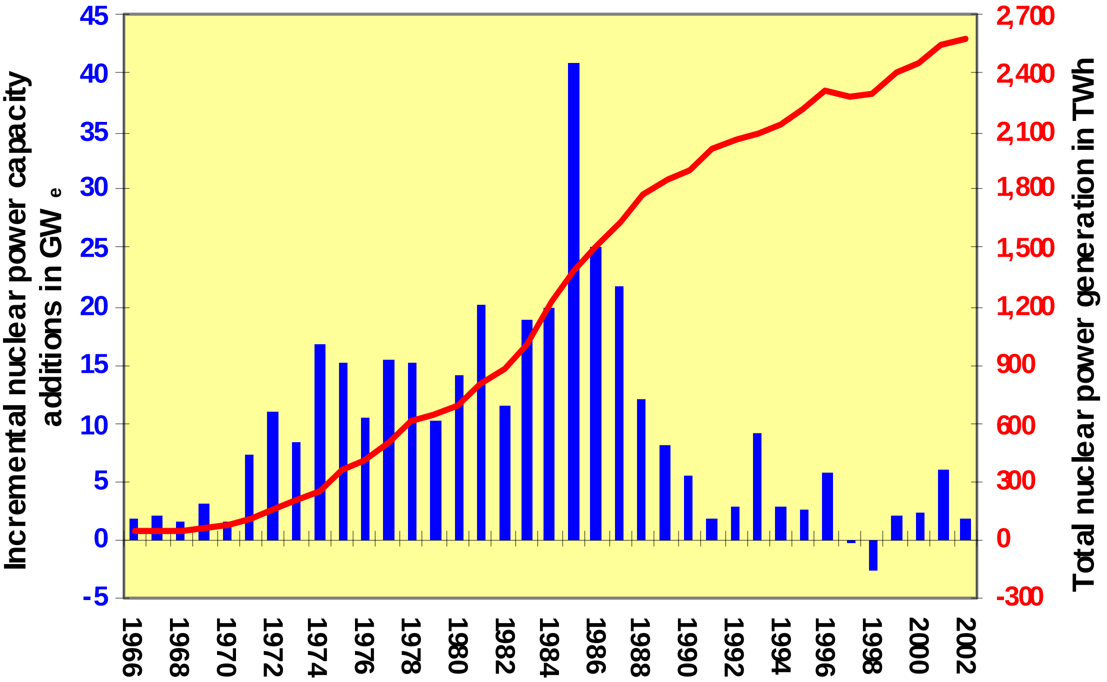
Source; Nobuhiro Horii, JETRO

Many factors are driving the coal price in China upwards (labour costs, improved safety, washing facilities and other clean technologies, the extension of logistics, the need to seek more difficult deposits), a development that also applies to other large coal consuming markets such as India, Poland and Russia. Government-industry partnerships on clean coal technologies, including carbon capture and sequestration, will hopefully bear fruit in the next few years. The recent creation of the Carbon Sequestration Leadership Forum by a number of developed and developing countries with important coal, oil and natural gas interests is noteworthy in this regard. Increased efficiency in coal production and utilisation with the extensive use of clean coal technologies could offset some of the concerns about uncertain supplies in places like China. If Annex 1 countries invest in and accelerate the transfer of such technologies to China and other developing countries to earn credits for the reduction of GHG emissions, coal could be a bigger factor as a driver of global energy supply in the future.

Nuclear

Graph III-19 shows the rapid growth in worldwide nuclear generating capacity in the 1970s and 1980s, followed by much slower growth since. However, because plant capacity factors have continually risen, total nuclear electricity production continued to grow after 1990.

GRAPH III-19 Annual Capacity Additions and Nuclear Electricity Generation 1965-2002



source: *IAEA*

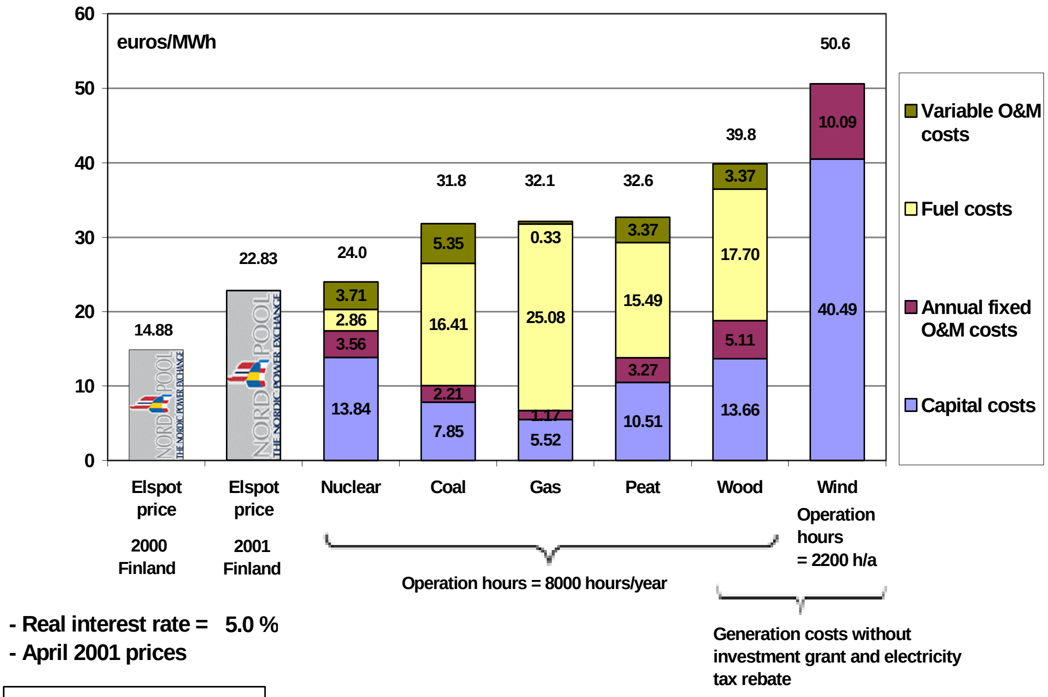
Deregulation has led to excess capacity, particularly in Europe, which lowers incentives for new power plants of any sort. Nuclear power's 'front-loaded' cost structure, with high capital and low operating costs, is also a particular disadvantage in deregulating markets that value rapid returns. In addition nuclear investments carry an extra financial risk due to political opposition of varying intensity in different countries, notably in Western Europe.

Nuclear power emits virtually no GHGs, and should GHG constraints be broadly implemented – whether through the Kyoto Protocol and successor agreements, broad carbon taxes, mandatory limits backed by fines, regional cap-and-trade systems or some combination of these – nuclear power's attractiveness will increase relative to higher-carbon alternatives. In a future carbon-constrained world, the most likely long-term competitors for the electricity (and possibly hydrogen) market will be nuclear power, other low-emission options such as wind and solar power and coal-fired plants with carbon capture and storage. In the even longer-term future, nuclear fusion and other less foreseeable options may also become serious alternatives.

Graph III-20 is a cost comparison of electricity generation for Finland. Together with the security of supply benefit and the consensus within the country for a final repository of long-term nuclear wastes, it highlights why the option of building a new nuclear plant has been accepted by the public and ratified by the Parliament in Finland. Of course, nuclear power costs are country dependent and vary widely. The Finnish approach might be duplicated in other industrialised or developing countries, although it is noted that some key countries, such as Germany, have specific phase-out plans, while strong views against building new plants prevail in the USA, the largest nuclear power market in the world.

Nuclear power is an important source of electricity in some important markets around the world. However, unless the perception of consumers about its acceptability improves, it is unlikely to play a larger role as an energy supply driver than it does today.

GRAPH III-20 ELECTRICITY GENERATION COSTS



Source: Ahti Tovoila, TVO

Modern Renewables[14]

Thanks to economies of scale and technological progress, modern renewables exhibit spectacular cost declines as shown in Graph III-21. Yet, in the view of Chauncey Starr, the founder of EPRI and its first chairman, all renewables unfortunately face practical barriers. Hydro is obviously limited to geographical settings, many of them in developing countries, and has manageable ecological constraints.

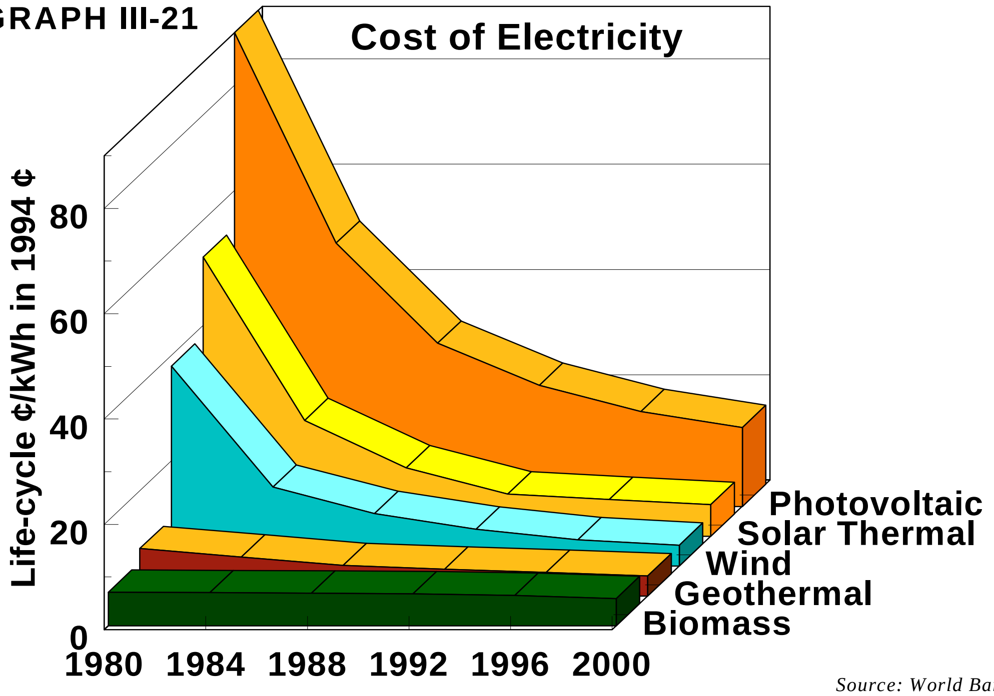
Biomass involves energy costs of transportation that generally limit its value to a collection radius of 25 miles around the power plant; UN and other studies on the health impact of different forms of biomass on a life cycle basis are also important. The intermittency of solar and wind (diurnal availability about 15-30% in the temperate zone) limits their contribution

[14] Readers should consult the WEC Statement 2003 at www.worldenergy.org about renewables and the risks of imposing quotas at the global level. This statement complements the short analysis developed in this section.

to supplement base load electricity. Adding storage for a continuous base load supply multiplies their capital investment by a rough factor of ten or more, making them impractical for such use.

Modern renewables are used for power generation, but except for very small niche needs, they are linked in a hybrid format with fossil fuel base load generation. In competitive niches (e.g., favourable geothermal sites in Iceland, Italy and the Pacific rim or areas with regular winds, such as offshore North Sea or some parts of California), they are economic, but in most markets they need to rely on public subsidies, ranging from a minimum of, say, 3 US cents per kWh up to 10 cents and more.

GRAPH III-21



Source: World Bank

As an order of magnitude, a 5% share in 2020 would represent 700 GW at the world level and about 200 GW for the USA. The corresponding subsidies would be in the order of magnitude of 100 G$ for the USA only. According to USDOE, up to now, USA subsidies for nuclear and renewables have amounted to:

- 50 G$ (current dollars) for hydro over the last century (share of the power output: ~10%);
- 25 to 50 G$ for civil nuclear over 50 years (share of the power output: ~20 %);
- 13 G$ for modern renewables over the last 15 years (share of the power output: ~0.5 %).

The fastest growing modern renewable is wind, followed by solar. Because they are intermittent (annual use of say 4000 hours at full capacity for offshore wind farms and half that for onshore windmills, even less for solar), they bear a rapidly rising cost for backup supply when their share in the electricity supply increases beyond say 5%[15]. So even with the three-cent subsidy, one cannot expect that their share will exceed this 5% limit of the world power supply (i.e., about 15 % in terms of capacity).

[15] According to the West Denmark regulator, for technical reasons of security and stability of the power delivery, the maximum possible contribution of intermittent renewables in an island system like that of West Denmark, when bottlenecks prevent trading with the Nordic system, is less than 10%.

The obvious conclusion is that, despite the optimistic views of some published scenarios, modern renewables other than hydropower may continue to grow, with double-digit growth rates from a very low base provided that subsidies are maintained, but they are unlikely to achieve a significant market share. The development of renewables could provide an appropriate solution for rural communities far from the main network, but as a group (apart from large hydro) they are unlikely to become a significant energy supply driver.

D. CONCLUSIONS ON THE 'ENERGY SUPPLY DRIVER'

Energy supply constraints may play an important role as a negative driver of the energy scene in the coming years in spite of the best efforts of governments and companies. They may originate from a temporary lack of production capacities (as for oil in the USA in 1973, coal in China after 1996, natural gas in North America or Western Europe today, possibly natural gas in the FSU in the years to come) or from a more fundamental shift away from one major energy source because of changes in relative costs or prices, external factors (e.g., wars or revolutions), public opinion (e.g., "a nuclear accident somewhere is an accident everywhere", or stringent environmental policies (e.g., the threat of climate change).

In contrast, as discussed in Part I, increasing energy supply to provide access[16] to those who have little or no access today to modern energy could be a positive driver of the energy scene. While even a minimal extra call on production capacities may raise policy and business concerns, such broadened access will enhance the global economic system and its flexibility to overcome changes and challenges, including possible future economic crises. There could be more peace and security in the world and therefore more reliability of energy supply.

No mention has been made of what the resource base might be for the three fossil fuels, nuclear or even renewables. This was a much discussed issue at the beginning of this study, but it disappeared progressively as a primary concern. As we have seen, the growth and decline of primary energies over time never leads to a complete exhaustion of reserves, because, with the right price signals and international collaboration, new, more competitive sources of energy emerge to take their place.

The uncertainties in energy markets, particularly with respect to moving plentiful supplies to where they are needed, coupled with the long lead times for new investments in exploration and production to meet new demand, reinforce the view that market forces alone are not enough to guarantee a sustainable balance among producer and consumer interests.

[16] See results of 18th World Energy Congress and WEC Statement 2002.

ANNEX A: STUDY GROUP MEMBERS AND INVITED EXPERTS

Study Group Members

Dr Majid A Al-Moneef	Study Chairman Ministry of Petroleum & Mineral Resources, Saudi Arabia
Jean-Marie Bourdaire	Director of Studies, World Energy Council
Dr Nourah Al-Yousef	King Saud University, Saudi Arabia
Jacobo Balbas	UNION FENOSA, Spain
Dr Mariano Bauer	Instituto Mexicano del Petroleo and UNAM, Mexico
Pablo Blanc	UNION FENOSA, Spain
Nabil Bouraoui	Observatoire National de l'Energie, Tunisia
José Malhães da Silva	Brazilian Member Committee, Brazil
Gerald Doucet	Secretary General, World Energy Council
Dr Alioune Fall	Power Sector Regulatory Commission, Senegal
Masaharu Fujitomi	Asia Pacific Energy Research Centre, Japan
Dr Hans-Holger Rogner	International Atomic Energy Agency (IAEA), Austria
C P Jain	National Thermal Power Corporation Ltd, India
Tatsuyoshi Kato	Chubu Electric Power Co, Japan
Malcolm Keay	World Coal Institute, United Kingdom
Dr Davood Manzoor	Bureau of Energy Planning, Iran
Richard McKean	Montreux Energy, Switzerland
Dr François Moisan	Agency for Environment & Energy Management (ADEME), France
Jean-Eudes Moncomble	French Member Committee, France
Dr Gerhard Ott	German Member Committee, Germany
Carlos Miranda Pacheco	Bolivian Member Committee, Bolivia
Francisco Saraiva	REN SA, Portugal
S Vijayaraghavan	Ministry of Petroleum & Natural Gas, India
Dr Rob Whitney	CRL Energy Ltd, New Zealand

Invited Experts*

Thomas Ahlbrandt	United States Geological Survey, United States
Francisco Barnés	Under-Secretary of Energy, Mexico
Dr Gustavo Best	UN Food and Agricultural Organisation IUNFAO), Italy
Dr Fatih Birol	International Energy Agency, France
Guy F. Caruso	US Department of Energy, United States
François Cattier	International Energy Agency (IEA), France
Bertrand Chateau	European Commission, France
Eric Chaney	Morgan, Stanley & Co International, United Kingdom
Chris Cragg	EP Global Energy, United Kingdom
Prof Adilson de Oliveira	Federal University of Rio de Janeiro, Brazil
Dr Brigitte Granville	Royal Institute of International Affairs, United Kingdom
Pietro Erber	Eletrobrás, Brazil
Nobuhiro Horii	IDE-JETRO, Japan
Jean Laherrere	Formerly Total Exploration, France
Tatsuo Masuda	Japan National Oil Corporation, Japan
Brent Moulton	Bureau of Economic Analysis, United States
Dr Nebojsa Nakicenovic	International Institute for Applied Systems Analysis (IIASA), Austria
Laurence Nayman	Centre d'Etudes Prospectives et d'Informations Internationales (CEPII), France
Johan Prinsloo	ESKOM, South Africa
Dr Sethuramiah Rao	Consultant, United States
Tahar Hadj-Sadok	UN Framework Convention on Climate Change (UNFCCC), Germany
Dr Adnan Shihab-Eldin	Organisation of Petroleum Exporting Countries (OPEC), Austria
Olga Côrtes Simbalista	Eletronuclear, Brazil
Scott Sitzer	Energy Information Administration, US Department of Energy, United States
Dr Jamil Tahir	Organisation of Arab Petroleum Exporting Countries (OAPEC), Kuwait
Richard Taylor	International Hydropower Association, United Kingdom
Paul Tempest	United Kingdom
Ahti Toivola	Teollisuuden Voima Oy, Finland

* The Invited Experts made useful contributions but did not participate in the study.

ANNEX B: LIST OF ABBREVIATIONS, GLOSSARY AND METHODOLOGY

LIST OF ABBREVIATIONS

3D-senarios	Three Dimensional Scenarios
AFTP	Association Française des Techniciens du Pétrole
b	barrel
b/d	barrels per day
BP	British Petroleum
C	carbon
CEE	Central and Eastern Europe
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales
CHP	combined heat and power
CO_2	carbon dioxide
DC	developing countries
EIA	Energy Information Agency; a semi-independent body within the US-DOE
EPRI	Electric Power Research Institute
ETW	*Energy for Tomorrow's World* (1993 WEC publication)
ETWAN	*Energy for Tomorrow's World – Acting Now!* (WEC's Millennium Statement - 2000)
EVA	Energy Ventures Analysis
G	giga, i.e. billion (10^9)
GHG	greenhouse gases (mostly CO_2 but also methane and nitrogen oxides)
GW	gigawatt
IEA/OECD	International Energy Agency; a semi-autonomous body within the OECD (Organization of Economic Development and Cooperation)
IFP	Institut Français du Petrole
IIASA	International Institute for Applied Systems Analysis
IT	information technology
K	kilo, i.e. thousand (10^3)
kWh	kilowatt hours
LNG	liquid natural gas
LPG	liquid propane gas
M	mega , i.e. million (10^6)
ME	Middle East
NRNW	new renewables
OECD	Organisation for Economic Co-operation and Development
OPEC	Organisation of Petroleum Exporting Countries
PC	Personal Computer
PPM	parts per million
PPP	purchasing power parity
SUV	sport utility vehicle
t	tonne

T	tera, i.e. million of millions (10^{12})
TPER	total primary energy requirement
tWh	tera watt hours
tc	tonne of carbon
tCO_2	Tonne of carbon dioxide (3.67 tCO_2 make 1 tc)
toe	Tonne oil equivalent (about 41.5 MJ)
UN	United Nations
US-DOE	Department of Energy of the United States
Y2K	Year 2000

GLOSSARY AND METHODOLOGY

GDP (Gross Domestic Product)

GDP data are the same as those used by the IEA. They are established by the CEPII (Centre d'Etudes Prospectives et d'Informations Internationales) which provides three sets:

- Current money GDP
- Constant money GDP
- Constant money PPP GDP (i.e., purchase power parity).

The set of data used in the report is the latest PPP (2003) version in 1995 $ value.

They are converted in 2000 $ value by multiplying the 1995 figures by 1.074. Without a PPP methodology, the relative weight of the developing countries would be underestimated, because, in most cases, their domestic currencies are undervalued (as a general rule, one may consider that the lower the GDP per capita, the more undervalued the local currency). The report takes a PPP approach systematically.

The only region for which PPP is uncertain is China, because given the apparently too high estimates of annual growth, one may wonder whether PPP should be based on the 1978 situation (starting point of the annual discrepancies) or on the most recent situation in 2002. The choice made in this report is the former, i.e., to assume that the 1978 GDP PPP for China is correct, then to estimate the actual growth since then and find a 2002 GDP PPP value.

ENERGY

Final energy is seen as the combination of three energy–related services: generated electricity (meaning that transmission losses are considered as part of overall demand), liquid fuels (mostly oil products) used for transportation (electric trains rely on a fixed infrastructure and are therefore not included in this item, but their electricity consumption is counted as an electricity service) and stationary fossil fuel end-uses (this last service includes both the heating provided by fossil fuels in buildings or industrial processes and the non-energy uses of fossil fuels, e.g., as feed stocks). Secondary heat is not taken into account because it corresponds to a better efficiency of the transformation of energy reflected by a lower demand for fossil fuels.

Primary Energy is called TPER (Total Primary Energy Requirements) and includes four categories:

- Commercial fossil fuels rated according to their standard thermal power (BP and IEA convention)

- Hydro and nuclear rated according to a theoretical efficiency of 38% when generating electricity (like BP but unlike the IEA, which takes a 100% theoretical efficiency for hydro power. and by doing so, lowers the hydro contribution by a factor of three)
- New renewables other than hydro (e.g., wind, solar, geothermal, tide) with a theoretical efficiency of 38%, as for hydro, when generating electricity (unlike BP, which ignores them, and unlike IEA, which takes a theoretical 100% efficiency for wind and solar but 10% for geothermal)
- 'Traditional' non-commercial fuels (mostly biomass, called CRW by the IEA, or combustible renewables and wastes). The values are those of the IEA, with the same conventions.

Based on this approach, TPER is equal to BP primary energy plus new renewables and biomass. It is slightly more than TPES (Total Primary Energy Supply) of the IEA because hydro and new renewables are assessed at nearly three times the IEA values (with the exception of geothermal, which has a lower weight, about 0.4 times that of the IEA). TPER was also used in the WEC 2000 publication, *Energy for Tomorrow's World: Acting Now!*.

REGIONS

Countries are aggregated into the following regions:

Three 'rich' developed regions with market economies

- North America with the USA and Canada (Mexico is not included because its energy profile is more like those of other Latin American countries than those of the USA and Canada)
- Western Europe, excluding Central/Eastern European countries (which are included with the FSU below because of the similarity of their energy profiles to that of the FSU) and Turkey (which is included in the Middle East region)
- Asia Pacific with Japan, Australia and New Zealand (South Korea is not included because of its fast-developing profile, similar to that of 'developing Asia')

Three 'poor' developing regions with market economies

- Latin America (including Mexico)
- Africa and the Middle East (including Turkey)
- Developing Asia (including South Korea)

Two regions 'in transition' towards market economies

- The FSU (former Soviet Union) and Central/Eastern Europe
- China and Hong Kong

ENERGY vs. GDP PROFILES OF THE REGIONS

When one compares the evolution of TPER or that of the energy-related services on a GDP PPP scale, one finds consistent paths across the different regions with three exceptions: the USA, China and Middle East:

- USA energy trends are consistent up to 1996 and change direction from 1996 onwards. As nothing particular in terms of energy availability and price can explain this divergence, the report proposes another explanation based on an over-evaluation of USA GDP growth since 1996;
- China energy trends are consistent up to the 1978-80 period, when the Cultural Revolution ended. After this period, the GDP-related energy intensity is much lower than that of the developing countries in general. The report suggests that the official GDP measurements may have been distorted by methodologies based on the 'net material product', i.e., that take into account the volumes produced rather than the

added value created. When volumes grow very fast, as has been the case in China for the last 20-25 years, economies of scale and productivity gains lower costs, prices and added values, leading to GDP growth lower than the growth of produced goods. The report's estimates based on energy trends are consistent with the revised estimates provided by Angus Maddison (OECD, Development Centre);

- Middle East energy trends are heavily distorted by the impact of oil revenues on GDP. Whereas the individual wealth of citizens has evolved slowly and has led to regular energy trends, GDP has increased at the time of oil shocks and decreased with the fall of production and prices, up to the 1985-1986 counter oil shock. However, even though the variations in GDP are large in national terms, they are small in comparison with other regions and the global trends.

ANNEX C: LIST OF GRAPHS AND TABLES

LIST OF GRAPHS

LIST OF TABLES