OECD Green Growth Studies

Energy

International Energy Agency

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Foreword

Global demand for energy is increasing rapidly, because of population and economic growth, especially in emerging market economies. While accompanied by greater prosperity, rising demand creates new challenges. Energy security concerns can emerge as more consumers require ever more energy resources. And higher consumption of fossil fuels leads to higher greenhouse gas emissions, particularly carbon dioxide ($CO_{2)}$, which contribute to global warming. At the same time, the number of people without access to electricity remains unacceptably high.

But such challenges can create opportunities. A sustainable energy future will require new thinking and new systems – essentially a transformation in the way we produce, deliver and consume energy. If our goal is to raise living standards, provide access to modern energy services, use energy more efficiently, protect the global environment and ensure reliable energy supplies, green growth must play a key role.

The OECD and IEA are actively supporting the transition to a greener model of growth. At its 50th Anniversary Ministerial Council Meeting in May 2011, the OECD launched a Green Growth Strategy to help policy makers and stakeholders to address the major environmental challenges of today's world, while expanding economic opportunities. The Strategy encompasses both policy recommendations to make economic growth "greener" and a set of indicators to monitor progress towards green growth. The Strategy is first and foremost about implementing change and achieving a common purpose: a world that is stronger, cleaner, and fairer.

This report highlights the challenges facing energy producers and users, and how they can be addressed using green growth policies. Because energy underlies the global economy, the decisions made today in the energy sector will be critical to achieving greener growth. We have a window of opportunity for establishing a policy framework to enable transformational change in the energy sector, including by facilitating technological innovation and the creation of new markets and industries, to reduce the sector's carbon-intensity and to improve energy efficiency.

The environmental imperative to reduce CO_2, emissions in the energy sector coincides with a looming new investment cycle in power generation in most OECD countries. In the emerging market economies, many power generation facilities are quite recent, but many more will be built in the coming years to meet growing energy demand. As power plants and other infrastructure tend to have long operating lives, we must avoid "lock-in" of CO_2 emissions by ensuring the latest clean technologies are used. We have a narrow margin. If we do not manage to slow current rates of emissions growth, we will hit the ceiling by 2017, meaning that to keep the global increase in temperature to 2 degrees Celsius; all new infrastructure will have to be zero-emission.

A large-scale transformation of the global energy sector is possible, although it will require significant investment. Global emissions could be halved by 2050, using existing and emerging technologies, at an additional cumulative investment of USD 46 trillion, a further increase of 17% on top of baseline investments. It is vital for governments to create an enabling policy framework to catalyse private-sector investment in the transition to a low-carbon energy sector. By acting now, long-term costs can be reduced. Every US dollar that is not spent on investment in the energy sector before 2020 will require an additional USD 4.3 to be spent after 2020 to compensate for increased greenhouse gas emissions by building zero-carbon plants and infrastructure by 2035.

There is an urgent need to create an enabling policy framework for the transformation of the energy sector. The task is daunting, but we must act together and now to create the momentum for fundamental change.

Angel Gurría, OECD Secretary-General and Maria Van der Hoeven, IEA Executive Director

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The report is released under the responsibility of the OECD Secretary-General and the IEA Executive Director. The process was conducted under the leadership of the Chief Economist and Deputy Secretary-General Pier Carlo Padoan and benefitted from the guidance of Bo Diczfalusy, Director, Sustainable Energy Policy and Technology and Simon Upton, Director, Environment Directorate. The project has been managed by Nathalie Girouard and supported by the Green Growth team.

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For more information on the OECD Green Growth Strategy, see www.oecd.org/greengrowth.

Table of contents

Boxes

Figures

Tables

Acronyms

AIDS	Acquired immune deficiency syndrome
APEC	Asia-Pacific Economic Cooperation
BAU	Business-as-usual
BRICS	Brazil, Russia, India, China, South Africa
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CSI	Cement Sustainability Initiative (of the WBCSD)
CSP	Concentrating solar power
EDI	Energy Development Index
EJ	Exajoule
EREC	European Renewable Energy Council
ETP	Energy Technology Perspectives
ETSAP	Energy Technology Systems Analysis Program
EU	European Union
EU ETS	European Union Emissions Trading System
G20	Group of 20
GDP	Gross domestic product
Gt	Gigatonnes
GW	Gigawatts
GWEC	Global Wind Energy Council
HIV	Human immunodeficiency virus
ICT	Information and communication technologies
IEA	International Energy Agency
IFI	International finance institutions
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producers
ISIC	International Standard Industrial Classification of All Economic Activities
ktoe	Kilotonne of oil equivalent
kWh	Kilowatt-hour
LED	Light-emitting diode
LPG	Liquefied petroleum gas
mb/d	Million barrels per day
mtoe	Million tonnes of oil equivalent
MVE	Monitoring, verification and enforcement
MW	Megawatts
NGLs	Natural gas liquids
NIST	National Institute of Standards and Technology
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PHCN	Power Holding Company of Nigeria
PHEV	Plug-in hybrid electric vehicle

ppm	Parts per million
ppm CO_2-eq	Parts per million of CO_2 equivalent
PV	Photovoltaic
R&D	Research and development
RD&D	Research, development and demonstration
RDD&D	Research, development, demonstration and deployment
SMEs	Small and medium-sized enterprises
SO_2	Sulphur dioxide
SSA	Sub-Saharan Africa
tCO_2	Tonnes of CO_2
TM	Transition management
TWh	Terawatt-hours
UAE	United Arab Emirates
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
WBCSD	World Business Council for Sustainable Development
WEO	World Energy Outlook
WHO	World Health Organization
WTO	World Trade Organization

Executive summary

Introduction

Energy is a fundamental input to economic activity. Modern energy services light up our homes and schools, fuel economic activity to produce and consume, provide comfort and mobility, pump water and contribute to health and well-being. Harnessing energy sources to replace manual and animal labour was the platform of the Industrial Revolution: a period of unprecedented economic and social development.

The 20th century witnessed large increases in the global population, economic output and fossil fuel consumption. The gains from growth have been impressive for many. Yet these gains have taken a toll on a range of environmental systems where unsustainable practices have dominated. Continuing deterioration of natural resources could stress the ability to meet the needs of a growing population and undermine economic activity. Green growth could meet this challenge. Green growth is about fostering economic growth and development while ensuring that natural assets continue to provide the ecosystem services on which our well-being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities.

The energy sector poses a particular challenge in the context of green growth due to its size, complexity, path dependency and reliance on long-lived assets. The current energy system is highly dependent on fossil fuels, whose combustion accounted for 84% of global greenhouse gas emissions in 2009. Global demand for energy is rapidly increasing, due to population and economic growth, especially in large emerging countries, which will account for 90% of energy demand growth to 2035. At the same time, nearly 20% of the global population lack access to electricity. A major transformation is required in the way we produce, deliver and consume energy.

A large-scale transformation of the global energy sector is possible, though it will require significant investment. Global emissions could be halved by 2050, using existing and emerging technologies at an additional cumulative investment of USD 46 trillion. It is vital for governments to create the enabling policy framework to catalyse private-sector investment in the transition to a low-carbon energy sector. It is cheaper in the long-term to act now, as every USD 1 of energy sector investment not spent before 2020 will require an additional USD 4.3 to be spent after 2020 to compensate for increased greenhouse gas emissions by building zero-carbon plants and infrastructure by 2035.

Benefits and opportunities

Moving economies in a greener direction will foster broad benefits. High levels of resource productivity and the efficient use of energy can lead to more dynamic and competitive economies which are, in turn, better able to respond to the scale of the transition that is required. Countries can gain an advantage by being the first ones to take action and realising the benefits related to competition in widening international markets for green energy goods and services. Green growth can reduce the burden on land, air and water resources while creating expanded opportunities for gains in productivity, quality of life and social equity.

The environmental imperative to reduce carbon dioxide (CO_2) emissions and ensure sustainable growth in the energy sector coincides with a looming new investment cycle in power generation in most OECD countries. In non-OECD countries, many power generation facilities are quite young, but more will be built in the coming years to meet growing energy demand. There is a window of opportunity to establish the policy framework to enable transformational change in the energy sector, including facilitating technological innovation and the creation of new markets and industries, to reduce the sector's carbon-intensity, and improve energy efficiency.

Overall, there are four key elements that provide the economic rationale for applying green growth strategies to the energy sector:

- *Economic costs of environmental damage and poorly managed natural resources*: Failing to address environmental concerns and not managing natural resources effectively poses risks to long-term economic growth, for example, via the growing scarcity and rising price costs of increased environmental damage of conventional fossil fuels and to well-being through the impairment of human health caused by pollution, for example.
- *Innovation to achieve environmental and economic objectives*: Innovation is fundamental to the objectives of green growth in that it can help to decouple environmental damage from economic growth. It is also at the core of economic objectives such as productivity growth and job creation. Innovation is particularly important in the energy industry, as we search for forms of energy that impose fewer environmental costs and for ways of improving efficiency in use as prices rise.
- *Synergies between environmental and productivity growth objectives*: Improved resource productivity and energy efficiency, through innovation or deployment of energy technology or processes, supports decoupling between economic growth, environmental damage and resource degradation.
- *Opportunities for new markets and industries*: Shifting toward green growth in the energy sector will require new technologies, fuel sources, processes and services that can spur new markets and new industries. Firms that are proactive in the face of these changes will be well-positioned to both contribute to and benefit from them.

Policies for green growth in the energy sector

Aligning the energy sector with a green growth framework requires a clear understanding of national priorities. While fostering greener growth will require international co-operation, it is largely a national matter and the policy mix will therefore differ across countries, according to local environmental and economic conditions, institutional settings and stages of development.

Policies will need to take into account the inter-relationships between economic sectors, transports, land-use patterns, social welfare and environmental integrity. A range of mutually reinforcing measures is required to address market failures and barriers, and create the enabling policy conditions for large-scale private-sector investment. This includes:

- *Rationalising and phasing-out inefficient fossil fuel subsidies* that encourage wasteful consumption, while adequately addressing the needs of low-income households through effectively targeted social policies.
- *Setting a price signal to value externalities* and provide robust signals for longer-term structural changes.
- *Establishing sound market and regulatory frameworks* that remove barriers to green investments and facilitate the move away from existing systems and patterns of fossil fuel energy use.

- *Radically improving energy efficiency* will reduce the need for investment in energy infrastructure, cut fuel costs, increase competitiveness, lessen exposure to fuel price volatility, increase energy affordability for low-income households and cut local and global pollutants improving consumer welfare.
- *Fostering innovation* by creating the enabling environment and regulatory frameworks to foster breakthroughs and overcome the inertia incumbent in today's energy systems, whether institutional or economic. Investment in relevant research and temporary support for the development and commercialisation of green technologies will be needed in certain cases. Intellectual property protection is important to the industry as reflected in the growing numbers of clean technology patent applications. In addition, governments need to implement effective policies for green energy innovation that target the cost competitiveness gap while also fairly reflecting the maturity and competitiveness of individual technologies and markets.

To achieve a green energy revolution and large-scale CO_2 emission reductions, all technology options will be needed. Energy efficiency, many types of renewable energy, carbon capture and storage, nuclear power, smart grids and new transport technologies can all contribute to curtailing greenhouse gas emissions, while promoting energy security and delivering wider environmental and social benefits. Constraining the types of technology that can be used in the energy sector transition will substantially increase costs.

Making green growth strategies work

Policy commitments to green energy growth are essential to providing policy certainty, clear direction for infrastructure investments and addressing structural change. Adoption of comprehensive strategies for energy efficiency, such as the International Energy Agency (IEA) 25 energy efficiency policy recommendations, provides resilient policy platforms for green energy growth.

Tailor-made energy policies for economies at different development stages can constitute the driver for a successful transition to green growth in the energy sector and the wider economy. The challenges to design and implement such a policy package with a consistent framework are considerable. Many energy systems are "locked-in" to high carbon production and consumption patterns that can be difficult to break for reasons that go beyond simple economics. Making reform happen will require attention to some common political economy challenges:

Structural adjustments: structural change involves not only a breakthrough of new technologies, but also corresponding shifts in the broader supporting system of infrastructure, supply chains, institutions, markets and regulations. Policies should aim to address barriers to change across the entire energy system and accelerate the "creative destruction" process. Specific actions include:

- Carefully designed *electricity market reform* to set incentives for suppliers to invest in efficiency with consumers and "green" capacity as well as environmentally friendly technologies to meet demand.
- *Dedicated supply chains* for efficient and clean energy applications, to combine specialised firms in geographical clustering, attract potential business partners and enhance conditions for local innovation and technology and infrastructure development, as well as to encourage international co-operation.
- *Targeted policy mechanisms* to attract private finance to the renewable energy and energy efficiency sectors.

Stranded capital: Sunk capital that is at risk of being stranded can act as a constraint on the rate of transition towards cleaner energy systems. Addressing the political economy of stranded capital will require:

- Carefully assessing future societal needs, seeking *less capital intensive options and opening up alternative low energy options* such as end use efficiency, distributed systems for services.
- Developing *standards for flexible options* such as carbon capture-ready fossil fuel plants that could retrofit at a later stage.
- *A regulatory framework* that provides a long-term view with clear milestones, to provide robust signals, reduce uncertainty and establish credibility.
- *A significant carbon price or proxy*, which provides a clear expectation of increase over time to create incentives strong enough to encourage sustainable energy solutions.

Distributional effects: Restructuring the energy sector is expected to have (relatively small) direct employment changes and wider equilibrium effects across the economy as well as between countries. Policies should help to ensure that while there will be winners and losers, the adjustment can be achieved in a way that is consistent with appropriate social policies. Specific policies include:

- Carefully designed package of *labour market and skills policies*, to help the labour market be dynamic and inclusive. This includes education policies that enable workers to acquire the training they need to move from contracting to growing industries and firms.
- *Consumer and demand side power in markets,* especially programmes to *expand the supply of safe, efficient and reliable energy* to the poorest sectors of society.
- Combining the *removal of environmentally harmful energy subsidies* with *effectively targeted policies for poverty alleviation* to offset the financial impacts on poor communities, allowing consumers to make more rational choices in their energy use and more efficient uses of government expenditures.

Monitoring progress towards green growth in the energy sector

Government progress on implementing policies that promote green growth in the energy sector can be evaluated using well designed operational sets of indicators, which the IEA and OECD are currently developing in consultation with a broad group of stakeholders.

The OECD has developed a conceptual framework for monitoring progress towards green growth, including a set of indicators. While the set of indicators is still being refined, key indicators pertinent to the energy sector are those that measure the carbon productivity or intensity of energy production and consumption (on various levels, including national and sectoral), energy intensity and efficiency, "clean" energy-related research and development and patents, as well as measures of energy related taxes and subsidies.

This needs to be complemented with *(i)* energy end-use indicators that help policy makers understand how users will respond to changes in energy prices, income, technology, energy efficiency, production patterns, and lifestyle *(ii)* additional energy-environment indicators, and with indicators characterising the level of access to energy.

While energy statistics and balances are generally well established in countries and at international level, measuring energy efficiency and innovation is difficult, and coherent industry level information is scarce. More needs to be done improve data quality, methodologies and definitions, and to link the data to economic information.

Chapter 1. Transforming the energy sector to sustain growth

Energy is a fundamental input to economic activity; however a major transformation is required in the way we produce, deliver and consume energy. The current energy system is largely dependent on fossil fuels, which negatively impact air quality, and contribute significantly to carbon emissions.

Global demand for energy is rapidly increasing, arising from population and economic growth, especially in emerging market economies, which will account for 90% of energy demand growth to 2035.

There is currently a window of opportunity to undertake transformational change in the energy supply sector to meet economic and environmental objectives, as there is a need to replace aging plants and add new capacity, especially in emerging economies, to meet growing electricity demand.

In the 20th century the world population grew 4 times, economic output 22 times and fossil fuel consumption 14 times (UNEP, 2011). The long term resilience of a wide range of environmental systems is now being tested by the requirements of a rapidly growing global population and the demand for higher living standards. This includes meeting the energy and food needs of 9 billion people in 2050. Without new policy action, a world economy 4 times larger than today is projected to use 80% more energy in 2050 (OECD, 2012 *forthcoming*).

The world faces twin challenges: expanding economic opportunities for a growing global population; and addressing environmental pressures that, if left unaddressed, could undermine our ability to seize these opportunities. Green growth seeks to reconcile these two imperatives. It is about fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities (OECD, 2011).

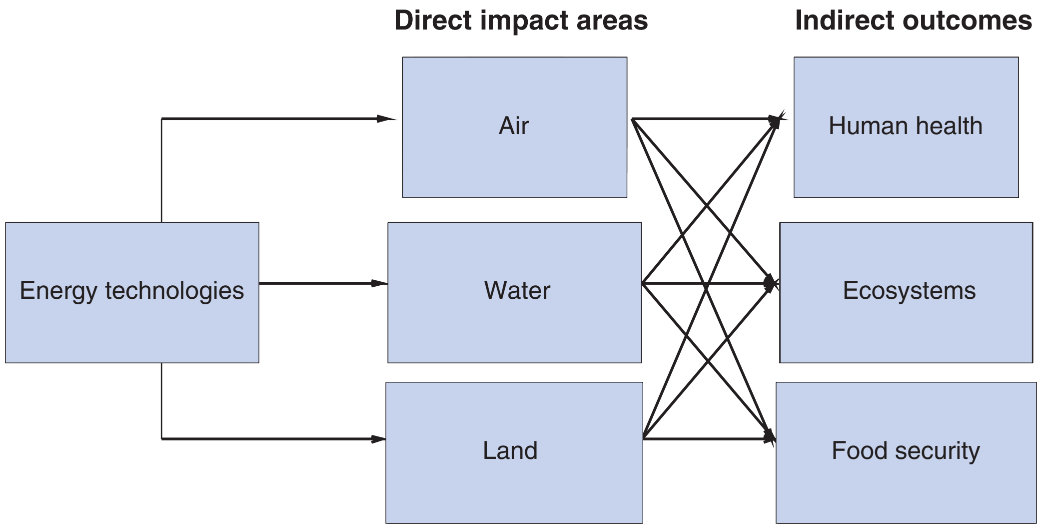
Greening our growth path calls for policies that properly reflect the value of natural assets and encourage more sustainable patterns of production and consumption. We need to decouple efforts to grow our economies from the persistent run-down of natural capital to ensure that the pursuit of progress today does not lead to impoverishment tomorrow and for future generations. This implies using natural resources and the technologies that we derive from them wisely and more efficiently. Green growth strategies aim to build upon the complementarities between economic and environmental policy, taking into account the full value of natural capital as a factor of production and its role in growth.

Green growth requires a green engine

Improving the environmental performance of energy transformation and consumption is a cornerstone of any attempt towards green growth. The demand for secure energy supply underpins economic activity whether it is a factory in Germany or a farming operation in Kenya. It is needed to grow crops just as much as it is needed to underpin the mobile phone network through which farmers can connect to their markets. Energy is an essential input to the production of food and the provision of water; it can eliminate the need for hours spent collecting fuel wood to make more time available for education and entrepreneurial activity; it offers mobility that makes trade possible. Energy fuels the movement of manufactured goods, people, services and ideas. Without energy there is no globalisation. It underwrites the emerging 21st century world in which information and communication technologies are re-shaping the economic, political, social and educational horizons of the world. Around 10% of children under five years of age die each year from water-borne diseases; energy plays a key role in mitigating these diseases through water pumping, filtration and ultraviolet treatment. Modern energy services are also a key to improving health outcomes - from powering maternity facilities and medical equipment to the safe storage of vaccines. Electricity in rural schools has significant positive impacts, providing access to modern learning technologies such as computers and electronic educational media.

But mobilising all this energy comes with large costs (Figure 1.1). Some 1.4 million people die prematurely every year, mostly in developing countries, due to the effects of breathing smoke from poorly-combusted biomass fuels in households (WHO, 2008). Dependence on liquid hydrocarbons for vehicle, aviation and marine transport is costly for importing countries, a source of strain in geopolitical relations and a major source of air pollution. Coal when burned is the dirtiest of all fossil fuels. By-products of coal combustion are hazardous to human health and the environment. Poor combustion of coal can severely deteriorate local air quality. At the same time, coal is generally affordable and resources are amply distributed across many regions.

Figure 1.1. Energy use has direct and indirect effects on the environment and human health



Source: IEA (2010), *Energy Technology Perspectives 2010: Scenarios and Strategies to 2050.*

The economic crisis in 2008 brought deep recession and all time high fossil fuel prices. Today geopolitical events are pushing prices higher. They bring near-term risks to economic activity as well as adverse medium and long-term risks to the world's natural capital. A clean energy engine to fuel green growth will enhance global energy security, enable responsible environmental stewardship and empower enduring economic growth (IEA, 2009).

Uncertainty over the economic costs of traditional energy resources, coupled with the need to avoid local pollution and climate change impacts has created significant pressure to diversify energy systems and to radically improve the efficiency of energy production, storage, distribution and consumption. If economic growth is to continue without proportional increases in fossil fuel consumption, it is vitally important to exploit new ways of generating value added. While most OECD countries have reduced fossil fuel inputs per unit of physical output (energy intensity) during the past three decades, there is still room for further improvement, especially in non-OECD regions. Therefore, energy efficiency is probably one of the main keys to long-term environmental sustainability (Ayres and Warr, 2003).

Overall, four key elements provide the economic rationale for placing the energy sector on a green growth path:

- **Economic costs of environmental damage and poorly managed natural resources**: Failing to address environmental concerns and not managing natural resources poses significant risks to long-term economic growth, through rising prices caused by resource scarcity, the growing burden of environmental damage caused by the conventional use of fossil fuels and to well-being through the negative consequences of climate change and the impairment to human health caused by pollution.
- **Innovation to achieve environmental and economic objectives**: Innovation is fundamental to the objectives of green growth in that it can help to decouple environmental damage from economic growth, and is also at the core of economic objectives such as productivity growth and job creation. It offers the opportunity to meet environmental challenges at a reasonable cost. Innovation is particularly important in the energy industry, as we search for forms of energy that impose fewer environmental costs and ways of improving efficiency in use as prices rise.

- **Synergies between environmental and productivity growth objectives**: Improved resource productivity and energy efficiency, through innovation or deployment of energy technology or processes, supports decoupling between economic growth, environmental damage and resource degradation.
- **Opportunities for new markets and industries**: Shifting toward green growth in the energy sector will require new technologies, fuel sources, processes and services that can spur new markets and new industries. There are also increasing demands from consumers and investors for environmentally-friendly products, services and production processes in the energy sector. Firms that are proactive in the face of these changes will be well-positioned to both contribute to and benefit from them.

Recognising that current investment shortfalls in clean energy could have severe consequences for energy security, long-term economic growth and the fight against climate change, many countries have launched stimulus programmes that include green energy, (amounting to USD 1.8 trillion in International Energy Agency (IEA) member countries with an average of 10% of this spending for clean energy technologies and energy efficiency). In the United States, for example, two packages allocated about USD 32 billion to renewable energy, among other energy-related measures.[1] Korea and China also included large green energy investments in their stimulus spending programmes. This support represents an important down-payment on the massive investment required to transform energy systems and avoid lock-in of yesterday's technologies and systems (Box 1.1).

Box 1.1. Power capacity additions: Exploiting opportunities and avoiding lock-in

The energy sector is on the verge of major new capital investment to replace aging plants and meet growing demand for electricity. Global total installed power generation capacity in 2009 was about 4 957 gigawatts (GW). Estimated gross capacity additions of 5 900 GW are needed in the period to 2035, while about 2 000 GW of existing capacity will need to be retired and replaced over the same period. Renewable energy technologies are likely to account for half the capacity additions, gas and coal for one-fifth each and nuclear power for 6%. Cumulative oil-fired capacity additions, one-third of which are in the Middle East, are less than 2% of total additions. China adds more coal, gas, nuclear, hydro, biomass, wind, and solar capacity than any other country.

Cumulative global investment in the power sector is estimated at USD 16.9 trillion (in year-2010 dollars) from 2011 to 2035, an average of USD 675 billion per year. New generating capacity accounts for 58% of the total investment, with transmission and distribution making up the remaining 42%. Renewables make up 60% of investment in new power plants, led by wind, solar photovoltaic (PV) and hydro, even though they represent only half of the capacity additions; their larger share of investment reflects their higher capital costs, relative to fossil fuel power plants.

About 60% of power plants in service or under construction today are projected to still be in operation in 2035, which will mean that 59% of power sector emissions in that year are already "locked in", unless future policy changes force early retirement of existing plants or their retrofitting with carbon capture and storage (CCS).

Source: IEA (2011), *World Energy Outlook 2011.*

The energy sector is facing unprecedented uncertainty. The strength and direction of the economic recovery holds a key to how energy markets will evolve over the next few years. It is what governments do, and how that action affects technology, the price of energy services and end-user behaviour, that will shape the future of energy in the longer term.

Addressing systemic risks and imbalances

Continuing growth in energy demand, record-breaking prices and stress in local and global natural resource systems are pushing energy security tensions higher. This poses a threat to the global economy and the welfare of millions of people. Continuing on a conventional growth route that undervalues natural capital will at some point run up against planetary boundaries which will limit growth prospects. Key pressure points include freshwater limits, ecosystem destruction, atmospheric aerosol pollution, biodiversity loss, climate change and chemical pollution (OECD, 2011). The way in which these problems manifest themselves is often unpredictable, involving a complex web of interlocking problems.

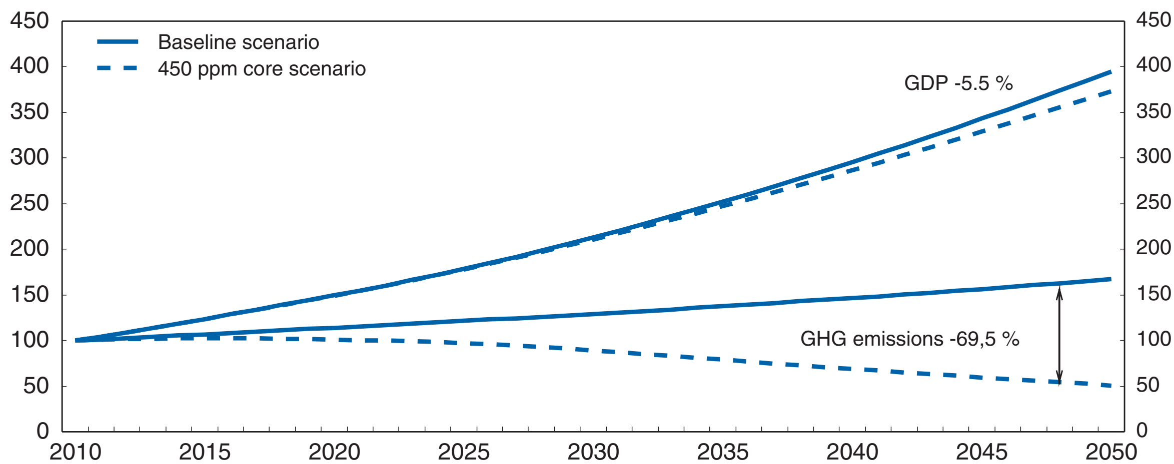
Take, for example, the linkages between energy and water. Both are key ingredients for economic growth and human welfare. Both are under strain. Many forms of energy production require ample and reliable water supply, a resource that is already in short supply in many parts of the world. Water is used at various stages of the power generation cycle, including fuel extraction and processing (mining and refining, liquefaction and gasification of oil, gas, coal, uranium and in the production of biomass/biofuels through agriculture) and generation (coal, gas, oil, nuclear and biomass plants). The power sector is one of the biggest water users in the world. In the United States, the electricity industry is second only to agriculture in water usage and each kilowatt hour of power from coal, which provides nearly half of power generation, requires about 95 litres of water. On the water supply side, energy needed for treatment and distribution accounts for as much as 80% of water supply cost, so an insufficient supply of affordable energy will have negative impacts on the price and availability of water in regions where water is in short supply.

Making judgements about systemic risks poses challenges. In the absence of clearly defined planetary boundaries, policy makers are called upon to make judgments about the speed of any transition to a green growth path. The inter-generational and spatial tradeoffs that need to be made are complicated, compounded by the short-term horizons voters use to judge their political officials and short-term market realities (OECD, 2011). But the consequences of holding back until tipping points are reached would be grave for human and economic conditions. Environmental assets operate in interdependent systems. Assessments from Rockstrom *et al.* (2009) indicate that the boundaries for earth-system processes may already have been crossed in the realms of rate of biodiversity loss, the nitrogen cycle and atmospheric concentrations of carbon dioxide (CO_2) (also see OECD, 2011).

Climate change is a serious global systemic risk. It threatens the basic elements of life for all people; access to water, food production, health, use of land and physical capital. Inadequate attention to climate change in the short-term will inevitably damage economic growth over the long-term. Inaction over the coming few decades risks major disruption to economic and social activity. And it will be difficult or impossible to reverse some of these changes. Tackling climate change is a pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries. The earlier effective action is taken, the less costly it will be (IEA, 2010; OECD, 2012 *forthcoming*; Stern, 2006). Recent OECD analysis shows that if countries start today to curb greenhouse gas emissions to achieve the long-run 450 ppm stabilisation target, the cost would be to slow the rate of economic growth by 0.2 percentage points per year on average, costing roughly 5.5% of global GDP in 2050 which will by then have quadrupled (Figure 1.2) (OECD, 2012 *forthcoming*). Moreover, benefits from action are not included in this GDP projection.

Figure 1.2. Global emissions and cost of mitigation

Index 2010 = 100



Source: OECD Environmental Outlook to 2050 baseline; output from ENV-Linkages

In late 2010, the world's governments recognised a goal to keep the global temperature increase below 2 degrees Celsius (°C) in comparison with pre-industrial levels. Further, the Cancún Agreements have begun to anchor the emission reduction pledges made at the 2009 Copenhagen session in the formal United Nations Framework Convention on Climate Change (UNFCCC) process. There was also agreement to create a Transitional Committee to design a Green Climate Fund that could become an important vehicle for delivering climate change finance to developing countries and contribute to the goal of mobilizing USD 100 billion per year by 2020 from various sources, including public and private financing, from developed to developing countries.

Nevertheless, these global summits are not the place where domestic policies are designed and implemented. Countries must also take decisive action domestically in order to address both local and global systemic environmental risks. Those that facilitate effective strategies and successfully implement them in the energy sector may gain first-mover advantages and benefit from expanding markets for green technologies, know-how and services, thereby adding to the durability of their economic development. Early action globally can reduce overall costs and allow for a smoother transition to a greener economy. However, it should be recognised that individually there are a number of disadvantages of being a first-mover, including higher technology risks and higher costs for deploying new technologies which have yet to benefit from economies of scale as they move down the learning curve.

World energy outlook

Major progress has been made in the energy policy of OECD countries over the last 35 years. Yet, much more needs to be done. Without new policies, we risk irreversibly damaging the environment and the natural resource base needed to support economic growth and well-being. The costs and consequences of policy inaction are likely to be high.

The OECD's *Environmental Outlook to 2050* shows that tackling the key environmental problems we face today – including climate change, biodiversity loss, water scarcity and the health impacts of pollution – is both achievable and affordable (OECD, 2012 *forthcoming*). The *IEA's World Energy Outlook* (*WEO-2011*) gives valuable insights into how the energy system could evolve over the next quarter of a century. Building from these projections, *Energy Technology Perspectives: Scenarios & Strategies to 2050* (IEA, 2010) explores the essential elements of the technology revolution needed to deliver a fundamental transformation of global energy systems to 2050, which are highlighted in Chapter 2. The latter three bodies of work use different modelling approaches that are in many ways complementary (Box 1.2). Importantly, they all provide the same message on climate change mitigation policy: delaying action by a decade only would lead to significantly higher costs. And a full transformation of the energy system is required for having at least a 50% chance of stabilising the climate at a 2°C global average temperature increase.

Box 1.2. Environmental-economic modelling at the IEA and OECD

The global transition to a more secure, sustainable and affordable energy future, in line with strong climate change mitigation action, is described in three of the key OECD/IEA publications: the IEA World Energy Outlook (WEO), the IEA Energy Technology Perspectives (ETP) and the OECD Environmental Outlook. The WEO uses the partial equilibrium World Energy model to provide regular updates on the latest energy demand and supply projections for different future scenarios, broken down by country, fuel and sector by 2035, while the ETP analysis focuses on longer run technological development trends to 2050. Both IEA models essentially take an energy systems approach to identify least-cost technology portfolios to satisfy energy demands, and project the associated future CO_2.

The OECD deploys the ENV-Linkages model for the economic analysis of mitigation action addressing the transformation of the energy system as well as mitigation action from other CO_2 sources (*i.e.* industrial emission processes and emissions related to land use, land use change and forestry) and emissions of non-CO_2 greenhouse gases. ENV-Linkages is a global recursive-dynamic general equilibrium model that uses a wide range of data covering all sectors of the economy as well as international trade aspects of all goods and services and links these economic activities in different economic sectors to emissions of greenhouse gases.

All three models aim to have consistent sets of assumptions to develop energy consumption patterns in their respective baselines. The modelling teams at the IEA and the OECD are investigating possibilities to further harmonise on economic growth projections.

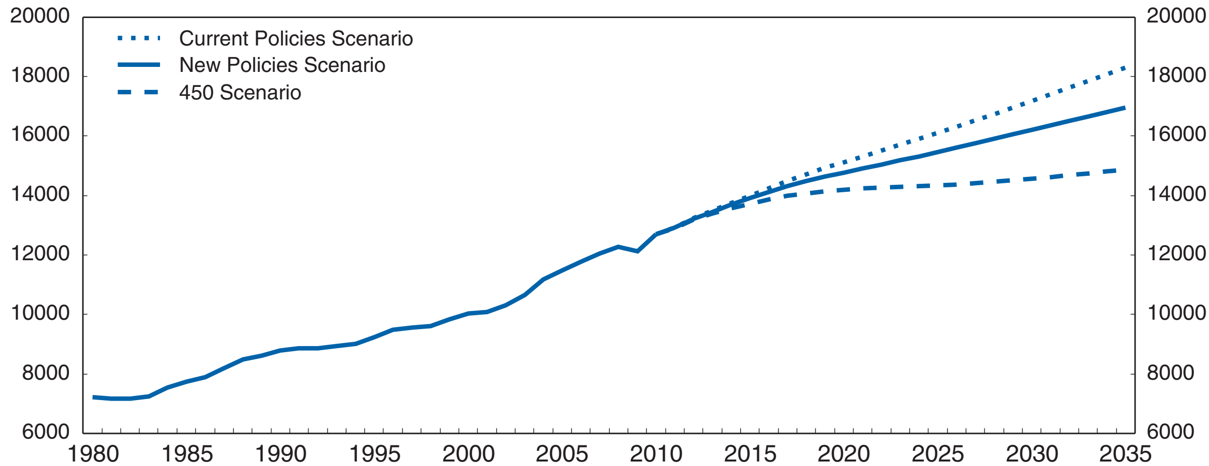
The IEA and OECD approaches are in many ways complementary. The IEA models, with their detailed representation of the energy system in various countries, shed light on issues such as the capital investment needs in low carbon energy and the degree of lock-in to current carbon-intensive energy infrastructure in absence of an ambitious mitigation policy. In contrast, the OECD model focuses on the interactions between the energy sector and the rest of the economy, and is well-suited to provide additional metrics on macroeconomic impacts corresponding to similar mitigation policies, such as GDP deviations and real income variations of households per country.

Despite structural differences in the three models, leading to slight differences in the deployment of mitigation options, they all provide the same fundamental message on climate change mitigation policy: countries have to act now on climate change, delaying action by a decade only would lead to significantly higher costs, and a full transformation of the energy system is required for having at least a 50% chance of stabilising the climate at 2°C global average temperature increase.

The *WEO-2011* presents three scenarios: the *Current Policies Scenario,* the *New Policies Scenario* and the *450 Scenario*. Assumptions about economic and population growth are the same in each scenario, while they differ with respect to assumptions about future government policies. The implications of these different policies on energy demand are shown in Figure 1.3.

Figure 1.3. World primary energy demand by scenario

Million tonnes of oil equivalent (mtoe)



Source: IEA (2011), *World Energy Outlook 2011.*

The *Current Policies Scenario* is a baseline in which only policies already formally adopted and implemented are taken into account. Under this scenario, the broad energy trends are:

- Global primary energy demand is projected to increase on average by 1.46% per year from 2009 to 2035.
- Fossil fuels remain dominant with an 80% share of the primary fuel mix in 2035.
- The annual average improvement in energy intensity is 1.4%.
- CO_2 emissions from fuel combustion increase by 1.6% per year to reach a long-term level consistent with a global average temperature rise in excess of 6°C.

The *New Policies Scenario,* the central scenario in the *WEO-2011,* incorporates the broad policy commitments and plans that have been announced by countries around the world to tackle energy insecurity, climate change and local pollution, and other pressing energy-related challenges, even where the specific measures to implement these commitments have yet to be announced. It assumes the introduction of new measures, but on a relatively cautious basis. It illustrates that these policies would, if implemented, have a sizeable impact on energy demand and related CO_2 emissions. Under this scenario, the broad energy trends are:

- Global primary energy demand is projected to increase on average by 1.3% per year from 2009 to 2035.
- Fossil fuels remain dominant with a 75% share of the primary fuel mix in 2035 (Figure 1.4).
- The annual average improvement in energy intensity is 1.7%.

- CO_2 emissions from fuel combustion increase by 0.9% per year to reach a long-term level consistent with a global average temperature rise of more than 3.5°C.

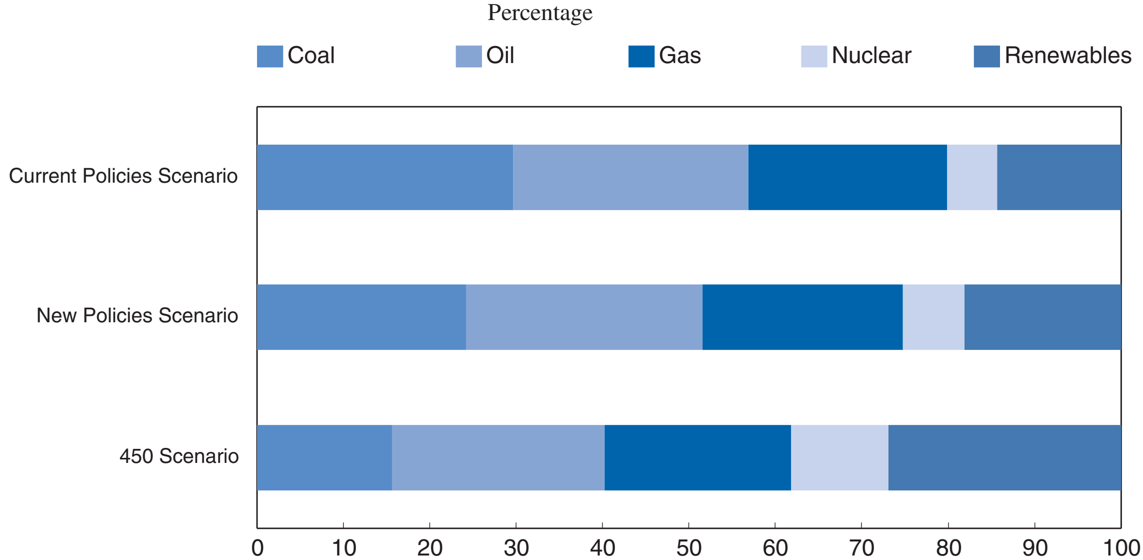
Fossil fuels still account for more than one-half of the increase in total primary energy demand in the *New Policies Scenario*. Rising fossil fuel prices, together with policies to encourage energy savings and switching to low-carbon energy sources, help to restrain demand growth for all fossil fuels. Oil remains the dominant fuel in the primary energy mix, though its share, which stood at 33% in 2009, drops to 27% by 2035 due in part to high prices and government measures to promote fuel efficiency. All of the net increase in global oil demand in the *New Policies Scenario* comes from the transport sector in non-OECD countries, growth being particularly strong in India, China and the Middle East.

Demand for coal is set to increase by 25% between 2009 and 2035 but the pace of this growth differs markedly over time. In the period to 2020, global coal demand experiences strong growth but then slows rapidly, with the level of global demand remaining broadly flat for much of the rest of the period, before then flirting tentatively with decline as 2035 approaches. The share of coal in the global energy mix peaks soon at 28%, and then declines gradually to 24% by 2035. Non-OECD countries account for all of the growth and China, the world's largest consumer of coal, will be pivotal in determining the evolution of global coal markets.

In the *WEO-2011 New Policies Scenario*, absolute growth in natural gas demand continues to exceed that of all other fuels, and is nearly equal to that of oil and coal combined over the period 2009 to 2035. The flexibility of natural gas as a fuel, together with its greater environmental and energy security attributes, makes it an attractive fuel in a number of countries and sectors. The share of nuclear power increases from 6% in 2009 to 7% in 2035. The use of modern renewable energy – including hydro, wind, solar, geothermal, modern biomass and marine energy – nearly triples over the period, its share in total primary energy demand increasing from 7% to 14%.

Figure 1.4. Share of energy sources in world primary demand by scenario

Percentage

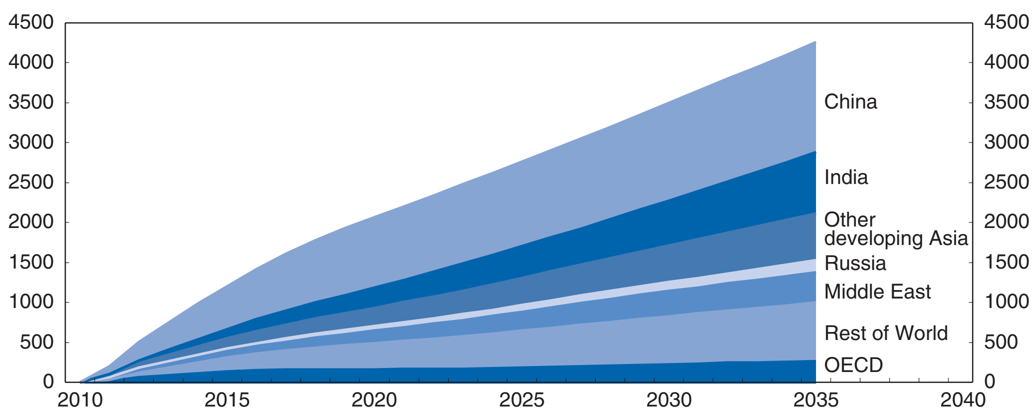


Source: IEA (2011), *World Energy Outlook 2011.*

Emerging economies, led by China and India, will drive global energy demand higher. Non-OECD countries account for nearly 90% of the projected increase in world primary energy demand in the *New Policies Scenario*, reflecting faster rates of growth in economic activity, industrial production, population and urbanisation (Figure 1.5). China, where demand has surged over the past decade, accounts for more than 30% of the projected growth in global energy use, between 2009 and 2035. By 2035, China accounts for 23% of world demand, up from 11% in 2000. India is the second largest contributor to the increase in global demand to 2035, accounting for 16% of the rise, its energy consumption more than doubling. Outside Asia, the Middle East experiences the fastest rate of increase, at over 2% per year. Primary energy demand in OECD countries grows by around 8% from 2009 to 2035. While the United States remains the second-largest energy consumer in the world in 2035, its total energy demand is only slightly higher than in 2009.

Figure 1.5. Projected increase in world primary energy demand

Mtoe



Source: IEA (2011), *World Energy Outlook 2011*.

It is hard to overstate the growing importance of China in global energy markets. From consuming less than half as much energy as the United States in 2000, it now consumes slightly more and, in the *WEO-2011 New Policies Scenario*, it is projected to consume nearly 70% more than the United States in 2035. Despite this, China's per-capita energy consumption is still at less than half the level of the United States in 2035. Consequently, the global energy projections in the *World Energy Outlook* remain highly sensitive to the underlying assumptions for the key variables that drive energy demand in China, including prospects for economic growth, changes in economic structure, developments in energy and environmental policies, and the rate of urbanisation. The country's growing need to import fossil fuels to meet its rising needs will have an increasingly large impact on international markets. In the *New Policies Scenario*, China overtakes the United States in terms of oil imports shortly after 2020 and becomes the largest oil consumer in the world around 2030, consuming nearly double the level of 2009. Given the sheer scale of China's domestic market, its push to increase the share of new low-carbon energy technologies could play an important role in driving down their costs through faster rates of technology learning and economies of scale.

In the *WEO-2011 New Policies Scenario*, the average IEA crude oil import price increases to approach USD 120 per barrel (in year-2010 dollars) in 2035. The growing concentration of oil use in transport and a shift of demand towards subsidised markets limit the scope of higher prices to choke off demand through switching to alternative fuels. Constraints on investments mean that higher prices lead to only modest increases in production. In the *New Policies Scenario*, the average IEA crude oil price rises from just over USD 60 in 2009 to USD 120 per barrel (in year-2009 dollars) in 2035. Primary oil demand continues to grow steadily, reaching about 99 million barrels per day (mb/d) by 2035[2] — over 12 mb/d higher than in 2010. All of the net growth comes from non-OECD countries; demand in the OECD actually falls, by more than 6 mb/d. Crude oil supply increases marginally to a plateau of around 69 mb/d and then declines slightly to around 68 mb/d by 2035. A growing share of global output comes from natural gas liquids, unconventional sources and light tight oil.

The *WEO-2011 450 Scenario* sets out an energy pathway that is consistent with a 50% chance of meeting the goal of limiting the increase in average global temperature to 2°C, compared with pre-industrial levels. According to climate experts, to meet this goal it will be necessary to limit the long-term concentration of greenhouse gases in the atmosphere to around 450 parts per million of carbon dioxide equivalent (ppm CO_2-eq). For the period to 2020, the *450 Scenario* assumes more vigorous policy action to implement fully the Cancun Agreements than is assumed in the *New Policies Scenario* (which assumes cautious implementation). After 2020, OECD countries and other major economies are assumed to set economy-wide emissions targets for 2035 and beyond that collectively ensure an emissions trajectory consistent with stabilisation of the greenhouse gas concentration at 450 ppm. Under the *450 Scenario*, the broad energy trends are:

- Global primary energy demand is projected to increase an average of 0.8% per year from 2009 to 2035.
- Fossil fuels remain dominant with a 62% share of the primary fuel mix in 2035.
- The annual average improvement in energy intensity is 2.2%.
- CO_2 emissions from fuel combustion decrease by 1.1% per year to reach a long-term level consistent with a global average temperature rise of 2°C.

This brings about a much faster transformation of the global energy system and a correspondingly faster slowdown in the growth of global CO_2 emissions. For example, oil demand peaks around 2016 before declining to around 78 mb/d in 2035, nearly 7% lower than 2009. Coal demand also peaks around 2016 and then declines by 2.7% per year on average. Demand for natural gas grows steadily, at 1.2% per year through 2030, stabilising thereafter. In the *450 Scenario*, the overall share of low-carbon fuels in the energy mix doubles from 19% in 2009 to 38% in 2035. Demand for all low-carbon fuels grows strongly.

Cutting emissions sufficiently to meet the 2°C goal would require a far-reaching transformation and rapid decarbonisation of the global energy system. The *450 Scenario* requires additional cumulative investment of USD 15.2 trillion relative to the New Policies Scenario, but delivers greater energy security, reduced pollution and significant health benefits. In the *450 Scenario*, lower oil-import requirements and lower international oil prices significantly reduce import dependence. Over the period 2009 to 2035, all oil importing countries as a group spend USD 9.1 trillion less compared to the *New Policies Scenario*.

New country-by-country analysis reveals that 80% of the total CO_2 emitted over the period 2009 to 2035 in the *450 Scenario* is already "locked-in" by our existing capital stock (*e.g.* power plants, buildings, factories), leaving little additional room for manoeuvre. If internationally co-ordinated action is not implemented by 2017, all permissible CO_2 emissions in the *450 Scenario* will come from the infrastructure then existing, so that all new infrastructure from then until 2035 would need to be zero-carbon. This would theoretically be possible at very high cost, but probably not practicable in political terms as this would encompass forcing premature retirements, refurbishment or retrofitting of existing capital stock, particularly with carbon capture and storage, or letting capacity lie idle to become economic. However, the lock-in effect and the corresponding prohibitive cost of delay in action shall be partially alleviated if strong mitigation of non-CO_2 gases emission is undertaken very shortly as illustrated in the *OECD Environmental Outlook to 2050*.

Implications of continuing current trends

Few trends put economic activity at risk like volatile oil prices. Current annual investments in the energy sector are estimated at between USD 650 billion and 750 billion (IEA, 2010). More than half of these investments are in the oil and natural gas sector, where a survey of the world's largest 50 oil and gas companies showed investments in 2008 of USD 525 billion. Investments by the largest 25 companies in the electricity sector in 2008 were USD 143 billion and in the 25 largest in the coal sector were USD 13 billion. In the same year, investments in low-carbon technologies were just under USD 162 billion (IEA, 2010).[3]

Current energy trends increase vulnerability and risks of shocks and depletion or destruction of natural capital. Looking at greenhouse gas emissions, the world is moving in the wrong direction at an accelerating rate. From 1990 to 2000, global CO_2 emissions increased by an average of 1.1% per year. It jumped to a 3% annual growth rate over the next 7 years. Two main factors contributed: rising energy demand in coal-based economies; and an increase in coal-fired power generation in response to higher oil and natural gas prices. The rate of increase in emissions from coal use rose from 0.6 % per year from 1990 to 2000 to 4.8% per year from 2000 to 2007. Ongoing dependence on fossil fuels, especially coal, continues to drive up both CO_2 emissions and the price of fossil fuels.

The fourth assessment report by the Intergovernmental Panel for Climate Change (IPCC) underscored the importance of mitigating future human-induced climate change and adapting to the changes that cannot be reversed (IPCC, 2007). It described that global CO_2 emissions must be reduced by 50-85% below 2000 levels to limit long-term mean global temperature rise (with a high degree of confidence) to 6°C or lower. Estimates of the damages of climate change and costs of mitigation and adaptation vary widely. Climate change will still occur even with a rapid greening of the energy system, but the consequences will be much higher if no action is taken.

The message is clear. A business-as-usual approach to energy policy will ultimately place at risk economic growth, security and the well-being of people and the planet. We must fundamentally transform the manner in which we produce, deliver and consume energy.

Notes

1. The Emergency Economic Stabilization Act (2008) and the American Recovery and Reinvestment Act (2009); these included extension of the production tax credits for wind and investment tax credits for solar.

2. Excludes biofuels demand, which is projected to rise from 1.1 mb/d (in energy-equivalent volumes of gasoline and diesel) in 2009 to 2.3 mb/d in 2020 and to 4.4 mb/d in 2035.

3. This excludes investments in the transport sector, electricity networks, nuclear and carbon capture and storage.

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Chapter 2. Promoting the transition to green growth

The energy sector presents a particular challenge to achieving green growth, due to its size, complexity, path dependency and reliance on long-lived assets. Green growth policies for the energy sector can achieve important outcomes, including better resource management, innovation and productivity gains, creating new markets and industries, and reducing environmental damage.

It is possible, using existing and emerging technologies, to halve global emissions by 2050, with an additional cumulative investment of USD 46 trillion. All technology options are needed, and fundamental changes are also required by key energy users: transportation, industry and buildings.

The energy revolution that is needed can be characterised by the following elements: improved energy efficiency, widespread introduction of carbon capture and storage, increased deployment of renewable energy, nuclear energy, continued fuel switching, and support for new and enabling technologies.

Broadly, the key policies that are required to set the framework for the transformation of the energy sector include (these will vary by energy sector):

- *Provide price signals for externalities.*
- *Eliminate fossil fuel subsidies.*
- *Set frameworks to make markets work.*
- *Radically improve energy efficiency.*
- *Foster innovation and green technology policy.*

Promoting the transition to a green energy economy is not about seeking some pre-determined outcome. Rather, it is about meeting the energy needs that a growing population and development aspirations demand while strongly diverging from the environmental pressures inherent in the current energy system. Given the preponderance of fossil fuel in the current energy mix, decarbonisation plays a centrally important part of the transition. But a green energy economy is about more than climate change and greenhouse gas emissions. The scale of the challenge is certainly big enough to evoke the need for Schumpeter's idea of "creative destruction". Breaking with the path dependency of existing technologies will require new technologies and ideas that are unlikely to spring from some predetermined and incremental plan.

The pace of change could be rapid. The costs of some renewable energy technologies have declined and additional costs reductions are expected. However, there remain significant barriers to deployment from inadequate infrastructure and regulatory approaches. Wind turbines will not deliver their product if grids are feeble, and plug-in electric vehicles cannot run on the wind power if there are not sufficient places to plug them in. Technology, infrastructure, markets and enabling conditions are all critical parts of the transformation. Drastically changing energy infrastructure and equipment on a national scale is a complex undertaking. Shifting to a green growth trajectory requires particular attention to energy efficiency and to network infrastructure such as electricity grids and transport networks that enable rather than constrain economic transformation, and avoid locking-in sub-optimal and long-lived capital assets.

This chapter presents some of the benefits and potential trade-offs of a shift to a greener energy system. It then discusses the technologies and main policy options that can accelerate the transition to a green growth trajectory.

Green growth and energy: What's at stake

Greening energy will be among the earliest drivers of greener growth. Meeting growing energy demand will mean a total investment in the sector of USD 270 trillion over the next four decades (IEA, 2010a). This potentially provides an enormous opportunity to create a more sustainable base for economic and social development. Innovative ways of providing the energy services that drive economic activities and underpin well-being in a clean and sustainable way could provide new growth opportunities, creating new businesses and jobs and offsetting losses from contracting sectors.

Developing countries have opportunities to leap-frog by employing greener and more efficient technologies, business models and regulatory frameworks. Emerging economies will not become rich by following the same path as those that industrialised earlier. The environmental costs would be too high, both at the local and the global level.

Policy makers and businesses are making commitments. National targets for renewable energy are spreading. More than seventy governments around the world, including all International Energy Agency (IEA) member countries, have put in place targets and policies to support development of renewable energy technologies. In doing so, they pursue a wide variety of objectives, including improving energy security and access to modern energy services; reducing dependence on energy imports; protecting the environment; providing employment; and strengthening the competitive edge of domestic industry (Philibert, 2011).

Clean energy investments and new market opportunities

Given the depth of the world recession that ensued after the financial crisis in 2008, it is not surprising that 2009 witnessed a drop in total investment in the clean energy sector. However, Bloomberg New Energy Finance figures (2011) show that new investment ended up dropping less than expected, partly due to soaring clean energy investment. Investments were particularly high in China. Full-year figures, based on actual transactions across all asset classes, show that new investment worldwide during 2010 totalled USD 243 billion (BNEF, 2011).

These findings highlight two things: that clean energy remains a sector with strong long-term growth fundamentals even during tough economic times; and that Asia has arrived not just as a big consumer of energy, but also as one of the regions investing the most in clean energy capacity. It is well documented that China's focus until recently was ramping up its domestic manufacturing capacity of renewable energy technologies. What changed in 2009 is the focus on building additional generation capacity in order to meet demand for power and absorb the output of China's manufacturers. The race for clean energy technology implementation by the world's nations is taking shape.

In 2010, China took first place among the G20 group of countries in clean energy investments, with total investments of USD 47.3 billion (renewable energy only). Mandatory targets for wind and solar power and the ample availability of credit have been the primary engines of China's clean energy growth. With 53 gigawatts (GW) of renewable energy in 2009, China was second in the world for installed renewable energy capacity, just behind the United States (GWEC, 2010). China also has some of the world's most ambitious renewable targets supported by fixed-rate feed-in tariff for wind, biomass and solar, calling for 2020 installation targets of 150 GW, 30 GW and 20 GW from these sources respectively. It has built a strong manufacturing base, particularly in solar, and is moving to meet growing domestic energy consumption through rapid installation of clean energy power generation capacity. China looks to become the market leader in low-carbon technologies, poised to play a key role in driving down costs to the benefit of all countries

The United States dropped to second place among the G20 countries in clean energy investments in 2009. It ended 2010 with total investments of USD 20.7 billion. Tight credit, uncertainty about tax incentives early in the year and lack of a strong national policy framework has constrained more robust investment. Also, ethanol investments that fuelled progress in the two previous years waned in 2008 and 2009. However, advanced biofuels, energy efficiency and smart grids saw investment gains. The 2009 enactment of long-term production tax credits (wind) and investment tax credits (solar) helped salvage what could have been a disappointing year. US clean energy investments were poised to climb in 2010, when much of the clean energy stimulus funding (USD 66 billion) was due to be spent. The United States continues to dominate venture finance and technology innovation, but it lags in manufacturing.

Reduce energy poverty

It is widely recognised that reliable and modern energy services are needed to facilitate the achievement of the UN Millennium Development Goals. The IEA's *WEO-2011* highlights how crucial modern energy services are to human well-being and to a country's economic development, and yet many poor households in developing countries still do not have access to them. Exposure to indoor air pollution from cooking with traditional methods creates serious health problems and greatly increases the risk of premature death. The numbers are striking: some 1.3 billion people – nearly 20% of the global population – lack access to electricity and 2.7 billion people – around 40% of the global population – rely on the traditional use of biomass for cooking (IEA, 2011a). Worse, *WEO-2011* projections suggest that the problem will persist in the longer term: in the *New Policies Scenario*, 1 billion people still lack access to electricity in 2030, more than 60% of which are in sub-Saharan Africa. In the same scenario, despite progress, population growth means that the number of people relying on the traditional use of biomass for cooking is still around 2.7 billion in 2030.

In order to provide universal modern energy access by 2030, cumulative investment of USD 1 trillion is required – an average of USD 48 billion per year, more than five-times the level of investment observed in 2009 (IEA, 2011a). Nonetheless, the total investment required is a small share of global investment in energy infrastructure, around 3% of the total. To arrive at this estimate, it was first necessary to assess the required technical solutions, such as the combination of on-grid, mini-grid and isolated off-grid solutions for electricity access. To identify the most suitable technology option, for providing electricity access in each region, *WEO-2011* analysis takes into account regional costs and consumer density, resulting in the key determining variable of regional cost per megawatt-hour (MWh). When delivered through an established grid, the cost per MWh is cheaper than that of mini-grids or off-grid solutions, but the cost of extending the grid to sparsely populated, remote or mountainous areas can be very high and long distance transmission systems can have high technical losses. It also estimates that achieving universal access by 2030 would increase global electricity generation by 2.5%. Demand for fossil fuels would grow by 0.8% and carbon dioxide (CO_2) emissions go up by 0.7%, both figures being trivial in relation to concerns about energy security or climate change.

Reduce air pollution – improve productivity and health

Sulphur dioxide, nitrogen oxides and particulate matter all have negative effects, both on human health and the environment. The effects of these gases are not limited to the country or region in which they are emitted, but are felt beyond national borders.

In China, the external costs of pollution – such as health costs, loss in labour productivity and loss in land productivity – amounted to 3.8% of GDP in 2005 (World Bank, 2007). Burning fossil fuels costs the United States about USD 120 billion a year in health costs, mostly because of thousands of premature deaths from air pollution (US National Research Council, 2009). This figure reflects primarily health damage from air pollution associated with electricity generation and motor vehicle transportation and does not include damage from climate change, harm to ecosystems, effects of some air pollutants such as mercury and risks to national security.

Coal accounts for about half the electricity produced in the United States. In 2005 the total annual external damages from sulphur dioxide, nitrogen oxides, and particulate matter created by burning coal were about USD 62 billion; these non-climate damages average about 3.2 US cents for every kilowatt-hour (kWh) of electricity. A relatively small number of plants, 10%, accounted for 43% of the damages (US National Research Council, 2009).

There is evidence indicating that an integrated approach addressing both air pollutants and greenhouse gas emissions, such as through energy efficiency improvements, can be considerably less costly than dealing with the issues separately (IPCC, 2007). While pursing air pollution and climate change objectives may not always be complementary, there are local air pollution benefits from pursuing clean energy policies which lower the net costs of greenhouse gas emission reductions. OECD analysis indicates that the co-benefits from climate change mitigation in terms of reduced outdoor local air pollution might cover a significant part of the cost of action, although air pollution control policies appear to be typically cheaper than indirect action via greenhouse gas emissions mitigation (Bollen *et al.,* 2009).

Potential trade-offs and adjustment costs

While the benefits and opportunities from moving towards a cleaner energy mix are considerable, the transition to a green energy system will not be without upfront costs. Careful attention will need to be paid to the associated adjustment and distributional challenges. Indeed, green growth in the context of energy generation presents particular challenges given the size, inertia and long-lived nature of many of the assets in energy systems. The entire structure of the energy economy of many countries is built around centrally supplied fossil fuel generated schemes that will take time to change.

This section reviews the range of cost estimates associated with a transition in the energy system required to tackle climate change, but does not attempt to formally assess the cost-benefit comparison. As shown in the section above, the benefits of greening the energy system go far beyond considerations of climate change. Nevertheless, from a political perspective, at least with respect to climate change, the Cancún agreement to limit global temperature rise to below 2˚C has already made this cost-benefit trade-off: the decision has been taken by the world's governments that the costs of inaction on climate change outweigh the costs of transition.

The sector with one of the highest adjustment costs in terms of additional capital investment will be in the transport sector. Of the cumulative additional investment from 2009-2035 in the IEA *450 Scenario* relative to the *New Policies Scenario*, USD 6.3 trillion, or over 40%, is needed in the transport sector. Most of this is directed towards the purchase of more efficient or alternative vehicles. The building sector is another large recipient of additional invest[2]ment in the *450 Scenario*, amounting to USD 4.1 trillion. Refurbishment of buildings in OECD countries and solar photovoltaic (PV) installations account for most of the investment. Within power generation, there is some avoided investment in electricity transmission and distribution lines, totalling about USD 930 billion. The lower level of electricity demand in the *WEO-2011 450 Scenario* – achieved through the USD 2.7 trillion investment made in buildings and industry in improving efficiency of electricity end-use – leads to a reduction in grid infrastructure investment of around USD 1.1 trillion. The increased usage of renewable energy, which requires greater investment in transmission and distribution than other energy sources, adds nearly USD 165 billion in the *450 Scenario*, partially offsetting the savings due to lower demand.

The additional capital only tells part of the story however, since it does not reflect overall return on capital or wider economic impacts. Similarly to many so-called integrated assessment models, the forthcoming OECD economy-environment modelling (OECD, 2012a *forthcoming*) provides a way of understanding how constraints on carbon emissions could impact economic growth over the course of the century. According to the OECD *Environmental Outlook to 2050*, a cost-effective 450 parts per million (ppm) pathway would lead to a reduction of GDP in 2050 of 5.5% (ENV-Linkages), but these costs rise rapidly when less cost-effective technology choices or timing of mitigation action are implemented. Recent reviews of models include Edenhofer *et al.* (2009, 2010) and the Energy Modelling Forum (Clarke *et al.*, 2009). These studies indicate that the total economic cost of limiting carbon emissions depends very strongly on the speed at which emission reductions are made, the overall level of emission reduction and thereby the overall constraint on carbon concentrations. Disregarding climate change externalities, the models estimate that limiting emissions to 650 ppm CO_2eq would result in an economic loss in the region of 0.5% of global GDP, a 550 ppm CO_2eq limit would cost between 1%-2% of global GDP, and a 450 ppm CO_2eq would cost around 2.5%-7% of global GDP.

The above values are averages across a number of different models, and the cost estimates vary widely between models depending on their structure and assumptions. Tavoni and Tol (2010) point out that the model average for the 450 ppm scenario is biased as it excludes results from models that were unable to reproduce the 450 ppm scenario (essentially finding this scenario technically infeasible). Deducing the implied average costs across a wider group of models, Tavoni and Tol estimate that the costs of a 450 ppm scenario could be as high as 8%-13% of global GDP. However, technology assumptions are critical. Tavoni and Tol show that including the possibility to capture CO_2 from biomass-fired plant (or some other backstop technology for removing CO_2 from the atmosphere) reduces the model average for 450 ppm to 2%-2.5% of global GDP.

The lower cost estimates are broadly consistent with the range identified in the Stern review, which based on a review of literature estimated adjustment costs to meet a 550 ppm CO_2eq constraint between1%-3.5% of GDP, with an average of around 1% (Stern, 2006).

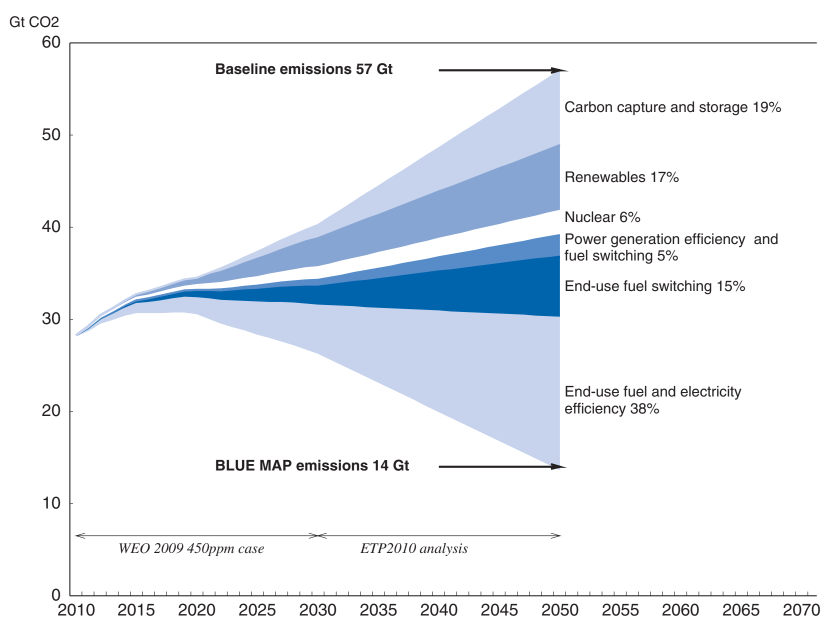
These adjustment costs have to be judged not in isolation, but against the welfare gains and avoided damages from addressing climate change and other environmental externalities, as well as the other potential benefits to energy security of diversifying away from the current dependence on fossil fuels. As well as providing estimates of the overall costs of transition, these modelling studies provide three distinct policy lessons:

- *All of these studies point to the need for early co-ordinated action*. Delays tend to increase costs, because they steepen the rate of transition required in later years.
- *Constraining the types of technology that can be used in the energy sector transition substantially increases costs*. For example, the IEA's Energy Technology Perspectives (ETP) model indicates that the additional costs of electricity generation in the Blue Map scenario could be anything from 6% to 38% higher than the baseline scenario depending on the level of nuclear power and carbon capture and storage available in the mix (IEA, 2010a).
- *Involvement of as wide a group of countries as possible in the energy transition is important*. The Energy Modelling Forum integrated assessment models typically show adjustment costs around 30%-100% higher under a scenario in which there is a delayed start amongst some countries towards meeting a 550 ppm target (Clarke *et al.*, 2009).

Key technologies for green growth and energy

Moving to a sustainable energy future will require an energy technology revolution. Using a combination of existing and new technologies, it is possible to halve worldwide energy-related CO_2 emissions by 2050 with respect to current levels (Figure 2.1). Achieving this will be challenging and will require significant investment, but the benefits will also be large. It is estimated that cutting emissions from 2005 levels in half by 2050 will require USD 46 trillion of new investments in clean energy, a further increase of 17% on top of baseline investments. Between 2007 and 2009, annual investments in low-carbon energy technologies averaged approximately USD 165 billion (IEA, 2010a) with investment in 2010 at nearly USD 250 billion.

Figure 2.1. Key technologies for a low-carbon energy system in 2050



Source: IEA (2010), *Energy Technology Perspectives 2010*.

It is important to note that all technology options are needed. For instance, *WEO-2011* and the OECD *Environmental Outlook to 2050* suggest that a progressive nuclear phase-out incur additional investments to 2035 of USD 1.5 trillion, globally leading to a reduction of household real income by more than 5%. Similarly, these studies reveal that the unavailability of carbon capture and storage (CCS) technology would need to be offset by more expensive alternatives, increasing costs by at least a third. The changes cannot be restricted to electricity generation; fundamental changes are also needed in industry, transport and buildings. The key potential contributions to this energy technology revolution are described in the IEA's *Blue Map* scenario:[1]

- *Improved energy efficiency* – the biggest share of the total emissions reduction (38%) comes from an increase in energy efficiency. The annual improvement in global final energy intensity would need to increase from 1.7% to 2.6%. This requires a *doubling* of the rate of energy efficiency improvement from a business-as-usual path. These accelerated rates of end-use efficiency gains will require the immediate implementation of stronger national energy efficiency policies and measures (IEA, 2009a) to overcome market barriers. These take many forms, from inadequate access to capital, isolation from price signals, information asymmetry, and split-incentives. In the industrial sector, national policies and measures and international sectoral agreements are needed to encourage the adoption of best available technologies to deliver more efficient processes and products (IEA, 2009b). Overall, increased energy efficiency will give net financial benefits, and experience shows that it can deliver significant co-benefits, including job creation and health improvements.

- *Widespread introduction of carbon capture and storage* – the second-largest share (19%) of least-cost emissions reductions comes from the rapid and widespread introduction of CCS, both in power generation and industry. Given the long life of boilers and power generating equipment, CCS capacity will need to be retrofitted to some existing facilities to achieve the levels of penetration needed.

  To make this contribution, it is estimated that about 100 projects would be required by 2020 to support CCS deployment globally, roughly half of them in developing countries (IEA, 2009c). Continued political leadership is essential at both national and international levels to achieve the goal of broad deployment of CCS by 2020. Heightened urgency on the part of all stakeholders is needed to realise the number of projects that constitute the critical first steps in the deployment of CCS. Greater engagement of developing countries through, for example, capacity building and mapping of storage potential, will also be important steps in furthering CCS deployment.

- *Increased deployment of renewable energy* – the third-largest share (17%) is due to substantial further deployment of renewable energy technologies. By 2050, almost half of total electricity generation would need to be from renewable energy sources, up from 19% today. Wind, solar photovoltaic (PV), concentrating solar power (CSP), biomass and hydro, in particular, will all have an important role to play. For example, the scenario envisages an average annual addition of 48 GW of onshore wind for the next 40 years. Over the same period an average of 325 million square metres of PV panels would need to be installed every year. Enhanced renewable power capacity will also require increased back up capacity based on fossil fuel technologies to ensure system reliability and to address the variable nature of certain renewables.

- *Continued fuel switching* – a major part of the emissions reduction is an increase in the share of nuclear. This would require around 30 nuclear plants of 1 000 megawatts (MW) to be built each year from 2010 to 2050. Countries are currently constructing 65 nuclear reactors that are due to add 60 GW by 2015. However, the recent damage to nuclear facilities in Japan in the wake of the earthquake and tsunami is likely to slow expansion plans, at least in the short term. The international system of safeguards on nuclear technology and materials should be maintained and strengthened where necessary. The physical protection of sites and materials must also be ensured. In addition, extensive fuel switching in industry from coal to low-carbon fuels, in particular biomass, as well as natural gas, has to be implemented. In the transport sector, sustainable biofuels, in particular advanced biofuels, together with increasing electrification of the vehicle fleet, will become increasingly important over the next decades.

A number of important cross-cutting enabling technologies will be needed to underpin these transformations. For example, to make the maximum use of energy efficiency, renewable power generation and electric vehicles, substantial investment will be needed in smart electric grids and in energy storage. Smart grids include systems to balance supply and demand, automate grid monitoring and control, flatten peak demand and communicate in real-time with consumers. Many emerging energy technologies show variability in their output (wind power, solar PV) and require a more flexible energy system (IEA, 2011b). For example, batteries and other energy storage technologies will be key enablers. Strong linkages between basic science and applied energy research are needed to maximise breakthroughs.

To help advance global development and uptake of key technologies, the IEA is developing a series of technology roadmaps. These identify priority actions for governments, industry, financial partners and civil society that are needed to realise the technology's full potential (IEA, 2010b). The roadmaps reveal a number of cross-cutting issues that need to be addressed to expedite a range of low-carbon technologies, including the need to:

- Strategically plan capital-intensive infrastructure such as smart grids and CO_2 pipeline networks on a regional basis.
- Involve local communities early in planning for large-scale demonstration and infrastructure projects for low-carbon developments to ensure that their needs are taken into consideration at the design stage.
- Increase outreach and communication on the scale of changes needed to achieve low-carbon energy outcomes and the associated costs and benefits over the next 40 years.
- Strengthen co-ordination and knowledge sharing in the international community to accelerate the transition from demonstration to commercialisation of the technologies.
- Facilitate emerging and developing economies to exploit clean energy through technology-specific capacity building and approaches tailored to their needs and opportunities.

To date, low-carbon technology roadmaps include: biofuels, carbon capture and storage, carbon capture and storage in industrial applications, cement, concentrating solar power, electric and plug-in hybrid vehicles, energy efficiency in buildings: heating and cooling systems, geothermal, nuclear power, smart grids, solar photovoltaic power and wind energy (Box 2.1).

Box 2.1. How to make a better and greener building block

Cement is the essential "glue" in concrete, a fundamental building block all around the world. Concrete is second only to water in total volumes consumed annually by society. But making cement co-produces CO_2 to the degree that the cement industry is responsible for 5% of global man-made CO_2 emissions. In developing countries, in particular, cement production is forecast to grow as modernisation and growth expands. Product substitution at a sufficient scale for real impact is not an option for at least the coming decade.

In recent years the cement industry has achieved a partial decoupling of growth and absolute CO_2 emissions: worldwide cement production grew by 54% from 2000 to 2006, whereas its absolute CO_2 emissions rose by 42%. Yet, this trend cannot continue past the point where the growth of market demand for concrete and cement outpaces the technical potential to reduce CO_2 emissions per tonne of product.

Recognising the urgency of identifying technology to reduce the carbon intensity of cement production, the World Business Council for Sustainable Development Cement Sustainability Initiative (CSI) joined with the IEA to develop a technology roadmap for cement. Since 2002, CSI member companies have collectively made significant progress on measuring, reporting and mitigating their CO_2 emissions, and sharing their progress with the rest of the cement industry. The roadmap is a logical and complementary next step. It outlines a possible transition pathway for the cement industry to reduce its direct CO_2 emissions 18% from current levels by 2050.

Source: WBCSD and IEA (2009), "Cement Technology Roadmap 2009: Carbon Emissions Reductions up to 2050".

A policy framework for greening energy

Given differing national circumstances and stages of development, there is no generic policy prescription for fostering greener energy systems. The transition will vary across regions and between countries depending upon their human and natural capital and economic conditions. However, in all cases, it should generally seek to foster growth while valuing, maintaining and restoring natural capital; promote enhanced resource and energy efficiency along the entire chain from production to end-use applications and waste disposal; move to low carbon technologies and processes and renewable energy sources; and enhance energy security and reliability.

Finding the right policy framework for growth has never been straightforward. Integrating green growth compounds the challenge. The experience of OECD countries, confirmed also by the experience of many emerging economies, suggests that while there is no single recipe for success, there are certainly some important common ingredients.

Green growth strategies need to consider a timeline spanning decades and examine how different existing and emerging technologies and new business models fit within the overall transition. At their heart they must be internalised in a government's core economic policies. Beyond that, pursuing green growth in the energy sector will require coherent and supporting policies in many other domains including agriculture, construction, industry, transport, investment, taxation, environment, science and technology and education. In addition, international co-operation will be critical, notably in setting robust and credible price signals and markets for carbon, advancing material and technology research, development and deployment, technology transfer and broadening markets for both goods and networks.

Powerful forces of competition and robust markets spur economic growth. In the environmental domain, however, markets are incomplete. To correct this, natural capital needs to be fully priced through market-based policy instruments. Putting a price on a pollution source or on the over-exploitation of a scarce resource to value the environmental externalities through mechanisms such as taxes or trading schemes is the most efficient single policy measure. Yet, given the presence of several interacting market failures, in many cases an appropriate policy response will involve a mix of complementary instruments including regulatory policies. Infrastructure is an important element of growth and as a consequence, getting this part of the policy mix right for energy and transportation systems is crucial, and innovation in these areas will be essential (OECD, 2011a).

Furthermore, policies are required to overcome the market failures associated with green innovation. Appropriate pricing of externalities, general innovation policies, technology transfer, and the development of enabling infrastructure can go a long way in addressing these market failures. But the emergence of new technologies is a process that requires long-term investment, often initiated in public research institutions before being picked-up by firms. Hence, more specific and possibly temporary direct support for clean technologies may also be needed.[2]

The future is inherently uncertain, so a portfolio approach to policy is likely to be needed. Policy priority should be given to implement "low-hanging fruit" options that will reap financial benefits. These can help "buy time" that is needed to decrease costs of emerging technologies through initial deployment and make novel technologies available through research development, demonstration and deployment (RDD&D).

Policy packages, based on free and open markets as a fundamental point of departure, will be required to deliver results. The key areas that are applicable to most countries and sectors are explored in more detail below.

Eliminate fossil fuel subsidies

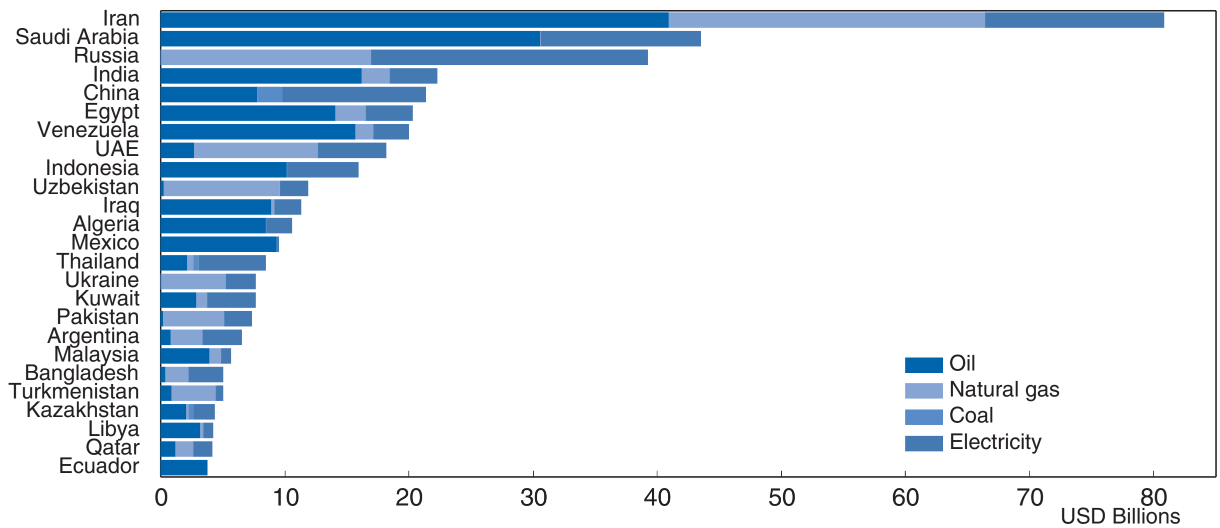
One of the most powerful tools to transition to green growth in the energy sector is to eliminate inefficient fossil fuel subsidies. These remain commonplace in many countries (Figure 2.2). They make carbon emissions cheaper, the very opposite of what any policy objective to reduce emissions calls for. Beyond that, they result in an inefficient allocation of resources and market distortions, while often failing to meet their stated objectives.

Fossil fuel consumption subsidies, as measured using the gap between domestic prices and an international reference benchmark, amounted to USD 409 billion in 2010, with subsidies to oil products representing almost half of the total (IEA, 2011a). Persistently high oil prices have made the cost of subsidies unsustainable in many countries and prompted some governments to act. The annual level can fluctuate widely with changes in international energy prices, domestic pricing policy, exchange rates and demand. These subsidies, identified by the IEA, are mainly found in developing and emerging economies. Only 8% of the USD 409 billion spent on fossil fuel subsidies in 2010 was distributed to the poorest 20% of the population, demonstrating that they are an inefficient means of assisting the poor; other direct forms of welfare support would cost much less.

The OECD has compiled an inventory of over 250 measures that support fossil fuel production or use in 24 industrialised countries, which together account for about 95% of energy supply in OECD countries. Those measures had an overall value of about USD 45-75 billion a year between 2005 and 2010. In absolute terms, nearly half of this amount benefitted petroleum products (*i.e.* crude oil and its derivative products), with the rest equally split between coal and natural gas. Because several OECD countries do not produce significant amounts of fossil fuels, consumer measures account for a large share of overall support. Producer support remains, however, far from negligible in those OECD countries that produce fossil fuels.

Figure 2.2. Fossil fuel consumption subsidies for top 25 economies

USD Billions, 2010



Source: IEA (2011), *World Energy Outlook 2011*.

A significant portion of the support provided in OECD countries is through tax expenditures such as tax credits, exemptions or reduced rates. These provisions provide a preference for fossil fuels compared with the "normal" tax rules in the particular country. Since normal tax rules and rates vary so much between countries, however, this type of support is not readily comparable. Nevertheless, the OECD inventory marks a significant step towards greater transparency and accountability with respect to those policies that relate to the production or use of fossil fuels. While it does not evaluate the merits of individual policies, the inventory is a critical first step that will facilitate analysis and understanding of which of these mechanisms may be inefficient or wasteful, and for identifying options for reform.

Phasing out fossil fuel subsidies represents a triple-win solution. It would enhance energy security, reduce emissions of air pollutants and greenhouse gases and bring immediate economic gains. IEA estimates indicate that, relative to a baseline in which rates of subsidisation remain unchanged, if fossil fuel subsidies were completely phased out by 2020, oil demand savings in 2035 would be equal to 4.4 million barrels per day (mb/d.) Moreover, global primary energy demand would be cut by about 5% and CO_2 emissions by 5.8% (2.6 gigatonnes, Gt) (IEA, 2011a). Reduced demand growth for fossil fuels would also lead to lower emissions of particulate matter and other air pollutants.

There is indeed significant scope for reducing the heavy burden that these subsidies place on government budgets, while also better targeting support to those who most need it. OECD analysis suggests that most countries or regions would record real income gains from unilaterally removing their subsidies to fossil fuel consumption, as a result of a more efficient allocation of resources across sectors. The cost of mitigation in the *450 Scenario* decreases if fossil fuel subsidies are phased out in parallel. These lower costs would occur first and foremost in the countries undertaking the subsidy reform, but also at the global level (OECD, 2012a *forthcoming*).

Considerable momentum is building to cut fossil fuel subsidies. In September 2009, G20 leaders committed to phase out and rationalise inefficient fossil fuel subsidies, a move that was closely mirrored in November 2009 by Asia-Pacific Economic Cooperation (APEC) leaders.[3] Many countries are now pursuing reforms, but steep economic, political and social hurdles will need to be overcome to realise lasting gains. The OECD and the IEA have established a joint online database to increase the availability and transparency of data on energy consumer subsidies and measures that support the production or use of fossil fuels in OECD countries (OECD and IEA, 2011). This represents an essential step in building momentum for a global fossil fuel subsidy reform.

A roadmap is also provided to guide policy makers in implementing fossil fuel subsidy reform (IEA, OECD and the World Bank (2010). It draws from lessons learned from case studies in developed and developing countries. Particular attention is devoted to how to identify those subsidies that should be phased out, to address implementation challenges including policy obstacles and affordability constraints, and to facilitate the reform process through the use of targeted assistance, safety-nets and industrial restructuring packages. It considers the challenges in both consumer and producer subsidies. The roadmap may help policy makers to diagnose the key problems and the required policy response for subsidy reform.

Many countries, both within and outside of the G20 group, are moving ahead with reforms. While this is a very encouraging start, the full extent of the potential gains will only be realised if more countries raise the level of ambition and implement fossil fuel subsidy reform.

Provide price signals for externalities

Numerous OECD studies highlight that appropriate pricing of externalities is a key to enable a more level playing field, influence consumer behaviour and promote innovation. The best choice of policy instruments to address environmental externalities will vary according to the nature and size of the predominant market failure as well as to the differences in institutional capacities of the respective countries, but there are many examples of success in the energy sector. For example, market-based sulphur dioxide (SO_2) allowance trading component of the US Acid Rain Program allows utilities to adopt the most cost-effective strategy to reduce SO_2 emissions at units in their systems and has had environmentally successful results.

Economists have long recommended using economic instruments to cut pollution at least cost through mechanisms such as taxes, emissions trading systems or hybrid systems. These should ensure that no emitter pays more, at the margin, than another. Hence the environmental goal is met at least cost for society. Both types of instruments have been introduced for CO_2 emissions from fossil fuel combustion in a number of countries and regions – CO_2 taxes since the early 1990s and emissions trading a decade or so later. Putting a price on greenhouse gas emissions through taxes and emission trading schemes introduces incentives to which investors are already reacting (Box 2.2).

A clear, predictable carbon price is likely to be an important driver of change. But it is unlikely on its own to drive short-term investments in the more costly technologies that have long-term environmental and economic benefits. While regional and some unilateral national initiatives on pricing are emerging and there is significant and positive experience with the EU ETS, a truly global carbon market looks unlikely to emerge in the near future. Many energy-efficient and some low-carbon energy supply technologies are available today at zero or low additional net cost. But a number of other technologies will not enter the market in a substantial way until prices are between USD 25 and 75 per tonne of CO_2 (IEA, 2010a). This is much higher than the CO_2 prices seen today (European Climate Exchange, 2011). Therefore to avoid locking in inefficient, carbon-intensive technologies during the next decade, governments will need to intervene with targeted policies to bring down the cost of low-carbon alternatives and to create markets for technologies that are not yet fully commercial in the context of their green growth strategies.

Box 2.2. Lessons from the EU Emissions Trading Scheme

Launched on 1 January 2005, the European Union Emissions Trading System (EU ETS) represents the world's largest greenhouse gas emission trading system. The system now operates in 30 countries (the 27 EU Member States plus Iceland, Liechtenstein and Norway). It covers CO_2 emissions from installations such as power stations, combustion plants, oil refineries and iron and steel works, as well as factories making cement, glass, lime, bricks, ceramics, pulp, paper and board. Together with nitrous oxide emissions from certain processes, the currently covered installations account for almost half of the EU's CO_2 emissions and 40% of its total greenhouse gas emissions.

Experiences from the EU ETS show that the price signal transmitted through trading systems is effective in triggering the search for less-emitting ways of production (Ellerman and Buchner, 2008; Ellerman, Convery and de Perthuis, 2010). Even in the first years of the system, when difficulties loomed large, the price signal induced economic actors to reduce their emissions cost-effectively despite robust economic growth and other factors that could have caused emissions to increase. Abatement during the trial period has been modest, probably between 120 and 300 million tonnes of CO_2, but this is in line with the ambition of the pilot phase, which was modest. In addition, it takes time for the effects of a CO_2 price to sink in and for investments to bear fruit.

Following the introduction of the EU ETS, the price of carbon is now an economic reality in the European Union, and is taken into account in operating choices and investment decisions in the industry and electricity sectors.

Set enabling conditions to support market functioning

Green growth strategies need to set the basic enabling conditions to allow markets to deliver the desired outcomes as well as additional measures in areas where market signals are not fully effective. Of course, the mix of policy tools, and how and when they are used, depends on national circumstances. Much research has examined the breadth and effectiveness of a multitude of policies and measures and different regulatory models that are used to address economic development and environmental protection with a view to achieving sustainable development.

Governments are responsible for creating the domestic conditions for private investment to flourish, through macroeconomic stability, good public governance, equitable and efficient tax systems, improved infrastructure and sound financial markets. Governments also set the frameworks for the protection of property rights and the promotion of good corporate governance, competition and open trade policies. Policy makers involved in green growth strategies should focus on enabling conditions including:

- Establishing sound regulatory frameworks over the long term that remove barriers to green investments; regulating environmentally harmful practices through standards or command and control regulations; and aligning regulatory regimes to foster green economic activity. This will include integration of clear environmental goals into investment policies through a mix of policies and instruments ranging from carbon pricing, research and development (R&D), financial, and regulatory policies to "soft" measures such as education and information (OECD 2012b, forthcoming).
- Directing public spending to priority uses such as procurement methods that help build markets for green products and services, and to infrastructure that enables the large-scale transformations needed in energy and transportation systems. Another priority use may be transitional support for immature technologies that is performance based and time-bound (*i.e.* with sunset clauses) (Kalamova, Kaminker and Johnstone, 2011).

- Investing in education, training and capacity building. Enabling actions to foster wider industry and public support for low-carbon energy systems include: fostering industry leadership; developing a skilled low-carbon energy workforce; deepening public engagement and strengthening international collaboration.
- Strengthening international governance in areas that regulate economic activity, *e.g.* trade and investment laws and multilateral environment agreements.

While public investment is needed to catalyse the transition to a green economy, it will be the private sector that will ultimately provide most of the investment. The transition offers significant new opportunities for business, as a large range of green technologies will need to be developed and deployed widely over the next few decades. Capital is limited and returns must be sufficient to warrant their associated risks. Investment in new energy technologies and systems will require higher returns than investments in traditional ones. Institutional investors, who hold the largest share of private-sector funding, are risk adverse and will require predictable income streams in order to invest. Governments need to pay close attention to the investment environment to ensure that there are framework conditions that will attract the necessary funding. Policy predictability is important to enable investors to evaluate the risk of policy changes on potential investments.

Box 2.3. Sample of recent national energy efficiency programme investments

Canada: The Government of Canada is investing CAD 400 million to renew the ecoENERGY Retrofit – Homes programme.

Chile: Economic incentives introduced recently include the creation of a tax exemption for installation of solar thermal systems; the implementation of a truck replacement programme (in 2009, the amount of the programme was USD 3.8 million) and the creation of a tax incentive for the purchase of hybrid vehicles in 2008. A National Agency of Energy Efficiency was established in May 2010.

France: Economic stimulus measures provide incentives for scrapping old vehicles and launch a zero-interest loan programme for residential energy efficiency improvements. They also included energy requirements for new buildings (50 kWh/m^2/year) and energy efficiency assessment and renovation of state-owned buildings.

Korea: Stimulus package funds of USD 6 billion are to promote green homes, light-emitting diode (LED) lighting in public facilities and efficiency in schools. USD 1.8 billion was allocated to support the development of fuel-efficient vehicles.

Spain: The new National Energy Efficiency Action Plan's goal is to reduce final energy consumption per unit of output by 2% annually between 2011 and 2020, or 133 000 kilotonnes of oil equivalent (ktoe) (965 million barrels) of primary energy in this period. Its implementation is expected to mobilise investment worth EUR 45.985 million.

United Kingdom: Funds were accelerated for investment in the Warm Front, which provides insulation and heating measures to vulnerable households.

Sources: IEA (2009), *Implementing Energy Efficiency Policies: Are IEA Member Countries on Track?*

Radically improve energy efficiency

Policies to enhance energy efficiency offer a powerful and cost-effective tool to contribute to green growth strategies (Box 2.3.). Efficiency improvements can reduce the need for investment in energy infrastructure, cut fuel costs, increase competitiveness, lessen exposure to fuel price volatility, increase energy affordability for low income households, cut local and global pollutants and improve consumer welfare. Efficiency gains can also boost energy security by decreasing reliance on imported fossil fuels.

And results can be delivered soon. Allocating resources to energy efficiency can achieve many policy objectives at the same time.

Further decoupling of energy use and economic growth demands efficiency gains along the whole energy system from production to transformation, distribution and end-use applications. Energy efficiency offers the biggest scope for better environmental performance and can also be a boost to green growth in employment and economic efficiency. Energy-efficiency investments in buildings, industry and transport usually have short pay-back periods and negative abatement costs, as the fuel-cost savings over the lifetime of the capital stock often outweigh the additional capital cost of the efficiency measure. Energy efficiency measures are often most cost-effective when new plants or buildings are being designed and built.

All countries state that significantly improving energy efficiency is a priority. To support the adoption of energy efficiency policy measures, a consolidated set of policy recommendations have been recently updated that cover 25 fields of action across seven priority areas: buildings, industry, power utilities, appliances, lighting, transport and cross-sectoral activities (Table 2.1) (IEA, 2011c). All recommendations were subject to a rigorous set of criteria and have been endorsed by IEA energy ministers in 2011. If implemented globally without delay, these policy actions could reduce global CO_2 emissions by 7.6 Gt per year by 2030 – equivalent to one and a half times the current CO_2 emissions in the United States. In 2010, this corresponded to energy savings of more than 82 exajoules (EJ)/year by 2030, or 17% of the current annual worldwide energy consumption.

Table 2.1. IEA's 25 energy efficiency recommendations

Across sectors	1.	Energy efficiency data collection and indicators
	2.	Strategies and action plans
	3.	Competitive energy markets, with appropriate regulation
	4.	Private investment in energy efficiency
	5.	Monitoring, enforcement and evaluation of policies and measures
Buildings	6.	Mandatory building codes and minimum energy performance requirements
	7.	Aiming for net zero energy consumption buildings
	8.	Improving energy efficiency of existing buildings
	9.	Building energy labels and certificates
	10.	Energy performance of building components and systems
Appliances and equipment	11.	Mandatory energy performance standards and labels for appliances and equipment
	12.	Test standards and measurement protocols for appliances and equipment
	13.	Market transformation policies for appliances and equipment
Lighting	14.	Phase-out of inefficient lighting products and systems
	15.	Energy-efficient lighting systems
Transport	16.	Mandatory vehicle fuel-efficiency standards
	17.	Measures to improve vehicle fuel efficiency
	18.	Fuel-efficient non-engine components
	19.	Improving operational efficiency through eco-driving and other measures
	20.	Improve transport system efficiency
Industry	21.	Energy management in industry
	22.	High-efficiency industrial equipment and systems
	23.	Energy efficiency services for small and medium-sized enterprises
	24.	Complementary policies to support industrial energy efficiency
Energy utilities	25.	Energy utilities and end-use energy efficiency

Source: IEA (2011), *25 Energy Efficiency Policy Recommendations.*

Governments need to employ a cohesive suite of measures because the barriers to energy efficiency are pervasive, dispersed and complex. Energy efficiency improvement is often hampered by market, financial, informational, institutional and technical barriers. These barriers exist in all countries, and energy efficiency policies are aimed at overcoming them. The major barriers are summarised in Table 2.2.

Table 2.2. Typical barriers to energy efficiency

Barrier	Example
Market	• Market organisation and price distortions prevent customers from appraising the true value of energy efficiency. • Split incentive problems created when investors cannot capture the benefits of improved efficiency. • Transaction costs (project development costs are high relative to energy savings).
Financial	• Up-front costs and dispersed benefits discourage investors. • Perception of efficiency investments as complicated and risky, with high transaction costs. • Lack of awareness of financial benefits on the part of financial institutions.
Information and Awareness	• Lack of sufficient information and understanding, on the part of consumers, to make rational consumption and investment decisions. • Incomplete information if technology has a lack of track record.
Regulatory and Institutional	• Energy tariffs that discourage efficiency investment, such as declining block rates. • Incentive structures encourage energy providers to sell energy rather than invest in cost-effective energy efficiency. • Institutional bias towards supply-side investments.
Technical	• Lack of affordable energy efficiency technologies suitable to local conditions. • Insufficient capacity to identify, develop, implement and maintain energy efficiency investments.

A recent assessment of progress with implementing the 25 recommended energy efficiency policies and measures found that although there is substantial energy efficiency policy action, there is still considerable scope for scaling-up efforts (IEA, 2011d).

Across all countries, policies for transport stand out as needing the most additional attention. About 60% of world oil is consumed in the transport sector. To achieve significant savings in this sector, complete package of policy measures is recommended including the introduction of mandatory fuel efficiency standards for cars and heavy-duty vehicles, complementary measures such as labelling and incentives, and improving overall transport system efficiency through modal shift and urban planning.

Progress is also needed in the buildings sector. Buildings account for 40% of energy use in most countries. Buildings offer one of the most cost-effective sectors for reducing energy consumption, with estimated savings of 1 509 million tonnes of oil equivalent by 2050, about the combined level of primary energy supply in Russia, Japan and Germany. Governments need to strengthen the energy efficiency requirements of building codes and standards, promote the adoption of low-energy houses and improve the monitoring of energy efficiency performance in existing structures.

Many governments are seeking assistance with how to implement the 25 energy efficiency recommendations in a way that suits their national context. A lack of experience or insufficient knowledge of how to deal with issues such as planning a strategy for implementation, stakeholder consultation, allocation of resources in the right time sequence, providing training and education, and communication of results can stand in the way of countries effectively implementing the recommendations. The IEA publishes the Policy Pathway series which provides guidance on the milestones in the steps to implementing individual energy efficiency policies.

A policy pathway on energy performance certification of buildings provides a "how to guide" to policy makers and relevant stakeholders on the essential elements to implement an energy performance certification of buildings programme (IEA, 2010c). Energy performance certification of buildings is a way to rate the energy efficiency of individual buildings – whether they be residential, commercial or public.

Performance certification is a key policy instrument that can assist governments in reducing energy consumption in buildings. The guide showcases experiences from countries around the world to show examples of good practice and delivers a policy pathway of ten critical steps to implement building energy performance certification programmes.

More than 50 countries worldwide implement end-use equipment programmes to improve energy efficiency. They cover energy efficiency schemes for end-use electrical appliances and equipment in the residential, commercial and industrial sectors. Another policy pathway gives clear guidance to policy makers and relevant stakeholders on best practice compliance, through monitoring, verification and enforcement (MVE), in end-use appliance and equipment standards and labelling programmes. Improving the design and implementation of MVE schemes can curtail the high levels of non-compliance that have hampered the effectiveness of some programmes in the past (IEA, 2010d).

The right technology and market mechanisms are crucial to achieve greater energy efficiency. But so are legal, institutional and co-ordination structures to promote the efforts. Drawing on the experience of hundreds of energy efficiency experts around the world, a handbook on energy efficiency governance provides useful guidance for government officials and energy efficiency practitioners on establishing effective structures to support national and sub-national efficiency policy implementation (IEA, 2010e).

Foster innovation and green technology policy

Innovation is a key driver in the transition to a green economy. It will be very difficult and very costly to address global environmental dilemmas such as climate change without successful innovation. Putting a price on pollution through measures such as environmentally-related taxes and tradable permits is a necessary condition for encouraging 'green' innovation (OECD, 2010a). However, this is unlikely to be sufficient, and the broader policy framework must complement targeted environmental policies.

One of the essential lessons in the OECD Innovation Strategy is that countries that harness innovation and entrepreneurship as engines for new sources of growth will be more likely to pull out of and stay out of recession (OECD, 2011a). Governments can help by creating the environment and safeguarding the drivers of innovation. Developing new sources of growth will depend on investing in innovation and skills. Policy makers have to take a lead, by tapping new sources of growth themselves, and setting the regulatory framework to allow breakthroughs to happen and to overcome inertia, whether institutional or economic, that prevent them.

Innovation is likely to be coupled with a process of creative destruction to bring new ideas and new business and institutional models to enable green growth. Such changes may include: the redesign of electricity delivery mechanisms to improve efficiency by cutting line losses, which amount to about 9% of global electricity production; accommodating low-carbon variable and decentralised supply sources; facilitating active network control and flatten peak demand curves to make better use of capital-intensive assets; and engaging consumers in demand-side management through price signals. This requires policies to promote innovation in technologies such as high-voltage direct current lines, information and communication technology (ICT) platforms and smart meters to name a few, but also new market and regulatory models.

The standardisation of technical specifications for converging technologies is necessary to foster green innovation (OECD, 2011a). As some business models for green innovation are still emerging, government engagement in the standardisation process can catalyse involvement of relevant stakeholders. Developing a common set of well-designed specifications, such as the inter-operability of smart grids and connections between electric vehicles and the charging stations, could contribute to developing the market, stimulating private investment and avoiding the emergence of incompatible technical elements. For example, the National Institute of Standards and Technology (NIST), an agency of the US Commerce Department, co-ordinates a Smart Grid Inter-operability Standards Project with the aim of identifying and developing standards critical to achieving a reliable and robust smart grid. NIST is conducting the project in three phases: identifying the gaps in available standards and priorities for revising existing or developing new standards; establishing a formal private-public partnership to drive long-term progress; and developing and implementing a framework for testing and certification.

Government policies need to ensure competitive selection processes, focus on projects that best serve public policy objectives, avoid favouring incumbents, ensure a rigorous evaluation of policy impacts and contain costs. Proven approaches include multiyear appropriations, independence of the agencies making funding decisions, use of peer review and other competitive procedures with clear criteria for project selection, and payments based on progress and outcomes rather than cost recovery (OECD, 2011a). Government support policies also need to be aligned with existing international commitments, notably under the World Trade Organization (WTO).

A range of OECD work underscores that innovation is core to moving onto a green growth path. For example, it looks at eco-innovation in industry (OECD, 2010b); greener and smarter information and communication technology (OECD, 2010c); and transition to a low-carbon economy (OECD, 2010d). Another demonstrates that green technology development is accelerating notably in air pollution control and renewable energy as measured by the number of patents (OECD, 2010e). Some conclusions arising from *Fostering Innovation for Green Growth* have particular relevance for the energy dimensions of green growth, as summarised below:

- Public investment in research is needed to help lower the costs of green innovation, to expand the scope for technological breakthroughs and to create new opportunities.
- Governments need to encourage the process of experimentation to bring about favourable options at the lowest cost. This involves a vigorous process of national and global competition among alternative technologies and innovations, to bring about those that have the best performance.
- Where solely private efforts are unlikely to be sufficient to commercialise technologies, government action, including public support, may be required to overcome market failures and barriers, such as dominance by existing business models and technologies. The primary market failure is the risks and time frames before profits are realizable can be too great for industry without government support. However, such policies should be well-designed to avoid capture by vested interests and regularly evaluated to ensure that they are effective and efficient in meeting public policy objectives.
- Countries may want to prioritise their efforts in areas where they have capabilities and a certain critical mass and focus on green technologies and innovations that are particularly relevant in the national context. In other areas, international collaboration provides a means to gain access to relevant research and work together for solutions to global issues (Box 2.4). At the same time, international competition will be essential to drive down the costs of green innovation and benefit from the global process of experimentation.

Box 2.4. The Low Carbon Energy Technology Platform

Created in response to a request from the G8 Summit in l'Aquila, Italy, and IEA Ministers, the International Low-Carbon Energy Technology Platform seeks to encourage, accelerate and scale-up action for the development, deployment and dissemination of low-carbon energy technologies. It does this by focusing on practical activities at international, national and regional levels to:

- Bring together stakeholders to catalyse partnerships and activities that enhance the development and implementation of low-carbon energy technology strategies and technology roadmaps at regional and national levels
- Share experience on best-practice technologies and policies and build expertise and capacity, facilitating technology transition planning that fosters more efficient and effective technology dissemination
- Review progress on low-carbon technology deployment to help identify key gaps in low-carbon energy policy and international co-operation, and support efforts to address these through relevant international and regional fora.

The Technology Platform is not a formal body or institution, but an informal forum that initiates activities and shares policy-related information among stakeholders interested and willing to help accelerate the spread of low-carbon energy technologies. The Technology Platform seeks to enhance collaboration among governments, business, the financial sector, expert bodies, international organisations and civil society. The focus is on practical action and the creation of networks through a wide range of activities that fall into one of four broad categories :

- Country-led collaborations
- Technology deployment through roadmap and strategy development
- Linking to other international collaborative efforts
- Technology deployment status, policy review, RD&D analysis

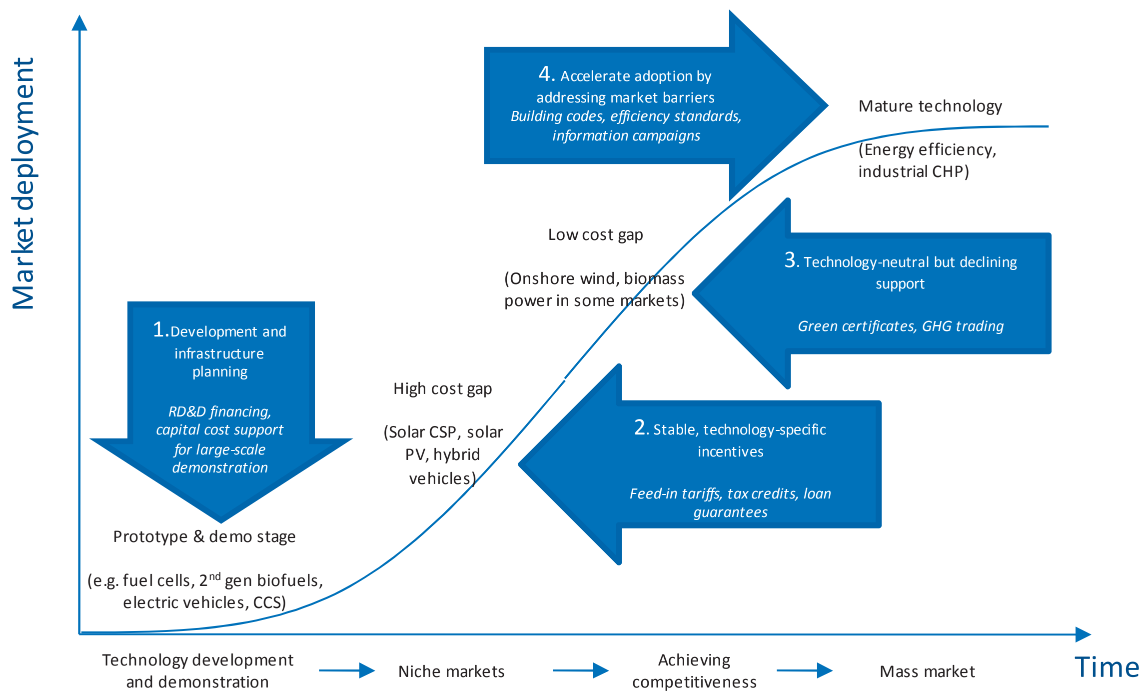
A concerted global effort to foster green innovations will significantly enhance the portfolio of options available. Many of the most promising low-carbon energy technologies currently have higher costs than the fossil fuel incumbents. Most new technologies will require, at some stage, both the "push" of research, development and demonstration (RD&D) and the "pull" of market deployment. As shown in Figure 2.3, in order to target the cost competitiveness gap, a range of policy measures will be required (IEA, 2010a):

- For promising but not yet mature technologies (Stage 1), governments need to provide financial support for additional research and/or large-scale demonstration and to start to assess infrastructure and regulatory needs.
- For technologies that are technically proven, but require additional financial support (Stage 2), governments need to provide support with capital costs, or to introduce technology-specific incentives such as feed-in tariffs, tax credits and loan guarantees, and appropriate regulatory frameworks and standards, to create a market for the relevant technologies.
- For technologies that are close to competitive (Stage 3), governments need to move towards technology-neutral incentives that can be progressively removed as technologies achieve market competitiveness.

- For technologies that are competitive (Stage 4), governments can best help scale up public and private investment by tackling market, informational and other barriers and by developing effective intervention policies and measures.
- Many technologies in practice straddle two or more stages of development. Government intervention needs to be tailored accordingly, in some cases providing support to all four phases of technology development simultaneously.

The overriding objectives should be to reduce risk, stimulate deployment and bring down costs. Evidence suggests that a large proportion of breakthrough innovations come from new firms that challenge existing business models. Thus, government steps to remove barriers to the entry and growth of new firms have an important part to play in low carbon energy technology development.

Figure 2.3. Policies for supporting low-carbon energy technologies



Note: The figure includes generalised technology classifications; in most cases, technologies will fall into more than one category.

Source: IEA (2010), *Energy Technology Perspectives 2010.*

Governance of intellectual property (IP) has an important influence on the marketability of new technologies. Private ownership of IP arising from government-funded R&D is a powerful tool for marketing research results. Experience from the United States indicates that governments should take steps to ensure that IP from public research is efficiently transferred to the private sector. The Bayh-Dole Act (1980) has made technology transfer a formal responsibility of government laboratories and has attributed the ownership of IP to the researcher, even when a project is funded by the government. Although initially restricted to universities and small business, coverage has since been progressively expanded. These policy changes spurred private entities and government to seek RD&D partnerships. Popp (2006) examined citations referring to patents in 11 categories of energy technology, and found that after the technology transfer acts came into force in the early 1980s, privately held patents that cited government patents became the most frequently cited, suggesting a fruitful transfer of government research results to private industry (IEA, 2011e).

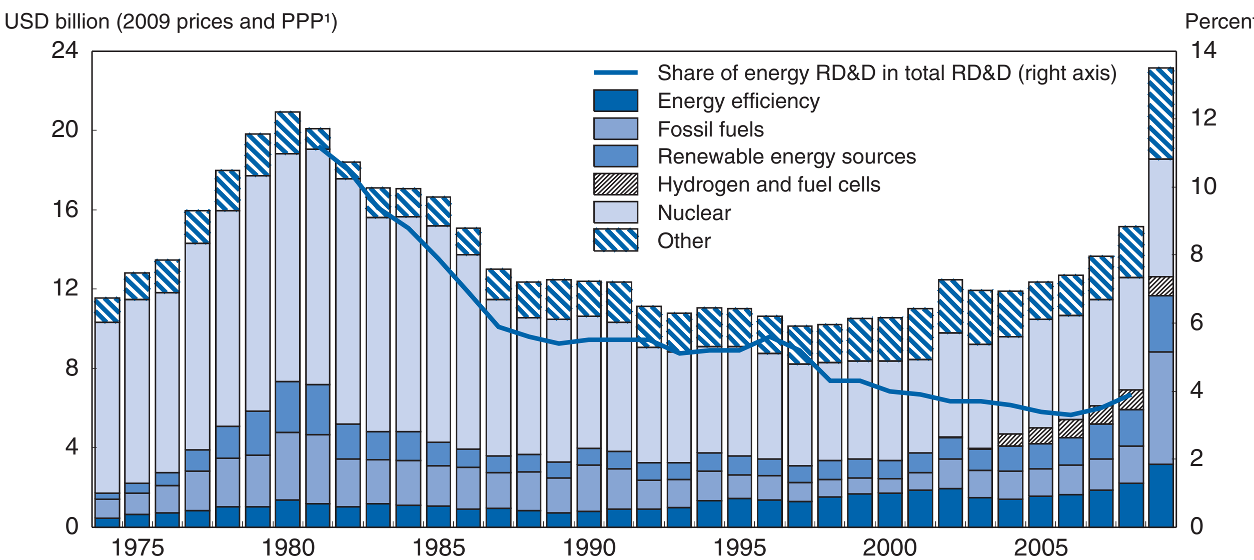
Energy RD&D expenditures

To achieve a 50% CO_2 emissions reduction objective, government funding for RD&D in low-carbon technologies will need to be two to five times higher than current levels (IEA, 2010a). This message is being taken seriously by many countries. Governments of both the Major Economies Forum and the IEA have agreed to dramatically increase and co-ordinate public-sector investments in low-carbon RD&D, with a view to doubling such investments by 2015. Simply increasing funding will not, however, be sufficient to deliver the necessary low-carbon technologies. Current government RD&D programmes and policies need to be improved by adopting best practices in design and implementation. This includes the design of strategic programmes to fit national policy priorities and resource availability; the rigorous evaluation of results and adjusting support if needed; and the increase of linkages between government and industry, and between the basic science and applied energy research communities to accelerate innovation.

More investment in low-carbon energy technology RD&D is needed at all stages of technology development. This should include direct government funding, grants and private-sector investment. After years of stagnation, government spending on low-carbon energy technologies has risen. But current levels still fall well short of what is needed to deliver green growth objectives. Data for private-sector spending are very uncertain.

Figure 2.4. Government RD&D expenditures in IEA member countries

1974-2008



1. PPP= Purchasing Power Parities. RD&D budgets for the Czech Republic, Poland and Slovak Republic have not been included for lack of availability.

Source: IEA databases, 2010 cycle.

Government energy RD&D budgets in IEA member countries declined between the early 1980s and the 1990s from USD 9 billion in 1980 to USD 8 billion in 1997 (Figure 2.4). The decline was associated with the difficulties of the nuclear industry and with the decrease in oil prices from 1985 to 2002. Since 1998, government expenditures on energy RD&D have started to recover, particularly between 2005 and 2008. Expenditure in 2008 was about USD 12 billion. The share of energy RD&D in total RD&D declined from 11% in 1985 to about 3% in 2006 but appears to be rising again.

Policies for green growth in specific energy sectors

This section looks at technology policy for three key components of a green growth strategy for energy – electricity, renewables and transport.

Electricity sector

In most OECD countries, a new investment cycle in power generation is looming. A window of opportunity now exists to establish policies that will deliver a cleaner and more efficient generation portfolio that will have significant impact on the energy sector and the environment for the next 40-50 years. However, the many uncertainties now inherent in the power sector create risks for investors, risks that may lead to under-investment – too little, too late, in the wrong location and with the wrong technology.

The ageing of existing units, and eventual need for replacement, is inevitable. Most OECD countries experienced an investment boom in the 1970s, in response to the oil price crisis. Many countries shifted generation portfolios away from oil, to coal and nuclear. Many these units are now approaching the end of their technical lifetime. However, investments in refurbishment and upgrades can extend the lifetime and capacity of units. Delaying the replacement process can be commercially attractive especially when faced with uncertainty over the pace of change in environmental regulation. Policies need to be robust enough to achieve closure of the dirtiest and least efficient plants at the earliest opportunity.

The liberalisation of electricity markets delivers considerable benefits if well designed and implemented and if backed by ongoing government commitment. In fact, competitive markets with cost-reflective prices are a strong instrument to effectively balance energy systems in terms of economic efficiency, reliability and environmental performance. Restructuring in power markets is one of the uncertainties for investors, but the risks can be greatly reduced when competitive and liquid markets are allowed to develop. Other uncertainties for investment include ambiguity about future CO_2 constraints and associated pricing of carbon power plant licensing, issues around nuclear power acceptability, local opposition to new energy infrastructure and government support for specific generation technologies. Government action is needed to significantly reduce policy uncertainty. This would serve to establish effective competitive markets and provide firm policy directions in those areas in which markets fall short, such as taking account of environmental costs. Governments must also clarify and simplify power plant licensing procedures to accelerate the approval of new generation units (IEA, 2007a).

One of the most difficult decisions for investors is the choice of technology, which obviously has implications for the environment and security of supply. Moreover, a well-diversified generation portfolio designed to deliver supply efficiently both now and in the future, will have to include several technologies. Thus, the choice for investors depends on many factors and is always made with an eye on the potential for profit. Small changes in the key cost factors, *e.g.* investment costs, fuel costs, CO_2 emission costs and utilisation rates, can significantly change the relative ranking of technologies in terms of total generation costs levelised over the lifetime of the plant. Well-functioning markets for electricity, fuel and CO_2 emissions provide strong incentives for investors to diversify and to opt for clean technologies although diversification is, obviously, limited to the technology options actually available.

Government policies play a critical role in keeping as many options open as possible by supporting R&DD of new technologies and through effective policies and regulation, including those that govern market competition, network access and rates.

Good market design, effective regulation, competition and clear, long-term environmental policy are critical factors for well-functioning electricity markets. The danger of a concentrated market is that firms with market power may withhold new investment as a means to push up prices and increase profits – outcomes that are ultimately detrimental to public welfare. Such a strategy can succeed for extended periods only if dominant firms can, at the same time, block or obstruct investments by competing firms. Thus, it is important to create the right conditions to encourage competing firms to enter markets, including rules and market design that are clear, efficient, and ensure equal treatment for all players. To this end, independent regulators and independent transmission system operators play critical roles in establishing trading rules and ensuring fair access to networks. These roles must be effectively separated from generation and retail supply.

Trade and co-operation across jurisdictional borders are also important benefits of liberalisation. Resources can be used more efficiently, which allows co-operating systems to function reliably with lower reserve margins. Trade can be particularly valuable for intermittent renewables to foster increased market penetration by smoothing supply variability. Cross-border trade is constrained by available transmission capacity, but with an appropriate market design the benefits also create incentives for investment in new transmission interconnections. The benefits are even more significant for smaller systems; indeed for smaller markets, cross-border trade may be the only way to improve competition among local generators.

Sectoral Approaches in Electricity: Building Bridges to a Safe Climate shows how the international climate policy framework could effectively support a transition towards low-CO_2 electricity systems in emerging economies, without waiting for countries to take on national commitments. These include sector-specific objectives for developing countries; new market mechanisms based on sectoral crediting or caps; and international support for sharing best technology and best practice in priority sectors such as electricity (IEA, 2009d).

Governments are best positioned to assess, on a broad scale, the environmental risks and costs associated with power generation, and possible macro-economic implications resulting from too high dependence on, for example, natural gas imports. That said, governments are not necessarily best equipped to actually manage risks by picking preferred technologies and generation portfolios. Many clean and non-import dependent technologies, including some renewable technologies, carbon capture and storage and nuclear power, need government support that reflects the added benefits for the environment and from reduced import dependence. Commercial investors have a long history of managing risk in the marketplace and are best placed to assess the optimal choice and combination of technologies, taking into account technology maturity and efficiency concerns. Governments and commercial investors are complementary. The principal role of government is, through market-based instruments, to create incentives for investment decisions that support policy objectives on environment, energy security and economic growth. Market-based instruments are already available for several environmental policy objectives; they have shown the potential to improve cost effectiveness and are compatible with liberalised electricity markets (IEA, 2007a).

Box 2.5. Policy action for smart grids

The world's electricity systems face a number of challenges, including ageing infrastructure, continued growth in demand, the integration of increasing numbers of variable renewable energy sources and electric vehicles, the need to improve the security of supply and the need to lower carbon emissions. Smart grid technologies offer ways not just to meet these challenges but also to develop a cleaner energy supply that is more energy-efficient, more affordable and more sustainable.

These challenges must also be addressed with regard to each region's unique technical, financial and commercial regulatory environment. Given the highly regulated nature of the electricity system, proponents of smart grids must ensure that they engage with all electricity system stakeholders, including equipment manufacturers, system operators, consumer advocates and consumers, to develop tailored technical, financial and regulatory solutions that enable the potential of smart grids.

Large-scale pilot projects are urgently needed in all world regions to test various business models and then adapt them to the local circumstances. Countries and regions will use smart grids for different purposes; emerging economies may leapfrog directly to smart electricity infrastructure, while OECD countries are already investing in incremental improvements to existing grids and small-scale pilot projects.

Current regulatory and market systems can hinder demonstration and deployment of smart grids. Regulatory and market models – such as those addressing system investment, prices and customer participation – must evolve as technologies offer new options over the course of long-term, incremental smart grid deployment.

Greater international collaboration is needed to share experiences with pilot programmes, to leverage national investments in technology development, and to develop common smart grid technology standards that optimise and accelerate technology development and deployment while reducing costs for all stakeholders.

A number of countries are already taking steps. For example, Korea announced its National Smart Grid Roadmap in January 2010, and has invested USD 230 million to establish a smart grid test-bed in the Jeju Island. Korea plans to increase investment in spreading smart grid technologies after developing new business models through the test-bed. Moreover, the Act on Facilitating the Smart Grid was approved by the National Assembly of Korea in April 2011, which will serve as a stable foundation for increasing the investment on the successful development and spread of the smart grid technologies. In 2011 the Italian regulator (Autorità per l'Energia Elettrica ed il Gas) has awarded eight tariff-funded projects on active medium voltage distribution systems, to demonstrate at-scale advanced network management and automation solutions necessary to integrate distributed generation. The Ministry of Economic Development has granted over EUR 50 million in the past 5 years for smart grid R&D activities through the Energy System Research Fund and over EUR 200 million for demonstration of smart grids features and network modernisation in Southern Italian regions.

Renewable energy

Renewable energy sources play a central role in moving the world onto a more secure and sustainable energy path. The potential is unquestionably large, but how much and how quickly their contribution to meeting the world's energy needs grows hinges critically on the strength of government policies to stimulate technological advances and make renewables cost competitive. The IEA's definition of renewable energy sources includes energy generated from solar, wind, biomass, the renewable fraction of municipal waste, geothermal sources, hydropower, ocean, tidal and wave resources, and biofuels (IEA, 2007b).

The greatest scope for increasing the use of renewables in absolute terms lies in the power sector. Renewables are generally more capital intensive than fossil fuels, so the investment needed to provide the renewables capacity is very large. Investment in renewables to produce electricity is estimated at USD 5.7 trillion (in year-2009 dollars) over the period 2010-2035. Investment needs are greatest in

China, which has now emerged as a leader in wind power and photovoltaic production, as well as a major supplier of the equipment. The Middle East and North Africa region holds enormous potential for large-scale development of solar power, but there are many market, technical and political challenges that need to be overcome.

Only a limited set of countries has implemented effective support policies for renewable energy technologies that have accelerated renewables deployment in recent years (IEA, 2008). The "OECD-EU" countries, which generally have a longer history of renewable energy support policies, show the highest policy effectiveness for "new" renewables for power generation. With more mature renewable electricity technologies such as hydro and in the heat and transport sectors, the picture is more varied with some non-EU-OECD and BRICS countries also having implemented relatively effective policies.

Non-economic barriers have significantly hampered the effectiveness of renewable support policies and driven up costs in many countries, irrespective of the type of incentive measure. Examples include administrative hurdles in land-use planning and siting, long lead times for permits, lack of co-ordination between relevant authorities; grid access; lack of technical capacity and training and social acceptance (IEA, 2008).

Overall the effectiveness and efficiency of renewable energy policy are determined by the consistency of measures and adherence to these key policy design principles:

- Effective implementation of transitional incentives, which are based on the maturity of the technology and decrease over time, to promote innovation and move technologies to market competitiveness.
- Need for a predictable and transparent support framework to attract investments.
- Adequately address non-economic barriers and social acceptance issues to stimulate market development.
- Take due consideration of the impact of large-scale penetration of renewable energy technologies on the overall energy system, particularly in liberalised energy markets with regard to overall cost efficiency and system reliability.

Transportation sector

Transport is a critical and difficult sector in the transition to green growth. Transport accounts for about 19% of global energy use and almost one-quarter of energy-related CO_2 emissions. With current trends these factors increase by more than 80% by 2050. Cars and trucks are the biggest contributors, but aviation and shipping are also growing rapidly.

Substantially greening the transport sector will require policies to promote both the widespread adoption of best available technology, and the longer-term development and deployment of a range of new technologies. It will also require strong policies to ensure the rapid uptake of these innovations and to encourage sensible changes in travel patterns (IEA, 2009e).

Fuel efficiency standards

The first priority should be policies for fuel efficiency improvements that employ technologies and practices that are already cost-effective. A 50% reduction in fuel use per kilometre for average new light-duty vehicles around the world, from incremental technology improvements and hybridisation, is possible by 2030 and is likely to be cost effective even at relatively low oil prices. Policies are needed both to ensure maximum uptake of efficiency technologies and to translate their benefits into fuel economy improvement. Fuel economy standards complemented by emissions-based vehicle registration fees can, and in fact already do, play an important role in OECD countries. Other countries, especially those with robust growth in vehicle use, need to adopt similar policies. All countries need to update these standards over time, rather than letting measures expire or stagnate. The Global Fuel Economy Initiative is focused on helping to achieve such outcomes (FIA Foundation, 2011).

Alternative fuels

Ethanol from sugar cane can already provide low-cost biofuels (depending on feedstock prices). Advanced (second-generation) biofuels, such as biofuels from waste and residues, ligno-cellulosic ethanol and biodiesel derived from biomass (biomass-to-liquids), appear to have the best long-term potential to provide sustainable, low life-cycle greenhouse gas fuels, but more RD&D is needed, as well as policy measures reducing the investment risk associated with commercial-scale plants. For all biofuels, important sustainability questions must be resolved, such as the impact of production on food security, sensitive ecosystems, greenhouse gas emissions and social aspects as a result of land-use change (Box 2.6).

Box 2.6. Biofuels and the food versus fuel debate

A considerable rise in agricultural commodity prices in 2006 - 2008 triggered a debate over the impact of conventional biofuels on global commodity prices and food security. This debate has cooled somewhat since then. Recent analyses suggest that biofuels had only a limited impact on those commodity price spikes, whereas rising oil prices and the use of commodities by financial investors in combination with adverse weather conditions probably were the main drivers behind the food price increase (World Bank, 2010).

Today only about 2% (30 million hectares) of the world's arable land is used to grow biofuel feedstocks. Plus in many cases, co-products occur that are used for energy generation or enter the food chain as a valued cattle feed, (*e.g.* 0.6 kilogram (kg) of dried distiller's grains per litre of corn-ethanol; 0.85 kg of soy-meal per litre of soy-biodiesel), and reduce the net land demand of biofuels. Biofuels should be promoted in a manner that encourages greater agricultural productivity and the use of degraded land. Biofuels impact on food security, nonetheless, remains a sensitive topic. A sound policy framework is required to ensure that biofuels are produced sustainably with regard to food security as well as other social, environmental and economic aspects. This should include adoption of sound certification schemes for biofuels based on internationally agreed sustainability indicators, for instance those being developed by the Global Bioenergy Partnership. Furthermore, land- and resource-efficient technologies, in particular advanced biofuels, need to be part of an integrated approach, as well as use of wastes and residues as biofuel feedstock (IEA, 2011f).

To ensure a vital and sustainable agricultural sector that can serve the wide range of biomass demand in different sectors in the future, substantial investments into agricultural production and rural infrastructure are needed. Sustainable biofuel production should be considered as one integrated aspect of land-use management, including promoting the use of degraded land along with production of food and other products. Biofuels can play a role in creating additional income in rural areas and trigger investments that benefit the agricultural sector as a whole. Integration of food and fuel production should provide opportunities for synergies which allow overall improvements in the efficiency with which land-based resources are produced and used.

Source: World Bank (2010), *Placing the 2006/08 Commodity Price Boom into Perspective*, IEA (2011), *Technology Roadmap – Biofuels for Transport*.

Advanced vehicle technologies

Policies and initiatives to promote electric vehicles and plug-in hybrid electric vehicle (PHEVs), and the continuing development of fuel cell vehicles, are extremely important. For governments, orchestrating the co-development of vehicle and battery production, recharging infrastructure, and providing incentives to ensure sufficient consumer demand to support market growth, will be a significant near-term challenge (Box 2.7). Demonstration programmes in selected regions or metropolitan areas that are keen to be early adopters can be an effective approach.

Advanced vehicle technologies will make a big impact, especially after 2020, not only in terms of transportation but also in how electricity networks are structured and managed. Electric vehicles are rapidly emerging as an important option, especially as lithium-ion battery costs decline. It now appears that batteries for a pure electric vehicle, in high-volume production, might cost as little as USD 500/kWh in the near term, low enough to bring the battery cost for a vehicle with a 150 kilometre range down to about USD 15 000. This is still very expensive. But with savings from removing the internal combustion engine, and with relatively low-cost electricity as the fuel, this might be sufficient to allow electric vehicles to achieve commercial success over the next five to ten years, if coupled with policy assistance such as support for the development of an appropriate recharging infrastructure. The cost of oil, the incumbent fuel, will also be an important factor. Since the impact of electric vehicles on CO_2 emissions depends on the carbon intensity of electricity generation, it would make sense to deploy electric vehicles first in those regions with already low CO_2 generation or firm commitments to move in that direction (IEA, 2009e).

A potentially important transition step to electric vehicles is offered by plug-in hybrid electric vehicles. By increasing the battery storage in hybrid vehicles and offering a plug-in option, these vehicles represent an important step toward vehicle electrification that builds incrementally on an emerging hybrid vehicle technology. For many drivers, running most of the first 40 kilometres per day on electricity could cut oil use dramatically, by 50% or more. PHEVs may also require less new infrastructure than pure electric vehicles since the car is not dependent solely on electricity and has a full driving range on liquid fuel (IEA, 2009e).

Box 2.7. France's strategy to launch electric vehicles

The French government committed USD 2.2 billion (EUR 1.5 billion) in October 2009 to a ten-year plan to help put two million plug-in electric vehicles on the road by 2020. The funds will help pay for:

- Manufacturer and buyer subsidies, including consumer purchase "bonuses" of up to EUR 5 000.
- Nationwide network of more than 4 million charging stations, with 1 million by 2015.
- Funding for battery manufacturing and industrial research.

The plan also includes supporting measures, such as requiring all new apartment developments to install charging stations, beginning in 2012. It calls for public and private tenders for electric vehicles to generate demand, with a target for these fleets to account for 100 000 by 2015.

The two major French car manufacturers, Renault and PSA Peugeot Citroën, have pledged to begin selling electric vehicles by 2012.

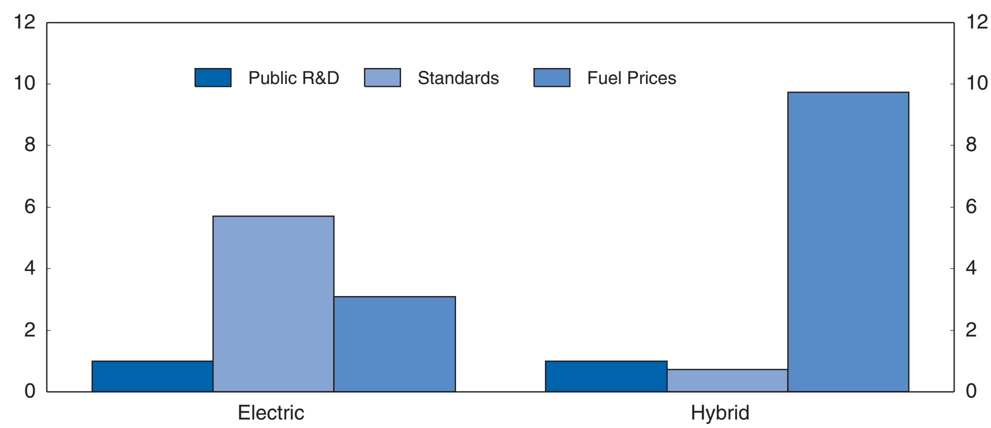
The government has named an electric vehicle co-ordinator to liaise between ministries, and to work closely with cities, electric utilities, vehicle manufacturers and other stakeholders to co-ordinate all aspects of electric vehicle development.

Source: French Ministry of Ecology press release (1 October 2009).

Recent OECD analysis indicates that relatively minor changes in a performance standard or automotive fuel prices would yield benefits in terms of innovation that are equivalent to a much greater proportional increase in public R&D budgets. However, there are significant differences between types of technologies. For example, in the case of electric vehicles the role of after-tax fuel prices is insignificant, but standards play an important role. Conversely, for hybrid vehicles it is after-tax fuel prices which are significant and not standards. Public R&D plays a much more important role for electric than hybrid vehicles (OECD, 2011a).

Figure 2.5 indicates the importance of the appropriate mix of policy measures. Relative prices may have a lesser role to play than ambitious performance standards or significant public support for research the further a technology is from being directly competitive with the incumbent technology (petrol- and diesel-driven technologies). While in theory a price sufficient to induce an equal level of innovation for such technologies could be introduced, such a measure would likely be politically infeasible in practice. Moreover, even if introduced, potential innovators may not perceive it as credible over the longer-term.

Figure 2.5. The effect of different factors on innovation in electric and hybrid vehicles



Note: For ease of interpretation, elasticities have been normalised such that effect of R&D=1.

Source: OECD (2011), *Invention and Transfer of Environmental Technologies.*

Modal shifts and green urban models

Beyond changes to future vehicles and fuels, shifts in some passenger travel and freight transport to more efficient modes can also play an important role in greening transport and should be a policy focus. Certainly from the point of view of cities around the world, developing in a manner that minimises reliance on private motorised travel should be a high priority given the strong co-benefits in terms of reduced traffic congestion, lower pollutant emissions and general liveability.

Shifting passenger travel to more efficient modes such as urban rail and advanced bus systems can play an important role. Policies need to focus on better urban design to cut the need for motorised travel, improving mass transit systems to make them much more attractive, and improving infrastructure to make it easier to walk and cycle for short trips. Rapidly growing cities in developing countries have the opportunity to move toward far less car-oriented development than has occurred in many cities in OECD countries. But it will take strong measures and political will, and support for alternative investment paradigms.

Notes

1. The percentage reductions are calculated as the difference in 2050 between emissions in the baseline and Blue Map scenarios and therefore do not reflect the full contribution of each technology compared to today's deployment level.

2. The OECD Framework for Assessing Green Growth Policies provides a thorough discussion of environmental externalities and key underlying market failures (de Serres, Murtin and Nicoletti, 2010). It reviews the relative strengths and weaknesses of different policy instruments and policy mixes to deliver green growth. Policy issues related to the development and diffusion of clean technologies are examined. Its taxonomy of policy tools and checklist of questions for green policy assessment can provide valuable guidance to policy makers' challenging tasks in providing an integrated strategy.

3. The G20 includes the G8 group of countries – Canada, France, Germany, Italy, Japan, Russian Federation, United Kingdom, United States – plus Argentina, Australia, Brazil, China, India, Indonesia, Mexico, Saudi Arabia, South Africa, Korea, Turkey and the European Union.

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Chapter 3. Implementing green energy: Reshaping the political economy

Current energy systems are "locked-in" to high carbon production and consumption patterns that can be difficult to break. Structural change in the energy sector will involve more than just changing existing technologies; it will also affect supply chains, physical infrastructure, user practices, markets and regulatory systems. Countries will choose the most appropriate option depending on national circumstances, whether it is low-carbon energy supply, carbon capture and storage or energy efficiency. Flexibility should be built into long-lived new energy assets to allow for changes of environmental regulations and wider economic conditions such as fuel prices.

The transition to a low-carbon energy system is likely to have a positive impact on employment within the energy sector, as renewable energy tends to be more labour-intensive than fossil fuel-based energy, although the actual employment impact will differ by energy technology. Governments should pay attention to the distributional impacts of the energy transition, both within countries in terms of the effect on the poor, who tend to spend a larger share of their income on energy, and between countries, as patterns of trade related to fossil fuels change.

The economic and environmental case for a green growth strategy in the energy sector is compelling. But the political economy of implementing the policies necessary to make the transition is fraught with challenges. This chapter discusses the factors that affect how quickly policy makers are able to gear up for green growth. Constraints relate to the fact that current energy systems are "locked-in" to high carbon production and consumption patterns that can be difficult to break for reasons that go beyond simple economics. Vested interests and sunk capital, the concern to avoid creating stranded assets, and the consequences of potential disruptions to existing patterns of employment are all factors that policy makers will have to tackle when contemplating changing the rules of the energy game. Underlying all these issues is the fact that the transition will involve both winners and losers, and potential losers often have a louder voice to resist change.

One aspect of the politics that plays in favour of change is the competitive pressure that will emerge between countries as a result of a global energy transition. The reality of the marketplace will be more dynamic, uncertain and disruptive to existing business models than predicted by equilibrium economics. Rather than strictly aiming for least-cost solutions (which are difficult to define in such dynamic contexts), countries may adopt strategic behaviour, aiming for competitive advantage through economies of scale in new markets which can be a significant source of gains from trade (Krugman, 1979).

When facing these disruptive forces, governments will have to take decisions that affect the long-lived capital structure of their energy systems. These decisions need to be robust in the face of significant uncertainty (Lempert, Popper and Bankes, 2003). The speed of transition of energy systems is a crucial decision. First-movers may gain advantages in new markets but face unknown technical risks, whereas rear-guard movers may gain from knowledge spill-overs, but face the risk of lock-in and stranded capital (Unruh, 2006).

Political economy – achieving change in different country contexts

All growth strategies will be driven by local priorities and conditions, so energy sector developments for green growth will vary significantly in different countries. Nonetheless, it is possible to identify three broad sets of circumstances which affect the political economy of the energy sector. These may overlap, so countries may identify with one or more of these categories.

Economies with established energy and industrial structures

Perhaps the biggest obstacle that policy makers have to overcome when considering the speed of transition is the effect on firms' competitiveness and the strong interests vested in the status quo due to the sheer size of the sunk capital at risk of being stranded. The most exposed is the power sector, which has an installed capacity world-wide of around 5 000 gigawatts (GW.) Given that around half of existing plants are over 20 years old (IEA, 2010), the asset value will be depreciated to around one-third of the new value, putting the value of existing capital stocks in the power sector at around USD 5 000 billion.[1] Sunk capital in other sectors is smaller in comparison but still substantial. Based on capital costs quoted by ETSAP (2011) and *WEO-2011*, and assuming a similar level of depreciation as for the power sector, order of magnitude estimates of asset values show that gas pipeline infrastructure (USD 400 billion), refineries and cement (USD 300 billion each), steel (USD 100 billion) and industrial boilers (USD 50 billion) are amongst the more exposed sectors of the economy. Together, these fossil fuel-dependent assets amount to around 15% of global GDP. Not surprisingly, the scale of the financial stakes results in some push-back from boards of companies.

Nevertheless, at the macro-economic level, there is clear evidence that countries with high levels of resource productivity and efficient use of energy tend to be those with a high index of competitiveness

(Bleischwitz, 2010). This has historically been the case in countries such as Japan where these resources have been particularly costly, leading to stricter standards and economic incentives to improve efficiency of use. Such conditions support further reductions in resource intensity as the economies of successful countries tend to move towards higher value-added activities.

Achieving such self-reinforcing shifts through regulatory measures may face initial opposition from business. Although it will be essential for policy makers to carry with them their key stakeholders when implementing change, lobbying positions of firms are not always in the economic interests of the country as a whole. Economic benefits can accrue from driving businesses to be greener, increasing firms' competitiveness by increasing their rate of innovation and overall productivity (Porter and von der Linde, 1995). Whilst it is hard to see how regulatory interventions requiring costly environmental measures could achieve this outcome in an equilibrium economy (Palmer, Oates and Portney, 1995), there is a growing literature that considers how real markets may diverge from perfect equilibrium such that environmental regulatory interventions can lead to greater competitiveness of individual firms:

- New markets for environmental goods and services may be created, and economies of scale in these new markets will reduce the cost of environmental improvement. This can reduce the marginal additional cost of abatement compared to companies in countries with less stringent environmental standards (Greaker, 2006).
- Stricter environmental standards may enable firms to provide goods and services to customers who are willing to pay more for environmentally superior products, but which would otherwise be undercut leading to suboptimal choices for consumers (André, González and Porteiro, 2009).
- Tighter environmental regulation can improve information flow within companies reducing the cost of identifying opportunities for productivity improvement (Ambec and Barla, 2002).

Such micro-economics explanations help lay the theoretical foundations to support the case for some green growth policies, even if these policies appear to lead to increased operating costs for companies in the short-term.

Countries with low energy access

The overriding concern in countries without established energy distribution systems is to increase energy supply to meet the growing needs of households and businesses. Lack of energy supplies in these countries can be a significant constraint on economic growth potential. It is estimated that there are 1.3 billion people in the world that lack access to electricity (IEA, 2011). *WEO-2011* analysis on providing universal electricity access to those that do not have it shows that grid extension is typically the most suitable option for all urban zones and for around 30% of rural areas, but does not prove to be cost effective in more remote rural areas. Therefore, 70% of rural areas are connected either with mini-grids (65% of this share) or with small, stand-alone off-grid solutions (the remaining 35%). These stand-alone systems have no transmission and distribution costs, but higher costs per megawatt-hour (MWh). Mini-grids, providing centralised generation at a local level and using a village level network, are a competitive solution in rural areas, and can allow for future demand growth, such as that from income-generating activities.

Achieving universal access to electricity by 2030 requires an increase in global electricity generation of 2.5% (around 840 terawatt-hours, TWh) compared with the *WEO-2011 New Policies Scenario*, requiring additional electricity generating capacity of around 220 GW. Of the additional electricity needed in 2030, around 45% is expected to be generated and delivered through extensions to national grids, 36% by mini-grid solutions and the remaining 20% by isolated off-grid solutions. More than 60% of the additional on-grid generation comes from fossil fuel sources and coal alone accounts for more than half of the total on-grid additions. In the case of mini-grid and off-grid generation, more than 90% is provided by renewables.

Perhaps these issues are clearest in the case of sub-Saharan Africa (SSA), where, despite only accounting for 12% of the global population it has almost 45% of those without access to electricity – an estimated 586 million people in 2009 (IEA, 2011). According to the *WEO-2011*, more than 60% of the additional investment required to provide universal access to electricity by 2030 is in sub-Saharan Africa. There is greater dependency here on mini-grid and isolated off-grid solutions, particularly in countries such as Ethiopia, Nigeria and Tanzania, where a relatively higher proportion of those lacking electricity are in rural areas. A recent review of the economics of renewables in SSA shows that when considering sparsely populated rural areas, the economics of localised renewables can be favourable compared to grid expansion, leading to the conclusion that decentralised wind power could already be cost-competitive in large regions in countries such as Ethiopia, Ghana and Kenya (Deichmann *et al.*, 2010). Nevertheless, the review shows that for a majority of households, grid-connected electricity will remain the cheapest solution for some time to come and that large-scale centralised technology such as hydro, concentrating solar power and geothermal may need to be prioritised if renewables are to make a significant contribution to overall electrification levels.

The development path for electricity grids could be strongly affected by the use of smart grids in the SSA context, allowing for leapfrogging of technical standards in grid design (Bazilian *et al.*, 2011a). These could bring immediate economic benefits through reduced losses on long-distance transmission lines, reduced non-technical losses (such as theft and billing errors), and the ability to link up mini- and micro-grids. The possibility of piggy-backing such developments with telecom service expansion could also bring new ways for low-income consumers to access energy services.

The need for accelerated electrification rates is well recognised politically at national level, with 75% of sub-Saharan countries having defined targets for electricity access (WHO and UNDP, 2009). At the international level, a number of initiatives have been established including the Africa-European Union Energy Partnership, as well as initiatives announced at the first Clean Energy Ministerial (2010) to help address these issues. The political economy is however still dominated by finance. Significant implementation will require agreements on how such investments are to be paid for, including decisions as to what contribution could come from the international community.

The focus for policy makers in these countries should be on cost-effective policies to improve energy access, whilst aiming to maintain enough flexibility in the energy systems being developed to enable a shift towards lower-emission solutions in the future. This will help countries to invest in critical infrastructure development, whilst avoiding the risk of creating stranded assets. In terms of electricity generation, policy makers should also balance access issues with security of supply concerns by avoiding too much concentration on particular generation technologies. Key technologies are likely to be flexible grid systems that can incorporate a range of different types of power generation over time, as well as building in the possibility of adding carbon capture and storage at a later date to any new fossil fuel plant added to the system. The balance of the overall generation portfolio, as well as the potential costs of environmental externalities that may have to be paid in the longer term should always be an integral part of the discussion whenever countries negotiate with donors on investment in new assets.

Resource-rich countries

Probably the greatest conflict between aims for energy security and environmental security comes in countries with significant domestic resources of fossil fuel, especially coal. Although international coal prices have risen dramatically over the past decade, the direct costs of coal-fired generation are often low compared to other sources, especially if the coal can be used close to its source, reducing transport costs. Even if global economics (taking environmental externalities into account) indicate that it would be optimal to shift away from coal use, the local economic incentives to develop these resources can be great. Political economy considerations may well prevent sufficient compensation being paid to developing countries to incentivise them to leave these resources in the ground.

An illustration of these tensions is provided by the recent decision to proceed with a coal-fired generation plant at Medupi in South Africa. The project is huge on several scales: at 4 800 MW, the plant will be the seventh-largest in the world, and the estimated construction costs of USD 17.8 billion is equivalent to 10% of South Africa's GDP. The electricity from the plant will provide much-needed supply to South Africa's mining and other industries, as well as generally supporting the quality of supply for household users. And being situated close to large low-cost domestic resources of coal provides a secure supply of fuel. The decision by the South African government to support this project was backed up by the World Bank which is providing just over USD 3 billion of loans, and USD 2.5 billion from the African Development Bank (Sovacool and Rafey, 2011).

The project planning documents state that the plant is consistent with South Africa's goals to lower carbon intensity and eventually emissions (a view endorsed by the World Bank, 2010), due to the fact that it replaces coal plants which are being retired, and that the low carbon transition scenarios mostly show a shift to low carbon generation sources only after 2020. Nevertheless, although the new coal plant may be retrofit-able with carbon capture and storage at a later date if this technology becomes proven and cost-effective (assuming an effective future pricing regime for carbon emissions), there are significant technological and policy risks in going down this path.

Clearly, South Africa is not alone – at the global level, the Medupi plant provides a microcosm of the issues facing a large number of countries, with coal users all over the world facing similar dilemmas (Bazilian *et al.*, 2011b). Policy makers can begin to address this dilemma by separating the potential risk of lock-in to coal generation plant *per se*, from the risk of lock-in to unsustainable industrial structures in the wider economy. The risk of creating stranded assets in the energy sector (discussed in the next section) may be dwarfed by the risk of creating stranded assets in the wider economy. Using cheap electricity to grow energy-intensive industry at the expense of more value-added economic activities may be unwise given the eventual need to internalise the cost of environmental impacts including carbon emissions, and the costs of industrial re-structuring this would imply in the future. Governments might instead choose to capture the rents associated with cheap electricity sources through state taxes, which could be used to promote green growth priorities, and encouraging a longer-term more sustainable industry structure, whilst building financial reserves to help tackle future energy-sector decarbonisation. In this sense, the dilemmas and solutions are similar to those facing oil-exporting nations (Box 3.1).

Structural adjustment

Structural change in the energy sector involves more than simply changing the existing set of technologies. The energy system comprises a consistent network of supply chains, physical infrastructure, user practices, markets and regulatory systems (Kemp, 1994). A major transition of one part is not possible without changing the wider system. Such "technological regimes" become dominant over their alternatives due to economies of scale that can provide significant societal benefits by reducing economic costs, creating stability and predictability in the system, and reducing complexity and facilitating regulation. However, this reduction in the technological and regulatory complexity also leads to "lock-in" (Unruh, 2000), with potentially both incumbent companies and their regulators being "captured" within the presiding regime, and making change more difficult. The fact that the capital costs of existing plants are sunk also creates an option value to retaining these plants in the face of uncertain economic conditions, implying the need for stronger incentives to be in place before these plants would be fully retired (Blyth, 2010).

Box 3.1. Ending dependence: Hard choices for oil-exporting countries

Development based on the export of hydrocarbons presents serious challenges. In the short term, spending the revenues that accrue from oil and gas exports can cause inflation and stimulate unsustainable government expenditure and subsidies. In the long term, depletion of the hydrocarbon reserves will limit what the hydrocarbon sector can do for the rest of the economy. The exploitation of resources may, however, become a cure for the problems of underdevelopment and poverty which affect many hydrocarbon-exporting countries – if the resources are used to develop the non-hydrocarbon potential of their economies so as to replace hydrocarbon income in the long term.

Oil exporters face the problem of how to sustain economic growth in the long term as hydrocarbon exports are increasingly constrained by depletion and rising domestic consumption. This will happen, within varying time frames, as (a) country production flattens and falls and (b) continuing domestic consumption absorbs more of each country's production. Some governments are questioning whether to "leave oil in the ground" now for production later which would delay and lessen the eventual changes needed to reduce dependence on the hydrocarbon sector. On the other hand, building up foreign investments can provide a strategic hedge against the uncertainties of future reserves and prices.

Different countries face the challenges of depletion with varying levels of urgency, but no country whose economy now depends on oil and gas exports can escape the eventual transition to lower dependence on hydrocarbons, which will involve a combination of:

- Domestic energy policy to restrain the growth of consumption and encourage the development of other fuels;
- More rapid growth of non-hydrocarbon sectors to pay taxes and generate exports (or reduce imports);
- Lower targets for economic growth.

In May 2010, top officials from Saudi Aramco warned that Saudi oil export capacity would be restricted to less than 7 million barrels per day by 2028 if domestic energy demand continued to rise at its current pace and that changes to energy prices may be needed to slow its growth. For other countries such as Algeria, Malaysia and Indonesia, whose production is already in or near decline, that transition begins very soon.

Source: Mitchell and Stevens (2008), "Ending Dependence: Hard Choices for Oil-Exporting States".

Nevertheless, regimes do eventually change due to inevitable unresolved difficulties such as the energy security and environmental concerns discussed in the previous chapter (Grubler, 2004). Several mechanisms influence such transitions (Geels, 2005). Firstly, changes in the socio-technical "landscape", including factors such as globalisation, environmental externalities and cultural changes, which can lead to wide ranging pressures on the existing regime that can open up opportunities for new approaches. Secondly, changes may occur in the socio-technical regime, including not just the physical aspects of the system such as generation plant and distribution networks, but also the rules embedded in institutions and practices. The regime is dynamically stable, but subject to pressures, either from "above" through landscape developments or "below" through technology developments. Thirdly, technological niches can play an important role. New technologies emerge and some develop within niche environments protected from the full effects of competition with the dominant technologies until conditions are right for them to trigger a wider shift in the regime.

Disruptions to the status quo arise through a process characterised by Schumpeter (1942) as "creative destruction" of the existing order, in which incumbent companies in the existing regime may fail in order to make space for new actors. Dosi (1982) points to the cyclical nature of such processes. As this process matures, the establishment of a new regime often shows also a process of stabilisation, with the development of new oligopolies creating economies of scale around the new set of technologies and rules.

There have been various attempts to influence these processes through a process of "transition management". One example of this is the energy transition project in the Netherlands, which is an explicit attempt to complement existing policies with a strategic long-term transition approach aimed at structural change, part of which involves using taxes and charges to level the playing field and then to foster diversity through creating space for niches but refrains from "picking winners". Such government initiatives can achieve a significant impetus for change, although they are not without risk of capture by the incumbent energy regime which may limit options for radical change of the energy system (Kern and Smith, 2008). In the words of Justin Lin, Chief Economist at the World Bank (Lin, 2010):

> *"...the failure of industrial policy is most likely to arise from mistakes made by policy makers in the growth identification process.... High-performing developed and developing countries are those where governments were able to play an active role in the industrial upgrading and diversification process by helping firms take advantage of market opportunities. They have generally done so by overcoming the information, co-ordination, and externality issues, and by providing adequate hard and soft infrastructure to private agents..."*

As well as responding to such outside pressures, the ease of transition in the energy system also depends on the adaptive capacity of the system to transform (Smith, Stirling and Berkhout, 2005). This adaptive capacity depends on the availability of resources such as alternative technologies, knowledge and capabilities, and governments can help to cushion the economic impacts of transition by investing in this capacity.

The broad range of literature on structural change suggests the following policy conclusions:

- Structural change involves not only a breakthrough of new technologies, but also corresponding shifts in the broader supporting system of infrastructures, supply chains, institutions, markets and regulations.
- The routes by which these transitions occur are hard to predict in advance, as they are the result of a series of complex path-dependent interactions between the many different components and actors in the system.
- An aim of policy should be to promote technological diversity, increasing the range of technological options available to the system in order to increase resilience in the face of uncertain future shocks.
- Innovation rates can be accelerated through sustained research and development (R&D) efforts combined with long-term consistent "landscape" changes such as carbon prices, and speedier retirement of old capital stock to accelerate the "creative destruction" process, aligned as far as possible with countries' latent comparative advantages.
- Technologies may need to be developed in niches before they can displace the dominant technologies in incumbent regimes, but transition is an inherently risky process. Failure of technologies and companies (both within and outside of the incumbent regime) is an important part of the experimentation, learning and creative destruction process, although politically difficult to engineer within a government-sponsored regulatory programme.

Experiences of structural adjustments in the energy sector

Structural adjustment relates to all aspects of the energy system, not just replacement of supply technologies. An important part of this system is the rule base on which electricity is bought and sold, which sets the incentives for suppliers to meet demand and invest in new capacity. Electricity market reform is an area where there is considerable international experience, and where results have been quite mixed (Dubash and Singh, 2005). Box 3.2 illustrates some positive effects of reform in India.

Box 3.2. Power sector reforms in India

India has struggled to provide reliable electricity supply to its population. Hundreds of millions in India still have no electricity, and those with electricity have unreliable access, usually only for a few hours per day. A major issue is the widespread theft of electricity by end-users. Every year about a third of the net electricity produced in India goes unaccounted. A large fraction of that is theft, along with poor technical management of the power supply system. Although India has initiated programmes to improve the electricity situation, the progress has been slow and limited to very few areas. For example, in Delhi, the use of advanced technology in power delivery and metering, as well as commercial incentives to power distributors has brought down the losses in the low-voltage electricity distribution from nearly 50% to 20% of the net supply in just five years (Central Electricity Authority).

A consequence of the Delhi reforms has been a significant reduction in growth rate of electricity demand, and hence, in carbon dioxide (CO_2) emissions. Rationalisation of tariffs and stricter compliant mechanisms mean that the end users are now more exposed to the true cost of power. As electricity distributors have used innovative technologies to crack down on theft, electricity demand in Delhi has grown much more slowly in the last 5 years (*i.e.* post reforms) than in the pre-2003 state-of-affairs, despite a much stronger economic growth in Delhi post-2003.

Our calculations indicate that power-sector reforms similar to Delhi, if replicated across India could lower India's CO_2 emissions by between 200 and 250 Mt CO_2/yr by 2017. This is equivalent to nearly 50% of India's total power-sector emissions in 2007 (520 Mt of CO_2) and about 6% of Europe's total emissions in 2006. Clearly, power-sector reforms will have a significant developmental impact in India by improving the access and reliability of the electricity system. Outsiders could help by co-funding efficiency improvement programs on a large scale across India. India could also be engaged early on in international efforts on advanced local-grid management systems that could enable further technical efficiency gains in India, under its "Electricity for all by 2012" programme.

Source: Rai and Victor (2010), "Identifying Viable Options in Developing Countries for Climate Change Mitigation: The Case of India".

Similarly positive impacts from combining revised incentive structures with technological improvements were experienced during China's major reform of the rural power management system in 1988. This was combined with rural grid enhancements, and helped reduce losses in low-voltage grids by 30–45% and consequently lowered electricity prices (Niez, 2010). Power market reforms have been widespread in Latin America and the Caribbean. Although these reforms may have fallen short of the full expectations of the market reformers, there have been significant accomplishments in moving away from politically-driven state-owned enterprises allowed to accumulate huge financial deficits towards improved incentive structures with tariffs that reflect actual costs, and raised efficiency levels. However challenges still remain in this region, notably in separating the various roles of the state and providing effective regulation, achieving competition in markets, and addressing the needs of the poor (Millan, 2005). On the other hand, in sub-Saharan Africa, electricity market reforms have been rather less successful, having generally failed to meet the required objectives of attracting investment, moving toward competition and achieving rural electrification (Wamukonya, 2005). And in the United Kingdom, electricity market reform introduced in the 1990s that was used as a template for reform in other regions is now having to be revisited to accommodate the significant structural shifts required to decarbonise the system.

Each of the above regions is trying to tackle different problems with different types of market reform. The collective experience indicates that good design can lead to positive outcomes, but that due to the dynamic nature of markets, reform is likely to be an on-going process as market players, regulatory regimes, technologies and consumer expectations adapt and evolve.

Industrial restructuring often involves a reorganisation not just within individual companies, but also across multiple companies and supply chains, and can lead to changes in the composition of trade (Hotopp, Radosevic and Bishop, 2005). This kind of specialisation of firms often goes together with geographical clustering, which has been an important feature of industrial organisation in the United States semi-conductor and automobile industries (Klepper, 2010).

This process has been evident in the rapid recent growth of Chinese wind power, where state intervention has helped create dedicated supply chains for clean energy applications. The bulk of investment in wind farms comes from the leading state-owned power generation enterprises (Liu and Kokko, 2010), despite the fact that wind power is not the dominant activity for any of these companies. The investments in wind power are primarily made in response to the requirement that all power generation companies must include a certain percentage of non-hydro renewable energy in their portfolios (Wang, 2010), and the expansion in the number of companies producing wind turbines has helped drive down costs and made China a major international player in the supply of turbines, but also leads to the potential for overcapacity (Liu and Kokko, 2010).

Following the success of export-oriented "special economic zones" earlier in China's economic restructuring, the government is now embarking on a number of "low-carbon zones", which aim to capture the benefits of clustering, not only in terms of clean energy supply, but perhaps more importantly in the wider systems, including buildings, transport and urban infrastructure. One example is Jilin City, which is currently dependent on heavy industry with less than 10% of production equipment being up to international or even national advanced standards. This move is expected to encourage international co-operation, attract potential business partners and enhance conditions for local innovation and technology development providing a demonstration ground for piloting and improving products which would later be exported to regional and global markets (Chatham House, 2010).

More generally, international research collaboration can be an important vehicle through which countries can share costs and increase knowledge spillovers. While this has often occurred international research collaboration has been common amongst OECD economies, it is interesting to note that for energy and climate technologies inventors in many emerging countries are collaborating with partners in the OECD. Table 3.1 shows the most active co-invention pairs for four environmental technologies (wind power, solar photovoltaic, energy storage and carbon capture and storage), as well as for all technologies combined. While major OECD economies dominate the latter the situation is much more mixed in the environmental fields, with emerging economies and small OECD economies in greater evidence. Indeed, geographical patterns of research collaboration are increasingly diverse.

Table 3.1. The top co-inventing country pairs for environmental and general technologies

Sector	1	2	3	4	5	6	7	8	9	10
All Technologies	GB-US	DE-US	CA-US	CH-DE	JP-US	FR-US	NL-US	DE-FR	CH-FR	CH-US
Wind	DK-GB	DE-US	CA-US	DE-NL	NL-US	DE-DK	IN-US	BE-**ZA**	**RU**-US	DK-ES
Solar PV	JP-US	DE-US	GB-US	CH-DE	AT-DE	CA-US	**CN**-US	DE-FR	DE-NL	GB-IT
Energy Storage	GB-US	CA-US	DE-US	JP-US	JP-KR	FR-US	CH-DE	CA-FR	**CN**-US	KR-US
CCS	CA-US	NL-US	GB-US	FR-US	DE-US	AU-NL	DE-GB	GB-NL	NO-US	**CN**-US

Note: Co-invention is measured as country of residence for patented inventions. Emerging economies are in bold.

Source: Kahrobaie, Haščič and Johnstone (2011), "International Research Collaboration in Climate Technologies: An Empirical Analysis of Technology Agreements" in *OECD Energy and Climate Policy and Innovation (forthcoming)*.

Given the potential benefits from international research collaboration it has been suggested that technology-oriented agreements may be a potentially useful means to complement emissions-based agreements at the international level. Measures that support international collaborative research activities across countries can be a helpful mechanism to encourage the development and diffusion of climate mitigation technologies internationally.

Renewables have also expanded rapidly in Europe in response to the introduction of targeted policy mechanisms. The policy approaches have varied across Europe, leading to a wide range of policy experience. This has led to significant learning about the design features of "investment-grade policy" that are needed to attract private finance to the renewable energy and energy efficiency sectors (Hamilton, 2009):

- To be "investment grade", policy needs to tackle all the relevant factors that financiers assess when looking at a deal. It must be embedded in wider energy policy, and be stable across the lifetime of projects. Investors need to be confident, in a policy-driven market, that governments are serious.
- A target, a fiscal incentive, or the availability of public finance alone will not be sufficient if there are cumulative high risks associated with other factors. Risk-adjusted returns must be commercially attractive.
- Different market characteristics of renewable energy subsectors, and energy efficiency, mean that policy needs to be well designed and precise. On its own, a blanket "low carbon" approach, or a carbon price, will not overcome specific market risks associated with differing technologies.
- Significantly scaling up renewable energy over the medium and longer term requires immediate government attention to the sequencing, planning and integration of the underlying infrastructure required to deploy renewable energy.

Stranded capital

Stranded capital refers to the situation where a plant becomes financially unprofitable to run due to changes in market or regulatory conditions. If this occurs early in the lifetime of the plant before it has recovered its capital costs, firms will lose money compared to the returns expected when they made the investment. In general, policy makers try to avoid regulatory changes that create stranded capital, as the negative impact on investors is likely to have a knock-on consequence on their willingness to invest in productive capital in the economy due to policy risk. This has an important influence on the rate at which policy makers may be able (or willing) to achieve decarbonisation in the energy system. The faster the rate of change, the more likely it is that plant will become stranded capital. The type of regulatory approach can also be important to the economic consequences for companies. Taxes and tradable permit systems that result in increasing costs over time can help smooth the transition, whereas environmental regulations based on enforcing absolute standards at individual plant level can lead to economic dislocations for those plants.

For capital to become fully stranded, the initial investment has to be irreversible, and designed for a particular outcome. Some technologies (such as the potential to retrofit end-of-pipe environmental clean-up technologies, or the ability to switch to lower-emitting fuels) can help reduce the degree to which assets may become stranded by increasing the plant's flexibility to operate under different regulatory conditions. Some plants are also inherently more flexible than others – for example, some coal-fired power generation plant may be more readily adapted than others to run with a fraction of biomass energy and/or have carbon capture and storage plant retrofitted at a later date once the economics become favourable. Such flexibility means that not all of a plant's value necessarily becomes stranded if regulatory or economic conditions change. However, in general at least some part of the asset value may nevertheless be at risk.

If companies know in advance what the emissions trajectory is going to be, then this stranded capital could perhaps be avoided. However, the political economy of stranded capital is complex. Whilst all energy companies know that there will be an eventual need to deviate from the business-as-usual path, the timescales for changing the emissions pathway (especially within a given country or regulatory regime) is quite uncertain. In theory, governments could allow companies to make losses on poor investment choices in the face of this uncertainty. However, in practice, energy sector investments tend to involve quite a high level of political involvement, so it may not be easy to separate political and commercial decision-making.

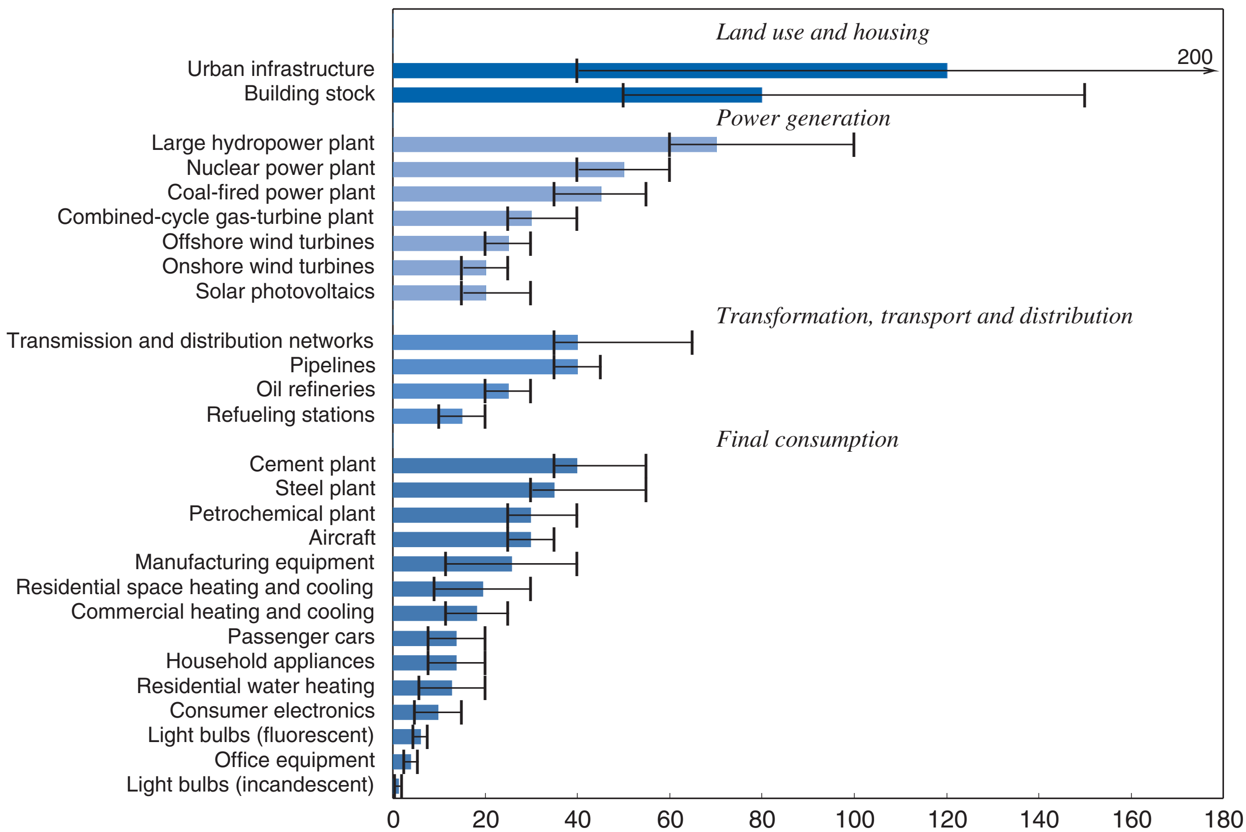
The relationship between states and large energy companies tends to be strong because of the size of many energy companies, and the strategic nature of energy as an essential input to the economy. In many countries, governments remain sole or majority shareholders of their major energy companies. Commercial investment decisions are therefore often closely tied to political decisions with respect to the development of the energy sector. If companies choose to invest in capital (such as fossil fuel-based power generation plant) that could be stranded at a later date by the introduction of new energy policies, then they are likely to have considerable political leverage to oppose such regulatory measures. This effect reinforces the need for creating clear policy signals as early as possible at national level as to the speed of transition in the energy sector.

The type of plant that is at risk of becoming stranded can also be affected by technological developments within the power sector. Odenberger, Unger and Johnsson (2009) show that gas-fired plant built over the next decade in Europe may become uncompetitive compared to coal-fired plant with carbon capture and storage (CCS) depending on the development of that technology after 2020.

Stranded capital will be most significant for long-lived capital plants. Figure 3.1 shows where these might be a particular problem. Infrastructure relating to the building stock and urban layouts are so long-lived, that the decarbonisation issue is not usually considered as a stranded asset problem, but rather a question of how to retrofit improvements, as complete replacements for these items are hardly feasible over reasonable timescales. But within these categories are areas where manufacturers face real dilemmas. Energy distribution systems (such as gas pipelines) could be at risk, as well as choices over transportation energy systems. Frenette and Forthoffer (2009) point out that vehicle manufacturer decisions regarding investment in the development of hydrogen fuel cells will be intimately bound up in long-term policy choices on infrastructure development because of the need to avoid creating stranded assets.

Figure 3.1. Capital stock turnover times for selected energy-related stock

Mean lifetime, years



Note: The bars show average lifetimes while the range lines show typical variations.

Source: IEA (2011), *World Energy Outlook 2011.*

Policy makers should therefore aim to encourage developers of long-lived new energy assets to build in flexibility as far as is economically possible to allow for changes in conditions of environmental regulations and wider economic conditions such as fuel prices. Uncertainty in these future conditions should automatically encourage companies to favour more flexible options, but policy makers can help for example by developing standards for flexible options such as capture-ready fossil fuel plant that could retrofit carbon capture at a later stage.

Ultimately policy makers will only be able to overcome these problems of lock-in if they are able to provide robust signals to companies regarding the pace of change that they should expect in relation to environmental regulation, and then ensure that this pace is consistently maintained. Decisions on the pace of change may take into account the degree to which stranded assets are likely to be created through the introduction of a given set of policies. However, policy makers should avoid creating an expectation that any existing plant will be protected from future losses arising from changes in environmental regulation. Such assurances would create a situation of moral hazard in which companies could continue to build plant that performs poorly in environmental terms, undermining the expectations of the rest of the market, and hampering efforts to enforce changes in the capital stock.

In addition to the electricity generation and gas supply infrastructure, the stranded assets problem also applies to fossil fuel resources that are in the ground. The IEA's *WEO-2011* puts remaining recoverable oil resources (conventional and unconventional) worldwide at nearly 5 500 billion barrels, with proven reserves amounting to about one-quarter of the total (IEA, 2011). The incentive to exploit this resource depends on the profit, based on the difference between market value and cost of production. As production is pushed harder to reach resources, costs would be expected to go up, and other technologies may start to compete, so not all of this resource may ultimately prove to be commercially exploitable. Nevertheless, to the extent that exploiting existing oil resources may be cheaper than the next available replacement technology, such a gap would need to be filled by incentives created through policy mechanisms.

From a political economy perspective, this has two implications. First, the potential for shifts away from oil dependence in the future could affect current production decisions to try to minimise stranded assets. This could encourage oil producers to accelerate current production if they believe that future demand (and therefore prices) will drop. Under conditions of uncertain future environmental costs, risk-averse decision-makers may decide to increase oil recovery rates in earlier periods compared to the socially optimal level (Dabirian and Wong, 1995). On the other hand, the opposite effect would occur for downstream oil infrastructure such as pipelines and refineries, where the substantial capital costs would present a barrier to accelerated development in the face of uncertain impacts of future environmental costs on oil demand.

Second, policy measures that imply leaving commercially viable oil underground will have to create incentives that are strong enough to counteract the incentives for exploiting that oil. Expressed in terms of a carbon price, USD 100/barrel equates to USD 240/tonnes of CO_2 (tCO_2). This does not mean that carbon prices would need to be this high to stop oil being pumped out of the ground – the required carbon price would need to reflect the cost differential between oil and its alternative. Some of these alternatives (such as demand-side measures to increase the efficiency of vehicles and appliances) could be relatively cheap. On the other hand, wholesale replacement of the existing transport fuel infrastructure with a green energy alternative implies very significant costs, implying the need for very robust policy frameworks in order to convince investors. As argued above, once a transition is complete, the problem of incentives may become less acute. For example, if the vehicle fleet and vehicle manufacturing base eventually moves away from petroleum-based fuels, then the system will be locked-in to a different regime, and so the question of pricing out oil becomes less significant. It is the incentives and politics during the transition that will be most difficult to manage. Nevertheless, such transitions are possible as a result of policy intervention. Box 3.3 describes the interventions taken in Brazil to drive the cost of ethanol as a transport fuel down the experience curve from being almost three times the price of gasoline in the early 1980s to being on a par or cheaper than gasoline by the late 1990s.

Box 3.3. Development of the ethanol market in Brazil

In the late 1970s, the Brazilian Federal Government mandated the mixture of anhydrous ethanol in gasoline (blends up to 25%) and encouraged car makers to produce engines running on pure hydrated ethanol (100%). Brazilian adoption of mandatory regulations determining the amount of ethanol to be mixed with gasoline (basically a Renewable Portfolio Standard for fuel) was essential to the success of the program. The motivation was to reduce oil imports that were consuming one-half of the total amount of hard currency from exports. But it was soon realised that the program had important environmental and social benefits. Conversion to ethanol allowed the phasing-out of lead additives and MTBE and reduced sulphur, particulate matter and carbon monoxide emissions. It helped mitigate greenhouse gas emissions efficiently by having a net positive energy balance. Subsidies for ethanol production are a thing of the past because new ethanol plants benefit from the economies of scale and the modern technology available today such as the use of high-pressure boilers that allow co-generation of electricity.

Source: Goldemburg (2007), "Ethanol for a Sustainable Energy Future".

Employment effects

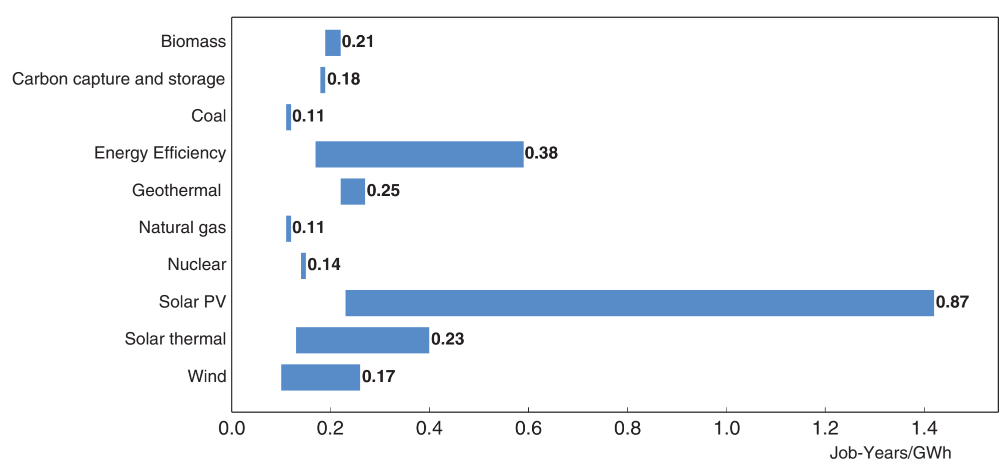
The energy sector is much larger in economic terms than in terms of employment. Whilst the total market value of energy products used globally accounts for around 10-15% of global GDP (depending on prevailing fuel prices), the energy sector's contribution to overall employment levels is only around 1-2% of the total global labour force. Restructuring the energy sector is therefore likely to have a relatively small impact on total global employment levels. Nevertheless, these direct changes are important to those in the energy sector, and are discussed first in this section. The section then considers the wider equilibrium effects across the economy.

Direct effects

In terms of direct employment effects within the energy sector of a shift towards green energy sources, there are a number of studies which indicate a positive net employment effect in the sector because of the higher labour-intensity of renewable energy production compared to fossil energy. In a review of 15 previous studies, Wei, Patadia, and Kammen (2010) find that for the United States, all renewable and low-carbon energy sources generate more jobs per unit of energy delivered than the fossil fuel sector. However, the type of employment differs between the technologies, with a shift from resource extraction to manufacturing for example, and the timing and location of employment within a region may vary. The estimated additional number of jobs created is expressed in job-years (i.e. the number of full-time equivalent jobs created with a duration of one year) per unit of electricity produced. The results shown in Figure 3.2 combine the additional jobs during the plant construction phase with the additional jobs associated with plant operation.

Figure 3.2. Range and average of direct employment factors for different energy technologies

Job-Years/ Gigawatt hour



Source: Wei, Patadia and Kammen (2010), "*Putting Renewables and Energy Efficiency to Work: How Many Jobs can the Clean Energy Industry generate in the U.S.?*"

Similar conclusions about positive direct employment impacts were found in a local fieldwork study carried out in Spain showing how renewable energy growth in Spain has led to growth in local businesses ranging from micro-businesses/small and medium-sized enterprises (SMEs) to large manufacturing companies dedicated to solar and wind technologies in Aragon (Llera Sastresa *et al.*, 2010).

At the European Union (EU) level, a study commissioned by the German Federal Ministry for the Environment, Nature Conservancy and Nuclear Safety (Jaeger *et al.*, 2011) concludes that 6 million additional jobs would be created as a result of increasing the stringency of the European Union greenhouse gas target from a 20% to a 30% reduction in emissions by 2020 relative to 1990. These jobs arise partly as a result of additional efforts to retrofit buildings and generally enhancing the built environment. Research by the Fraunhofer Institute and others (Ragwitz *et al.*, 2009) conclude that implementing renewable energy policies in Europe would lead to 2.8 million new jobs in renewable energy sector by 2020, and 3.4 million by 2030. Net employment (*i.e.* accounting for employment effects in the wider economy) in this study shows a positive employment increase in the short-term (to 2020), but a reduction in the longer term (to 2030) due to the increased costs of energy.

In the United States Stimulus bill, USD 41.4 billion (5% of the total allocation) was targeted to the clean energy industry; the two largest portions of that were put into energy efficiency and smart grid technology (Copenhagen Climate Council, 2009). Energy efficiency investments are estimated to create around 13 full-time equivalent jobs per million dollars invested into energy efficiency from direct installation and production of relevant materials alone, excluding the indirect effects resulting from an increase in disposable income households mentioned above. Smart grids are another promising vehicle for job growth and could create many permanent new jobs not only from direct utility jobs but from enhanced investment in infrastructure equipment manufacturing as well. The in-home devices that are needed to broker between power suppliers and consumers are another potential new market for manufacturers.

At the global level, a joint report for Greenpeace and the European Renewable Energy Council estimated that there would be 2.7 million more jobs created by a transition to a sustainable energy system than under a business-as-usual scenario in 2030, an increase of around 30% for the energy sector. Within this overall figure, there are much bigger shifts between sectors, with coal, gas and oil sectors losing around 2.5 million jobs, and the renewables sector gaining around 5.3 million under their clean energy scenario (EREC, 2010).

Economy-wide effects

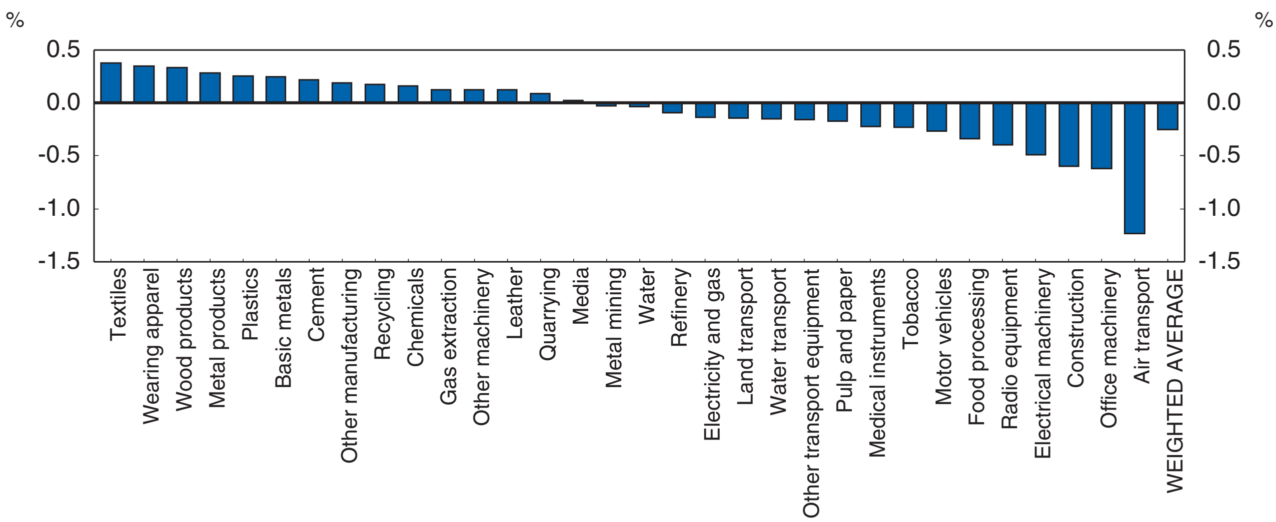
The evidence on the employment effects across the economy as a whole is mixed; with most research suggesting that the impact of green structural changes on the total level of employment is relatively small. One reason for the smaller net impact at the level of the entire economy is that a shift to greater use of renewable energy is often predicted to raise energy prices throughout the economy. Production and employment in other sectors of the economy can also be held down, when the energy sector absorbs more workers and greater investment in physical capacity. For example, some upward pressure on wages or interest rates could arise that would discourage job creation in other sectors.

Empirical studies on the effects of environmental regulation also tend to show rather inconclusive evidence regarding net employment effects. Enevoldsen, Ryelund and Andersen (2007) analysed the effects of energy taxes on eight sectors in seven European countries, and showed a slightly negative effect of energy taxes on competitiveness and output. However, Henderson and Millimet (2005), using a US sample found insignificant effects of environmental stringency on state-level output. Roland-Holst (2008) found that in California, energy efficiency measures have, enabled households to redirect their expenditures toward other goods and services, creating about 1.5 million full-time equivalent jobs with a total payroll of USD 45 billion, driven by well-documented household energy savings of USD 56 billion from 1972-2006.

Commins *et al.* (2011) uses firm-level data to look at the influence of carbon and energy taxes in Europe on employment levels, investment behaviour and productivity in European companies for the years 1996-2007. The average partial effect of a 1% rise in energy taxes on firms' employment for different sectors is shown in Figure 3.3. This illustrates very clearly that the rebalancing between sectors may be very much more significant than the total aggregate employment effect. These shifts in response to energy taxes could be used as a guide to the employment response to an equivalent increase in energy prices as a result of a move towards more sustainable energy technologies.

Figure 3.3. Effect on employment of a 1% increase in energy tax

% change in number of employees



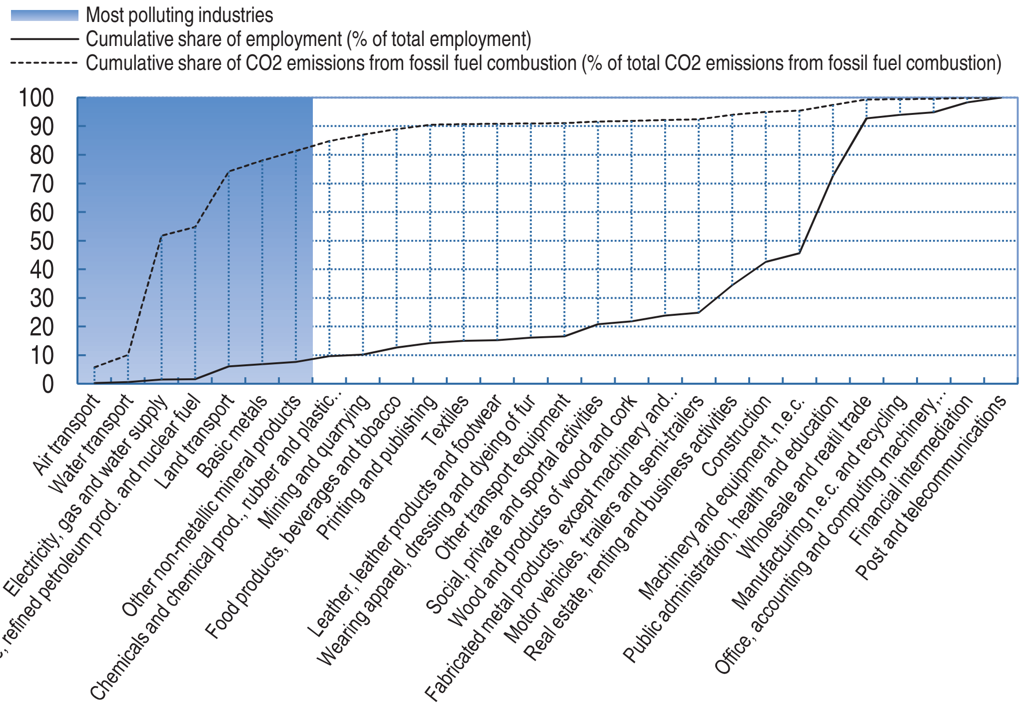
Source: Commins *et al.* (2011), "Climate Policy and Corporate Behaviour". Reprinted with permission from International Association for Energy Economics, Publishers of the Energy Journal.

As Figure 3.4 suggests, the potential adjustment associated with greening growth is likely to be concentrated on a small portion of the total workforce. Indeed, while the most intensely-polluting industries account for a large share of total CO_2 emissions, they account for only a small share of total employment. In 2004, on average across OECD countries for which data are available, 82% of CO_2 emissions in the non-agricultural sector were generated by these industries, whereas they employed less than 8% of the total workforce (OECD, 2011).

While there are conflicting views about whether any changes in total employment would be positive or negative, there are likely to be quite significant impacts in terms of shifting employment patterns between sectors as economic development shifts from "brown" to "green" economic sectors. Such changes could also have important geographical employment consequences, implying shifts in labour requirements between regions within a country, or even between countries, which could have significant political consequences.

Figure 3.4. Sectoral employment and CO_2 emission intensity

Unweighted average across 27 OECD countries, 2004[1]



1. Sectors are ranked by increasing CO_2 emissions intensity, defined as the ratio of CO_2 emissions to valued added. At the level of disaggregation shown in the chart, seven sectors stand out as being the most polluting industries: three transport sectors, two energy producing sectors and two manufacturing sectors.

Source: EU-LFS, GTAP database, KLEMS database.

The role of labour market policies

The impact of environmental taxes on employment is affected by how these taxes are integrated into the overall fiscal system. Some early research has noted the potential for a so-called "double dividend" that could be created by introducing environmental taxes which are then recycled to reduce labour taxes leading to an improvement in both employment and environmental quality (Repetto *et al.*,1992). Early general equilibrium models tend to show by contrast that environmental taxes interact with existing taxes to exacerbate rather than improve tax inefficiencies, implying that environmental regulation would lead to an overall increase in business costs, discouraging employment and investment (Bovenberg and de Mooij, 1994, Parry, 1995). However, extensions of these earlier models show that recycling environmental taxes can in fact have a beneficial effect on employment, but that this depends on the characteristics of the pre-existing tax regime (Bento, 2007). Applications of such models on a regional basis have indicated for example: that using carbon taxes to finance reductions in distortionary capital tax can lead to an overall growth effect (Takeda, 2007); that the recycling of energy taxes in Taiwan to offset income taxes would stimulate domestic consumption and investment (Bor and Huang, 2010); that that environmental taxation can bring economic benefits in Turkey when fuels are the primary source of pollutant emissions (Kumbaroglu, 2003).

Based on a cross-country multi-sector general equilibrium model, OECD illustrative simulation exercises[3] indicate that climate change mitigation policy has a limited impact on economic growth and job creation (OECD, 2011). In the presence of labour market rigidities, mitigation policy actually boosts employment growth when revenues from carbon pricing are used to reduce taxation on labour. For an intermediate degree of labour market rigidities, OECD employment would increase by 7.5% over the period 2013-2030, against 6.5% in absence of mitigation actions, and this, without any loss of purchasing power for workers.

The adjustment costs associated with the structural changes driven by green growth policies should be addressed through a carefully designed package of labour market and skill policies that can help the labour market be dynamic and inclusive. This includes education policies that enable workers acquire the training they need to move from declining to growing industries and firms. This should help to ensure that whilst there will be winners and losers in this transition, the adjustment can be achieved in a way that is consistent with appropriate social policies. In particular, OECD work on green growth draws attention three policy areas that should be given priority in order to promote a smooth, inclusive transition (OECD, 2011):

- A strong skill development system and active labour market programmes that facilitate a quick re-integration of jobseekers into employment are key supply-side policy elements for reinforcing the structural adaptive capacity of labour markets.

- On the demand side, moderate employment protection and strong product market competition are important supports for vigorous job creation as environmental policies and eco-innovation create new green competitive niches.

- Policies that increase the adaptive capacity of labour markets need to be combined with flanking measures, such as unemployment insurance and in-work benefits, which assure that dynamism is not achieved at the cost of excessive insecurity or inequality for workers and their families.

Distributional effects

Distributional effects are important to the political economy of energy transition because even if the overall costs of transition are modest, governments have to be careful to avoid any adverse effects for the poor, and any shift in wealth from one group to another tends to create political resistance. Distributional effects may also occur between countries associated with changes in patterns of trade in fossil fuel.

For countries with low levels of energy access, improving electrification rates can be one of the most significant ways of reducing energy poverty, and can bring important improvements in terms of distribution of wealth to poorer communities. Brazil has introduced programmes to expand the supply of safe and reliable energy to the poorest segments of society, including those living in remote rural areas. Pereira, Vasconcelos Freitas and da Silva (2011) show that rural electrification in Brazil leads to a significant reduction of the energy poverty level and a consequent improvement in energy equity. Similar conclusions have been reached for Bangladesh, (Barnes, Khandker and Samad, 2011) where 58% of rural households are energy poor, versus 45% that are income poor. They also suggest that policies to support rural electrification and greater use of improved biomass stoves might play a significant role in reducing energy poverty. Installing household photovoltaic (PV) in Ghana has led to reduced energy expenditure, and an increase in the number of children with access to lighting in those households (Obeng *et al.*, 2008). Creating suitable investment incentives for electrification however remains a challenge, as discussed in Box 3.4.

One of the key transitions that needs to be made in moving towards a greener energy system is to remove energy subsidies so that consumers make more rational choices in their energy use. Energy subsidies are typically in place in order to help poor people afford basic energy services. Despite the distortions created by energy subsidies, their removal is likely to be politically difficult without countervailing measures to offset the financial impacts on poor communities. An analysis of subsidy removal in Nigeria notes that subsidy removal, without spending of the associated savings, would increase the national poverty level (Nwafor and Asogwa, 2006). This is due to the consequent rise in inputs' costs which is higher than the rise in selling prices, and because petroleum products provide income for an extremely low number of households. Governments can alleviate this by spending the additional savings through transfers to households. This will tend to favour rural communities more than urban, but governments would have to balance the inflationary effects of such transfers.

The World Bank (2009) notes that government funding of energy subsidies creates a considerable drag on developing country economies, and that in fact most subsidies go to better-off consumers. This implies that subsidy reduction would not only be economically efficient, but could also be progressive if the savings were used to fund social protection that is better targeted to poor people. Given the magnitude of subsidies, there is comparatively little information on their beneficiaries. However, the scattered information that is available shows that these subsidies are not well targeted due to the relation between income and energy consumption. Most poor people in developing countries are not connected to the electric grid and do not own cars, so they get no direct benefit from fuel and gasoline subsidies. They do receive indirect benefits through lower prices of energy- intensive goods and services such as public transit. Nonetheless, a study by Coady *et al.* (2006) found that even when such indirect benefits are considered, the bottom 40% of the population in Bolivia, Ghana, Jordan, Mali, and Sri Lanka received only 15 to 25% of fuel subsidies.

This conclusion is supported by Gangopadhyay, Ramaswami and Wadhwa (2005) who show that LPG and kerosene subsidies in India prior to energy sector restructuring were mostly used by higher expenditure groups in urban areas, and that much of the subsidy was wasted because about half of the subsidised kerosene supplies is diverted and never reaches consumers. These findings suggest that the subsidies are very ineffective in improving the welfare of the poor. Similarly, Lin and Jiang (2011) show that in China, low-income households, who accounted for 22% of the total population, only shared 10% of the electricity subsidy to the residential sector. However, the top 9% of the population in terms of income received 19% of the subsidy. Redistribution of these subsidies to improve the social security system would have positive impacts on social welfare and macroeconomic variables.

The policy implication of these results is that whilst simply removing energy subsidies would be bad for the poor, there is an opportunity for government expenditure to be rebalanced away from energy subsidies which are not particularly effective at achieving progressive wealth distribution, towards more effectively targeted policies for poverty alleviation. Reallocating government revenues in this way would be more efficient and therefore lead to overall economic gains.

In higher income countries, the distributional impacts of energy pricing policies are rather different. Because most households have sufficient income to meet basic energy needs, the proportion of income spent on energy generally declines as income increases. This means that raising energy prices through for example energy and CO_2 taxes tends to increase costs disproportionately for the poorer sections of society in those countries. Denmark today has one of the highest rates of environmental tax in the world, bringing in around 10% of public revenues. Wier *et al.* (2005) indicates that while evaluations have shown that the Danish CO_2 and other environmental taxes work as an effective measure to reduce emissions, taxes imposed on energy consumption in households, as well as in industry, do in fact tend to be regressive, and therefore have undesirable distributional effects. As taxes appear to be regressive, governments should ensure that sufficient compensation measures are in place to reduce the undesirable distributional effects. The compensation can be introduced by reducing other types of taxation or creating transfer payments for specific groups.

On the other hand, Oladosu and Rose (2007) suggest that a CO_2 tax for one particular region of the United States would be mildly progressive because of the unevenly distributed sectoral output changes, as well as income and consumption patterns. The sectors affected most, both directly and indirectly, cause the impacts to be relatively greater on middle- and higher-income groups (*e.g.*, unionised coal miners, utility shareholders). This contrasts with the lower impacts on food, housing, and service sectors, which make up a larger portion of the consumption basket of lower income brackets. The decrease in business profits due to the imposition of the carbon tax reinforces the result because its incidence is felt more strongly by the upper income bracket. Policy makers therefore need to carefully consider their own particular economic structures when considering the distributional effects of their policies.

Much of the literature relating to distributional effects concerns the impact of policies that create explicit price effects, such as energy taxes, subsidies or permit systems. However, in general, all policies including direct regulation will have some distributional impact which can often be regressive. For example, Sutherland (2006) argues that appliance energy efficiency standards usually affect market choices by removing the low-end and less energy-efficient units from the market. Comparatively wealthy consumers apparently purchase about the same appliances as they would in the absence of energy efficiency standards, and hence suffer minimal losses. However, comparatively poorer consumers find their preferred choices eliminated from the market via government energy efficiency standards, which necessarily makes these customers worse off. Such regressive measures may not always create a very vocal opposition, but policy makers should nevertheless be mindful of these effects, particularly the extent to which they can accumulate to create significant effects over multiple regulatory interventions.

Box 3.4. Creating investment incentives in Nigeria

Investment in clean energy systems in Africa has been relatively low, reflecting not only weak incentives for sustainable energy investment in particular, but a much weaker investment environment in general. An example of this is the electricity system in Nigeria which currently has a chronic lack of generation and distribution capacity (only around 5 GW for a population of 140 million people, compared with around 75 GW in the United Kingdom for less than half the population). Electricity needs are often met with local diesel generators. A reliable electricity system in Nigeria has been identified as one of the most important infrastructure developments required to enable economic growth. Local banks do not have a strong track record of debt financing for energy projects, although some deals were being put together prior to the financial crisis with up to 25% debt funding from Nigerian commercial banks (Taylor, 2009). Despite the good prospects for growth (and therefore financial returns), the project risks are high because of the structure of the Nigerian power market.

One of the key reasons for the chronic under-investment in the power sector is that electricity tariffs are set too low to be able to recoup the capital costs of projects in the power sector. This means that not only is there no incentive for independent power producers (IPPs) to enter the market, but the state-owned Power Holding Company of Nigeria (PHCN) does not have the finances to invest either. The policy response to this situation has been to propose that the tariffs would be stepped up over a number of years to a level that would be able to attract investment.

In such circumstances, there can be a strong role for public international financial institutions (IFIs). Direct co-financing of energy projects by IFIs can help gear up private-sector investment by providing a degree of political insurance, since recipient governments will be perceived as less likely intervene (*e.g.* by appropriating assets) if the project is backed by a major institution such as the World Bank which has a financial relationship with the host country. The major development banks are all involved in significant programmes for promoting clean energy investment. (For example, for a review of development banks' activities in the area of energy efficiency financing, see UNEP-FI (2009), "Energy Efficiency and the Finance Sector".)

A different category of distributional effects of a transition towards a low carbon economy are associated with the balance of trade between countries, especially between importers and exporters of fossil fuels. The Organization of the Petroleum Exporting Countries (OPEC) has argued during international climate negotiations that a global energy transition would lead to lower incomes because, all else equal, the total volume of oil consumption would be lower in a carbon constrained world. This conclusion is drawn in modelling by Ghanem, Lounnas and Brennand (1999), and van Vuuren *et al.* (2003) similarly show that the costs to oil exporting regions from lost oil revenues could be of a similar order of magnitude to the direct costs of climate mitigation policies, with oil trade from Middle East countries reducing from over EUR 400 billion under their baseline scenario in 2050 to around EUR 260 billion under their 550 ppm scenario. *WEO-2010* suggests a slightly smaller decline, with OPEC incomes around 16% lower in the 450 ppm scenario than the New Policies scenario in the period 2010-2035.

Not all studies come to this same conclusion however. Persson *et al.* (2007) suggest that because of the constraints on supply of conventional oil outside of the OPEC region, marginal supplies in the global oil market will in future tend to come from heavier and more polluting sources such as tar sands and coal-to-liquids. Since a carbon tax would increase the cost of such sources more than conventional oil, this would allow oil exporting regions to increase the level of rents charged. This result does not however hold if there is a wholesale shift away from liquid fuels for transportation, for example towards electric vehicles.

Notes

1 Based on a simple 7% annual discounting rate.

2 Of which, 40GW is located in South Africa.

3 The illustrative policy scenario applied in the modelling is an emission trading scheme which, over the period 2013-2050, progressively reduces greenhouse gas emissions in the OECD area as a whole by 50% in 2050 as compared to their 1990 levels. The target is less stringent for non-OECD countries: emissions are reduced by 25% in 2050 as compared to what would be observed in these countries in the absence of mitigation efforts, under the so-called business-as-usual (BAU) scenario. Moreover, these countries do not participate in the OECD cap-and-trade scheme and, hence, undertake their emissions reductions independently. This scenario does not account for any inefficiency in BAU or the welfare gains from avoiding damages from climate change.

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Chapter 4. Monitoring progress towards green growth

Developing and implementing green growth policies in the energy sector requires appropriate information and indicators to support policy design and analysis and monitor progress. The OECD has developed a conceptual framework for monitoring progress towards green growth. While the set of indicators is still being refined, indicators pertinent to the energy sector are those that measure the carbon-productivity or intensity of energy production and consumption, energy intensity and efficiency, "clean" energy-related research and development and patents, as well as measures of energy related taxes and subsidies.

This needs to be complemented with (i) end-use indicators that help policy makers understand how users will respond to changes in energy prices, income, technology, energy efficiency, production patterns, and lifestyle, (ii) additional energy-environment indicators, and with indicators characterising the level of access to energy.

While energy statistics are well established in countries and at international level, measuring energy efficiency and innovation is difficult, and coherent industry level information is scarce. More needs to be done to improve data quality, methodologies and definitions, and to link the data to economic information.

Developing and implementing framework conditions that promote green growth in the energy sector requires a good understanding of the energy-environment-economy relationships and of related trade-offs or synergies. It also requires appropriate information and indicators to support policy design and analysis, identify ineffective or no longer needed measures, and monitor progress. Well-designed, operational sets of indicators are key to monitor trends and structural changes, and gauge how well policies are performing with respect to green growth. Ultimately, the indicators need to be capable of sending clear messages which speak to policy makers and the public at large.

This section looks at possible ways to monitor progress towards green growth related to energy, building on existing work in the OECD and the International Energy Agency (IEA). First, it provides an overview of the OECD's measurement framework for green growth and of the proposed energy-related indicators. It then dwells upon a few topics and indicators of particular relevance to energy, *i.e.* the carbon dioxide (CO_2) intensity or productivity of energy use, technology and innovation, the CO_2 intensity of electricity production, the efficiency of energy end-use, and energy poverty.

The indicators presented and discussed here are neither final nor exhaustive. They require further elaboration and efforts to improve data quality, methodologies and definitions.

The OECD framework for green growth indicators

The OECD has developed a conceptual framework for monitoring progress towards green growth, and for identifying relevant indicators for OECD countries and major emerging economies (OECD, 2011a). The framework is of a general nature; it comprises four inter-related groups of indicators that capture the main features of green growth: the environmental and resource productivity of production and consumption; the natural asset base; the environmental dimension of quality of life; the policy responses and economic opportunities. They are complemented with indicators describing the socio-economic context and characteristics of growth (Box 4.1).

A preliminary selection of indicators was made on the basis of existing work in the OECD and elsewhere, considering the indicators' policy relevance, analytical soundness, and measurability. The set has been kept flexible so that countries can adapt it to different national contexts. Further work will aim at refining the indicator set and selecting a small set of "headline" indicators that track central elements of the green growth concept and that are representative of a broader set of green growth issues. This will help conveying clear messages to policy makers, the media and citizens.

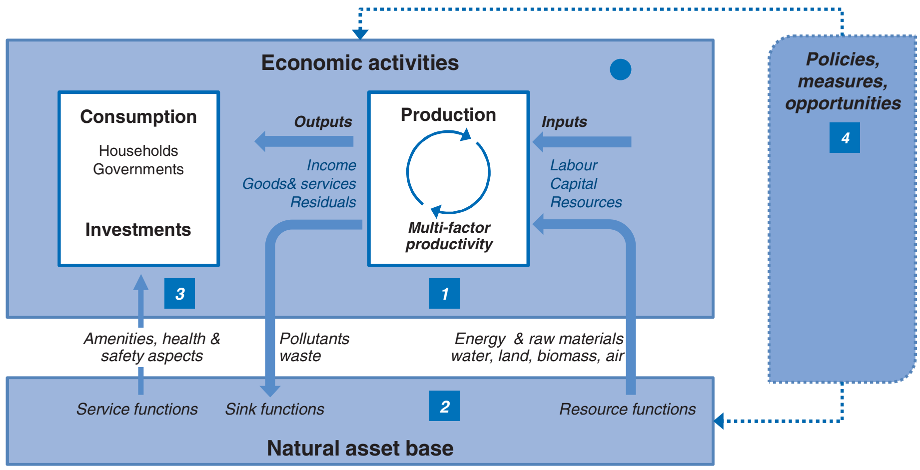
Energy related green growth indicators

Energy is a major component of the economy, both as an industrial sector in itself and as an essential factor input to most other economic activities. Through its effects on the environment, energy is one of the key variables of sustainable economic development and green growth. Fuel combustion is the main source of air pollution and greenhouse gas emissions; other energy activities, including energy production, transformation and distribution, have major water pollution, land use and other environmental effects. Covering these dimensions and interactions requires a sufficient number of indicators to do justice to the issues at hand.

The proposed OECD set of green growth indicators includes several indicators that are directly pertinent to energy (Table 4.1). The measurement framework and its four dimensions can also be used to identify additional, more specific indicators related to energy and the energy-environment linkages, building on existing OECD and IEA sets (*e.g.* the IEA scoreboard and energy efficiency indicators for industry, and the OECD set of indicators to monitor the integration of environmental concerns into energy policies developed in cooperation with the IEA (OECD, 1993)).

Box 4.1. The OECD framework for monitoring progress towards green growth

The measurement framework



Indicator groups and topics covered

1 The environmental and resource productivity of the economy	• Carbon and energy productivity • Resource productivity: materials, nutrients, water • Multi-factor productivity
2 The natural asset base	• Renewable stocks: water, forest, fish resources • Non-renewable stocks: mineral resources • Biodiversity and ecosystems
3 The environmental dimension of quality of life	• Environmental health and risks • Environmental services and amenities
4 Economic opportunities and policy responses	• Technology and innovation • Environmental goods & services • International financial flows • Prices and transfers • Skills and training • Regulations and management approaches
Socio-economic context and characteristics of growth	• Economic growth and structure • Productivity and trade • Labour markets, education and income • Socio-demographic patterns

Source: OECD (2011), *Towards Green Growth: Monitoring Progress: OECD Indicators.*

Table 4.1. Energy-related indicators in the proposed OECD set of green growth indicators

Group/theme	Proposed energy-related indicators
Environmental and resource productivity	
Carbon & energy productivity	**CO_2 productivity** Production-based and demand-based CO_2 productivity (GDP or real income per unit of energy-related CO_2 emitted) **Energy productivity** Energy productivity (GDP per unit of Total Primary Energy Supply, TPES) Energy intensity by sector (manufacturing, transport, households, services) Share of renewable energy (in TPES, in electricity production)
Natural asset base	
Non-renewable stocks	**Mineral resources** Available (global) stocks or reserves of selected minerals (to be determined): metallic minerals, industrial minerals, fossil fuels, critical raw materials; and related extraction rates
Environmental quality of life	
Environmental health and risks	No specific energy related indicator proposed under this heading
Environmental services and amenities	Could include an indicator on access to energy and energy services
Economic opportunities and policy responses	
Technology and innovation	**Research and Development (R&D) expenditure of importance to green growth (GG)** - Renewable energy (in % of energy related R&D) - Environmental technologies (in % of total R&D, by type) **Patents of importance to green growth** Environmentally related patents, including electric and hybrid vehicles, energy efficiency in buildings and lightning, renewable energy (in % of country applications under the Patent Cooperation Treaty)
Environmental goods and services	**Production of environmental goods and services (EGS)** 1.1. Gross value added in the EGS sector (in % of GDP) 1.2. Employment in the EGS sector (in % of total employment)
International financial flows	**International financial flows of importance to GG** (in % of total flows; in % of Gross National Income) 1.3. Official Development Assistance 1.4. Carbon market financing 1.5. Foreign Direct Investment (to be determined)
Prices and transfers	**Environmentally related taxation** Level and structure of environmentally related taxes (by type of tax base) **Energy pricing (share of taxes in end-use prices)** *To be complemented with indicators on:* • *Environmentally related subsidies (to be determined)* • *Environmental expenditure: level and structure*

CO_2 intensity and productivity

About 84% of CO_2 emissions are fossil fuel combustion related while about 65% of the total basket of all greenhouse gas emissions can be attributed to energy supply and use. Energy is a driver of economic activity and is widely measured, at least at production and aggregate consumption levels.

Two of the proposed key indicators relate to greenhouse gas and CO_2 emissions from domestic production and consumption. These indicators can be expressed as productivity or intensity ratios, by relating emissions to measures of production or consumption, or as decoupling trends showing the two variables separately. The ratio between CO_2 emissions from production and GDP is a widely used indicator. It brings together several aspects related to the environmental efficiency of production and is a prime indicator of relative decoupling between carbon from fossil fuel use as an input and domestic production. The CO_2 intensity of production is also representative of other environmental issues, in particular emissions of greenhouse gases and to some extent air pollution, which are correlated with the carbon intensity of economic production.

Two caveats with *production-related measures* have to be kept in mind:

1. An indicator of relative decoupling expressed as a ratio gives no indication whether environmental pressure has actually decreased or not, let alone whether this pressure is compatible with sustainable management of natural assets. A similar point applies from a growth perspective. The evolution of emission intensity over time provides little insight into whether there has been any economic growth or not: GDP could simply be contracting at a slower rate than greenhouse gas emissions, leading to an increase in the indicator. The conclusion is that the evolution of the two components of the greenhouse gas intensity measure should be separately identifiable. The ratio itself could give an indication about the greening of production and about structural economic shifts, but not necessarily about the greening of growth.
2. A decline in the emission intensity of production gives no indication of whether such a reduction has been achieved through genuine efficiency improvements or changes in the energy mix, or by substituting away from energy-intensive production through purchases of carbon-intensive intermediate products abroad, among a number of other explanations.

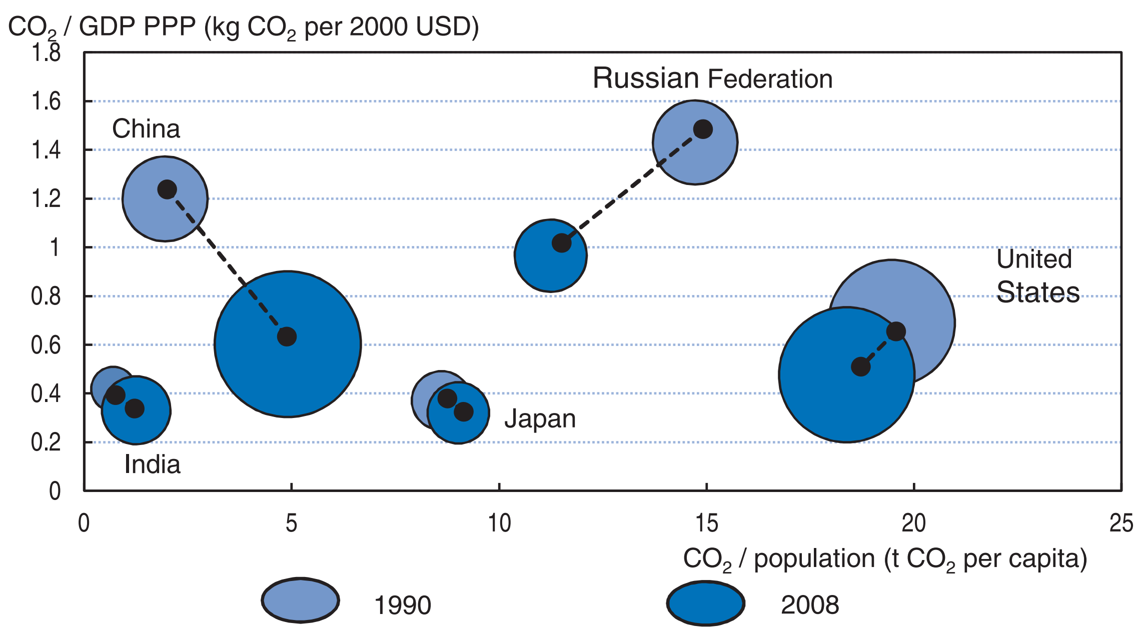
This is where demand-based measures of CO_2 intensity or productivity come in. The associated possible indicator compares the evolution of demand-based CO_2 emissions with the evolution of economic growth. To compute demand-based emissions, the emissions embodied in imports of goods from abroad are added to the emissions from domestic production, and the emissions embodied in exports are deducted. The resulting figure informs about the direct and indirect contents of environmental services in domestic final demand – essentially consumption of households, governments and investment. From such computations arises new and complementary information on countries' respective contributions to pressures on the environment.

When taking a demand perspective, a measure of income other than GDP should be considered, for example real disposable income that reflects income flows in and out of a country and is expressed in equivalent consumption units.[1] Putting it in relation to demand-based CO_2 emissions indicates the emission-intensity of the generation of one real unit of income. Both the OECD and the European Commission advocate for a measure beyond GDP such that a nation's progress is measured not only by an increase in commercial transactions but by an increase in general well-being and protection of the ecological commons.

CO_2 emissions linked with socio-economic indicators are sometimes used in cross-country comparisons. Figure 4.1 shows trends in CO_2 intensity for the top five countries. In 2008, the largest emitters (China, United States, Russian Federation, India and Japan) comprised 45% of the global population and together produced 55% of the global CO_2 emissions and 50% of the world GDP. However, the relative shares of these five countries for all three variables were very diverse.

In the United States, the large share of global emissions in 2008 is associated with a commensurate share of economic output, the largest in the world. Japan, with a GDP more than double that of the Russian Federation, emits 28% less CO_2. Although climate and other variables also affect energy use among countries, relatively high values of emissions per unit of GDP indicate a relative higher potential for further decoupling CO_2 emissions from economic growth. Possible improvements can derive from fuel switching from carbon-intensive sources or from energy efficiency at all stages of the energy supply chain (from fuel extraction to energy end-use). Among the five largest CO_2 emitters in 2008, China, the Russian Federation and the United States have significantly reduced their emissions per unit of GDP between 1990 and 2008. The other two countries, India and Japan, already had much lower emissions per GDP.

Figure 4.1. Trends in CO_2 emission intensities for the top five emitting countries



Note: Size of circle represents total CO_2 emissions from the country in that year.

Source: IEA (2010), *CO_2 Emissions from Fuel Combustion*.

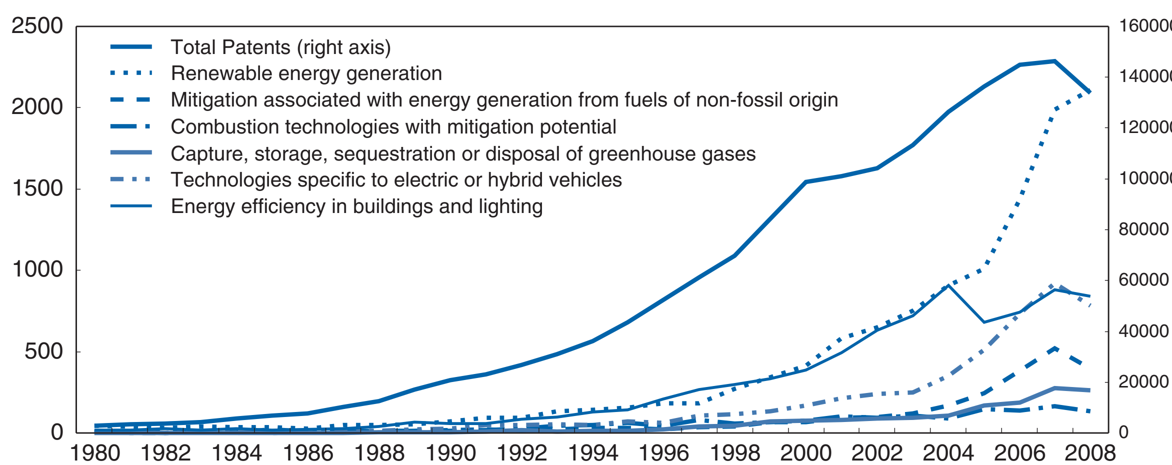
Technology and innovation

Innovation is clearly central to the idea of green growth and its role is described in a recent OECD report *Fostering Innovation for Green Growth* (OECD, 2011b). Innovation drives multi-factor productivity change, and so helps decoupling of outputs from inputs in general. General innovation has to be distinguished from green innovation. The latter is a particular aspect of the former and mainly relates to environmentally-related research and development and technologies. Thus, looking at green innovation will only tell part of the story that innovation at large plays in the transition to green growth. A trade-off arises from the perspective of constructing green growth indicators. Focusing on green innovation indicators does not do justice to the full importance of innovation, but general indicators of innovation are not very helpful in monitoring society's responses to the green growth challenge. The choice fell on indicators of green innovation such as patenting activity in environmental technologies but their specific nature has to be kept in mind when discussing the role of innovation in green growth.

Building from the Patent Database[2], recent OECD analysis looks at the generation and diffusion of selected climate change mitigation technologies and their respective links to key policies. The data covers a selection of relevant technology fields and all countries over the last 30-35 years. The evidence indicates that the rate of innovation has accelerated for many of these technologies, coinciding approximately with the passage of the Kyoto Protocol.[3] This is particularly true of those technologies that were closest to being competitive, *i.e.* wind power, some solar power, biofuels, geothermal and hydro. Patent activity for other technologies, *i.e.* carbon capture and storage showed declines, even in comparison with the rate of patenting in general and for other energy technologies (Haščič *et al.,* 2010).

Figure 4.2. Trends in climate mitigation innovation trends

Patents filed under the Patent Cooperation Treaty by inventors residing in OECD countries



Note: For search strategies and methodology see www.oecd.org/environment/innovation/indicator.

Source: OECD (2012), *Energy and Climate Policies and Innovation* (forthcoming)

As with other areas, there is no single indicator of innovation that would capture both the process of innovation and major aspects of innovation policy. But some indicators emerge as particularly relevant from a policy perspective and one of them is public investment in research. Research can help to address fundamental scientific challenges and foster technologies that are considered too risky, uncertain or long-gestating for the private sector. The IEA tracks government research, development and demonstration (RD&D) expenditure in member countries for energy efficiency and energy sources and compares those levels with total RD&D spending (See Figure 2.4). As well, public spending on low-carbon energy RD&D for about nine technologies, energy efficiency in industry and buildings, carbon capture and storage, and smart grids are available through IEA statistics and could be useful in the development of green growth indicators for the energy sector.

Data on RD&D and patenting of environmental technologies provide some insight on the upstream aspects of green innovation. Information on the financing of clean energy technologies involving risk or equity capital can help to assess innovation that is moving closer to commercial application in the marketplace. Available data on venture capital investment in green technology shows strong growth in recent years. Nearly a quarter of all venture capital investment in the United States went to clean energy technology in 2010, compared with less than 1% in 2000. The key areas were solar power, transport, energy efficiency, biofuels, smart grids and energy storage. Monitoring these trends can inform policy makers, RD&D actors and green entrepreneurs. The data are readily available from Cleantech Market Insight (2011) and Bloomberg New Energy Finance (2011).

CO_2 intensity of electricity production

Monitoring the carbon intensity of electricity can shed light on progress towards a greener engine for economic and social development. Since electricity supply and demand must be balanced at all times, an increase in demand is the ultimate driver of the increase in production.

Worldwide electricity generation increased 70% from 1990 to 2008 and its associated CO_2 emissions by 66%. Electricity production accounted for 41% of global CO_2 emissions in 2008 (IEA, 2010).

In the electricity generation sector, if all countries produced electricity at current best practice levels of efficiency then fossil fuel consumption for electricity generation could be reduced by between 23% and 32% (IEA, 2010). The largest savings of both fuel and CO_2 emissions are from improving the efficiency of coal-fired plants.

Clearly, monitoring trends related to choice of technology in new plant construction; fuel switching; efficiency improvements from technical fuel savings; and reductions in transmission and distribution line losses could provide useful insights on progress to a low-carbon electricity supply. Electricity is an energy carrier that faces huge increases in demand in the near and long term. Reducing losses in transport and distribution as well as improving the efficiency of plants will be particularly important.

The electricity sector is well covered in energy balances at national and international levels. However, improvements in the quality of data is needed, especially in terms of power plant inputs and outputs, use of renewables to generate power, electricity generation and use from auto-producers and combined heat and power. Time series data for CO_2 intensity, measured as grammes (g) of CO_2 per kilowatt-hour, for 140 countries by region and individually, and by sector (manufacturing, transport, etc.) as well as by the three major fossil fuels are published annually by the IEA (IEA, 2010). They provide readily available trend data for taking the pulse of progress in green growth strategies at global, regional and national levels.

Energy end-use indicators: Unravelling the complexity of energy consumption

Energy end-use indicators delve deeper than highly aggregated statistics and the correlation over time between energy demand and economic activity as measured by GDP. While energy demand rises with economic growth almost everywhere, the significant part of the story lies in how this coupling varies from sector to sector, from country to country and from period to period. It is important to understand how energy users respond to a host of variable factors with specific impacts: energy prices; income; technology; energy efficiency; structural changes in the mix of goods and services demanded and produced; and changes in levels of mobility and comfort that people either have or aspire to.

Energy end-use indicators, for example, show an important shift in the 1970s and 1980s from direct use of fossil fuels to electricity and the consequent development of a strong link between GDP growth and electricity consumption. Broad indicators also reveal how the oil price crises in those times deeply affected the use of fossil fuels through price effects which resulted in much fuel savings. [4]

Economic growth in OECD countries in recent decades has increased personal wealth and created many new opportunities for individuals. People travel more and own more and larger cars. They have more spacious and comfortable homes, with a greater number and variety of appliances. They enjoy a greater range and higher quality of shops, leisure facilities, schools, hospitals, and other services. This is all good news. But it has also created greater demand for the services that energy provides, *e.g.* heating and cooling, lighting, transportation. Increased service demand need not have led to a rise in actual energy use, provided that, among other factors, improvements in energy efficiency kept pace. However, this was not the case. In fact, since 1990 the rate of improvement in energy efficiency has been about half of what it was in the two previous decades (IEA, 2009a).

We are increasingly aware of the urgent need to make better use of the world's energy resources and move to more sustainable and greener development paths. Improved energy efficiency is often the most economic and readily available means to do that. What progress are we making in efforts to improve energy efficiency? Why are countries' energy intensities so different? And how can the introduction of best available technologies help reduce energy use? To answer these questions, the IEA has developed in-depth indicators – tools that provide state-of-the-art data and analysis on energy use, efficiency developments and CO_2 emissions.

There are some signs that the rate of improvement in energy efficiency has been increasing slightly in the last few years, as a result of the many policies initiated. In addition to these recent improvements, there remains a large potential for further energy savings across all sectors. For instance, analysis shows that the application of best available industrial technologies and practices on a global scale could save between 18% and 26% of current energy use in industry. The largest savings potentials can be found in the iron and steel, cement and chemical and petrochemical sectors (IEA, 2009b).

To facilitate the reporting of comparable data, the IEA has worked with the ODYSSEE Network (European Union) and the Asia-Pacific Economic Cooperation (APEC) to develop a standard energy efficiency indicators template. The template establishes uniform system boundaries, data definitions and methodologies specific to energy consumption and related data. Early use of this template by select countries has allowed the IEA secretariat to define a series of disaggregate energy indicators that aim to capture key data relevant to each major sector. The information collected through the template is used to develop energy and energy efficiency indicators that explain the changes in energy consumption over time. As an example, key energy and efficiency indicators for the industry sector and their purpose and limitations are presented in Table 4.2.

Generally, these disaggregate indicators probe deeper than energy balances by focusing on activity levels, structural effects, energy efficiency trends and potential for future energy savings. They provide a much more effective means of tracking the evolution of energy use within a country and conducting comparative analyses. They can help to identify emerging trends and the underlying factors in end-use sectors. Disaggregate indicators also help to spot opportunities for improving energy efficiency. Thus, indicators can be used both to shape priorities for future actions and to monitor progress.

In taking forward the indicators to monitor progress, the most urgent need is to improve the availability, timeliness, quality and comparability of the underlying data. The situation is most challenging for non-OECD countries, with little or no detailed data available for most countries. Data quality and comparability also still need to be improved in OECD countries, particularly for the industry sector.

Table 4.2. Key indicators to understand trends in energy and energy efficiency in industry

	Indicator	Data required	Purpose	Limitation
ENERGY AND ACTIVITY INDICATORS	Total industry energy consumption by energy source	Total industry energy consumption by energy source	Insights on the role of the final energy mix on total final energy consumption. Insights on the trends in CO_2 emissions.	• Observed energy trends not necessarily a result of improved (or worsening) energy efficiency. • One element, amongst many others, influencing trends in energy consumption. • Can be attributed to changes in relative fuel prices, shifts in industry structure and processes and implementation of environmental legislation that favours the use of cleaner fuels.
	Energy consumption by industry sectors and by energy source	Energy consumption by industry sectors and by energy source	Explain the role energy mix played on the trend in energy consumption in each industry. Insights on the trends in CO_2 emissions. Not influenced by industry structure when develop at a much disaggregated level.	• Observed energy trends not necessarily a result of improved (or worsening) energy efficiency. • Influenced by changes in relative fuel prices, shifts in industry processes and implementation of environmental legislation. • Influenced by industry structure if develop at an aggregate level (*e.g.* 2-digits International Standard Industrial Classification (ISIC)).
	Composition of industry value-added (in constant currency)	Value-added in constant currency by industry sector at the 2-digit ISIC level (or more detail)	Provide information on the relative importance of each sector. Insights of the impact of the structure of the industry on energy consumption. Qualitative information helping to explain trends in energy consumption.	• Value-added are influenced by a range of pricing effects unrelated to changes in the level of physical production. • Composition of industry value-added, at 2-digit ISIC level, may hide some important structural shift within an industry sector. • Does not provide the link between value-added and energy required to quantify the impact of the structural change.
	Total industry energy consumption by unit of value-added	Total industry energy use Total industry value-added (in constant currency)	Reflects the trends in overall energy use relative to value-added. Indicates the general relationship of energy use to economic development.	• Influenced by factors such as geography, climate and structure of the economy. • Changes over time are influenced by factors not necessarily related to energy efficiency.
	Industry sectors energy consumption by unit of value-added	Energy consumption by industry sector Corresponding value-added (in constant currency)	Indicate the general relationship of energy use to economic development.	• May hide some important structural shift within an industry (but this impact will be somewhat offset by using more detailed energy and value-added data). • Value-added are influenced by a range of pricing effects that are unrelated to changes in the underlying physical production.

Table 4.2. cont. Key indicators to understand trends in energy and energy efficiency in industry

	Indicator	Data required	Purpose	Limitation
ENERGY EFFICIENCY INDICATORS	Industry sector energy use by unit of physical production	Energy consumption by industry sector Corresponding physical unit of production	Often called the "specific" or "unit energy" consumption. Indicate the relationship of energy use to physical production. At the disaggregated level, can give a better measure of the technical efficiency of a particular production process.	• It is not possible to compare indicators defined in differing unit. • Cannot provide an aggregate picture of energy efficiency for the whole of industry.
	Decomposition of changes in industry energy consumption	Energy consumption by industry sector and energy source Corresponding physical unit of production (if available) Corresponding value-added (in constant currency)	Quantification of the factors underlying the changes in energy consumption over a defined period of time. Changes in energy consumption are decomposed between industry structure effect, energy mix effect, and specific intensity effect (a proxy of energy efficiency) This is the best indicator for total industry that can be developed with the data required in the IEA energy efficiency indicators template.	• This proxy for energy efficiency still includes effects that are not related to technical efficiency (such as the impact of climatic conditions and the change in the processes used within a facility).

Source: Trudeau and Murray (2011), *Development of Energy Efficiency Indicators in Russia*.

Energy access as an indicator of human development

In addition to measuring indicators of linkages between economic growth and environmental integrity, green growth aims for qualitative gains in both of those dimensions and in social welfare. In OECD countries the path is to decouple growth from environmental degradation while expanding eco-friendly goods and services and improving well-being. In developing countries, the path aims to provide significantly greater economic and social standards without exceeding natural capital carrying capacity. Monitoring energy access is one measure of progress for those countries.

Access to modern forms of energy is necessary for poverty reduction, including through the provision of clean water, sanitation and healthcare. It provides enormous benefits to development through the provision of reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunication services.[5]

Two indicators of energy poverty - the lack of access to electricity and reliance on traditional use of biomass for cooking - are revealing. According to the IEA's *WEO-2011*, 1.3 billion people – nearly 20% of world population – currently lack access to electricity and about 2.7 billion people – 40% of the world population – rely on the traditional use of biomass for cooking (IEA, 2011a). The outlook suggests that the problem will persist and even deepen in some places. The IEA and World Health Organization estimate that household air pollution from the use of biomass in inefficient stoves would lead to more than 4 000 premature deaths per day in 2030, greater than estimates for premature deaths from malaria, tuberculosis or Human Immunodeficiency Virus (HIV)/Acquired immune deficiency syndrome (AIDS) (IEA, 2011a).

The Energy Development Index (EDI) (IEA, 2011b) tracks developing countries in their progress towards modern energy access. The index seeks to capture the quality of energy services as well as their quantity. It is calculated in such a way as to mirror the United Nations Development Programme's Human Development Index. Annual updates of the EDI aim to raise the international community's awareness of energy poverty and to assist countries to monitor their progress towards modern energy access.

Notes

1. Real disposable income has been calculated by using a deflator for private consumption and is thus expressed in equivalents of consumption goods and services. Volume of GDP, on the other hand, reflects the quantity ('volume') of consumption goods and services, investment goods, government services and exports and imports. Preferably, incomes are also measured net of depreciation to account for the use of capital goods in production.

2. Note that the OECD Patent Database will have publicly-available patent data for about 30 fields related to clean energy technology for all countries available before mid 2011 at: *www.oecd-ilibrary.org/science-and-technology/data/oecd-patent-statistics/patents-by-main-technology-and-by-international-patent-classification-ipc_data-00508-en*.

3. The Kyoto Protocol is a protocol under the United Nations Framework Convention on Climate Change (UNFCCC) agreed in December 1997 and entered into force in February 2005 in which participating countries committed themselves to a reduction in four greenhouse gases and two groups of gases.

4. This section draws on IEA's extensive energy indicators work since 1997. For more information, see: *www.iea.org/subjectqueries/keyresult.asp?KEYWORD_ID=4125*.

5. Modern energy services include electricity and clean cooking facilities (*i.e.* clean cooking fuels and stoves, advanced biomass cook stoves and biogas systems). Electricity access refers to a connection at the household level. The number of people relying on the traditional use of biomass is based on survey and national data sources and refers to those households where biomass is the primary fuel for cooking.

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OECD Green Growth Studies

Energy

The OECD Green Growth Strategy aims to provide concrete recommendations and measurement tools, including indicators, to support countries' efforts to achieve economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which well-being relies. The strategy proposes a flexible policy framework that can be tailored to different country circumstances and stages of development. This report was coordinated with the International Energy Agency (IEA).

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