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Chapter II

Climate mitigation and the energy challenge

INTRODUCTION

A maximum temperature increase of 2° C above pre-industrial levels is the consensus science-based target for prevention of dangerous, perhaps irreversible changes in the earth's climate; this can only be achieved by very rapid reduction in greenhouse gas emissions. At the same time, developing countries need to achieve a sustained annual growth rate of at least 6 per cent to “catch up,” or close the income gap with developed countries within a reasonable length of time. Those two broad objectives frame the mitigation and development challenge facing policymakers at the national and international levels. This chapter looks at mitigation options that would allow for both climate stabilization and rapid economic growth in developing countries.

The 2° C target, according to recent analyses, requires reducing global emissions by 50–60 per cent from 1990 levels by 2050, or about 3 per cent annually, with a peak no later than 2020. This is no small undertaking and requires significant economic adjustments in both developed and developing countries. There are significant win-win options (where energy savings pay for mitigation investments in a short period of time), particularly in energy efficiency, but there are not nearly enough of these costless options to meet stabilization targets. Large-scale, upfront investment in electricity production will be needed, including new sources of renewable energy, along with related investments in transportation and construction.

What is required is a gale of “creative destruction” driven by massive investments and innovative technologies. This is not inevitable but will require dedicated and strategic policy action at all levels. As Nicholas Stern has warned, there is a danger that if we delay such action, current and near-term investment projects will lock in older technologies for decades, leading to a ratcheting up of the stock of emissions to dangerous levels, and requiring much-costlier economic and social adjustments in the future.

Despite the accumulating scientific knowledge and growing public awareness of climate change, effective mitigation action has lagged in developed countries, primarily due to a persistent disconnect between

environmental and economic objectives. For developing countries, meanwhile, effective mitigation requires not only a change in global and national focus on climate and development policy, but also strategic thinking to integrate mitigation efforts with poverty reduction, rural development, energy access, industrial expansion and infrastructure provision.

The energy sector, broadly defined, accounts for 64 per cent of global emissions (table I.1 in chap. I), or 28.4 gigatons (Gt) of carbon dioxide equivalent (CO₂e) in 2005. Within this category, electricity and heat produce the largest share of emissions, 12.4 Gt CO₂e in 2005; transportation produces about one-fifth of energy-related emissions, as does manufacturing and construction. Without significant changes in energy production and consumption, it will not be possible to meet stabilization targets.

The next largest source of emissions is agriculture (particularly rice paddies and livestock), which produced 6.1 Gt of CO₂e in 2005, or nearly 14 per cent of global emissions, surpassing deforestation, which accounted for about 12 per cent. Deforestation does remain a major concern, especially in developing countries: in 2005, land use and deforestation accounted for 21 per cent of emissions in non-Annex I countries and 48 per cent in least-developed countries.¹

This chapter focuses on energy in particular because it is the pivotal issue at the interface of climate and development. This is not to say that mitigation options in other sectors are unimportant—but unless the energy challenge is addressed, developing countries will not be able to mitigate their emissions or transform their economies to meet climate and development goals.

STABILIZATION SCENARIOS AND MITIGATION OPTIONS

The more than 200-fold growth in global CO₂ emissions between 1750 and the present has resulted in a dramatic increase in atmospheric concentrations, from about 280 parts per million (ppm) to more than 390 ppm of CO₂. The increase in CO₂ emissions is the most important contributor to global warming, but other greenhouse gas emissions have also increased rapidly, including methane, several other gases, and a fundamentally new, man-made addition to the atmosphere: chlorofluorocarbons (CFCs). Further complicating the picture is the fact that sulphur and particulate-matter emissions, posing other health and environmental hazards, are caused by the combustion of coal and other fossil fuels. Yet despite the importance of other greenhouse gases—and, in many cases, the low cost of reducing their emissions—the heart of the problem is still the reduction in CO₂ emissions.

The climate challenge demands fundamental changes in the global energy system, land-use patterns and human behaviour. Managing those changes will require an integrated policy framework to move from current emissions-intensive patterns of wealth creation to a future low-emissions global economy. Timely, widespread technological improvements will be of the utmost importance, including both new technologies, and induced changes to existing technologies.

The energy intensity of the global economy will have to be cut to one-half or even one-third of historical levels. All stabilization scenarios call for a huge share of emissions reductions, in the range of 60–80 per cent, from changes in energy systems. The solutions will vary across regions, with different shares of renewable energy, nuclear energy, carbon capture and sequestration (CCS), biomass and hydrogen and other advanced energy carriers. Energy efficiency will also play a crucial role, though as noted in chap. I, it can by no means fully solve the problem.

Achieving low stabilization levels will require early (upfront) large-scale investments and substantially more rapid diffusion and commercialization of advanced low-emissions technologies. Such investments will need to be made worldwide on the required scale, implying that effective technology and resource transfers will need to be made to countries lacking those means (see chaps. V and VI).

Currently, there are several options for curbing emissions without jeopardizing economic growth, especially in developing countries. These include a switch to renewable energy technologies (most notably wind and solar power), the enhancement of terrestrial sinks through afforestation in conjunction with sustainable biomass use, and investment in energy efficiency solutions. Another major option, the use of CCS technologies at fossil fuel plants, is under development but not yet ready for widespread adoption.

The greenhouse gas abatement cost curve developed by McKinsey & Company provides a useful quantitative estimate of both the costs and the actions needed to achieve such reductions (figure II.1). The curve ranks technologies and industrial processes according to the net costs of avoiding a ton of CO₂ emissions, taking into account both the capital costs and the operating costs of low-emissions technologies. Figure II.1 starts with opportunities for negative cost (or win-win) emissions reductions where the upfront capital costs are more than offset by future energy savings. Most of these savings are achieved through improved energy efficiency. The curve then progresses through reduction opportunities with positive, although often very

Figure II.1
Global GHG abatement cost curve beyond business-as-usual, 2030

Source: McKinsey & Company, 2009.

low, net costs. Technical abatement opportunities up to a cost of €60 per ton of CO₂e include energy efficiency, low-emissions energy supply, and forestry and agriculture (figure II.2). These options generate a total abatement of 38 Gt CO₂e per year in 2030 relative to annual business-as-usual emissions of 70 Gt CO₂e. Abatement opportunities in these three categories are spread across many sectors of the economy, with approximate figures of 29 per cent for the energy supply sectors (electricity, petroleum and gas); 16 per cent in the industrial sector; 22 per cent in transport, buildings and waste; and 33 per cent in land-use sectors (forestry and agriculture). In all, developing countries have 70 per cent of the reduction opportunities, while developed countries have 30 per cent.

The central feature of these options is that they assume an immediate start up—a delay of 10 years would almost certainly mean missing the 2°C target. Many developing countries are already taking steps on mitigation. However, more action will be required. The policy challenge is to ensure that such action supports, rather than obstructs, the achievement of development goals.

Figure II.2
Major categories of abatement opportunities

Source: McKinsey & Company, 2009.

ENERGY AND ECONOMIC DEVELOPMENT

The evolution of the energy system

In 1800, the world’s population was approximately one billion, representing a little more than a fourfold increase over the population in AD 1. With the spread of industrialization, things changed radically. In the next two centuries, global population grew sevenfold, to 7 billion (see table II.1; note that it has since grown by almost another billion)—corresponding to an annual growth rate of close to 1 per cent, and a doubling of population every 80 years. This sustained population growth has been a result of drastic decreases in mortality and increases in longevity. Improved water quality, diet, sanitary conditions and medicine have all contributed, and all are correlated with increased availability of energy resources.

Gross world product increased much faster than population: production grew more than 100-fold during the last two centuries, corresponding to an average increase of more than 2 per cent per year and a doubling every 32 years. To a large extent, this was made possible by the replacement of human workers and draft animals with machines fuelled by fossil energy, and the resulting release of labour in high-productivity activities such as manufacturing.

Technological advances have gradually reduced the energy-intensity of the global economy, so that energy use increased “only” 41-fold over the same span of time. Most of that surge in energy use came from fossil energy sources, with the unavoidable by-product of rising CO₂ emissions. Additional technological advances, and the shift from coal to oil and gas,

Table II.1 Population, economic activity, energy use and emissions, 1800–2010			
	1800	About 2010	Ratio (2010/1800)
Population (billions)	1.0	6.9	6.9
World gross product (trillions of 2005 US dollars)	0.5	50	100
Primary energy use (exajoules)	13	530	41
CO ₂ Emissions (Gt CO ₂)	1.1	29	26
Mobility (km/person/day)	0.04	40	1 000
Sources: Nakicenovic, 2009 for 1800 data. The sources for the data for 2010 or most recent are as follows: population (2010) from United Nations, World Population Prospects: The 2010 Revision, Population Division, Department of Economic and Social Affairs; world gross product (2010) from UN/DESA database for World Economic Situation and Prospects; primary energy use (2009) from United Nations, World Economic and Social Survey 2011: The Great Technological Transformation, New York, p. 21; CO ₂ emissions (2008) from the International Energy Agency (http://www.iea.org/stats/indicators.asp?COUNTRY_CODE=29); and the mobility indicator (2000) from Nakicenovic, 2009.			

slowed the increase in energy-related CO₂ emissions to a mere 26-fold, to about 29 Gt of CO₂ in 2000. Thus there has been a long-term trend toward lower energy intensity, and toward lower carbon intensity—but these trends have only moderated, not stopped or reversed, the relentless effects of economic growth.

In 1800, the world still depended on traditional biomass (mostly wood and agricultural waste) as the main energy source for cooking, heating and manufacturing. Human physical labour and animals were the main sources of mechanical energy, with some, but much more humble, contributions from wind and hydraulic power. By 1850, coal already met some 20 per cent of global primary energy needs; the figure rose to almost 70 per cent by the 1920s (figure II.3). This shift may be characterized as the first energy transition. The coal age brought such transformative technologies as railways, steam power, mass production of steel, large-scale manufacturing, and the telegraph.

Around 1900, motor vehicles were introduced along with petrochemicals and other technologies that depend on petroleum. It took another 70 years for oil to replace coal as the dominant source of energy in the world. Today, the global energy system is much more complex, with many competing

Figure II.3
Global primary energy requirements since 1850

Source: Nakicenovic, 2009.

sources of energy and many high-quality and convenient energy carriers. Electricity is most often produced from coal, natural gas, or renewables; liquids (petroleum products, or ethanol) are primarily used in transportation; various forms of biomass are still widely used in the developing parts of the world (where one third of the global population still does not have reliable access to modern energy services). Taken together, fossil energy sources provide some 80 per cent of global energy needs, while wood, hydropower and nuclear energy provide almost all of the rest.

Energy and growth

Energy is the critical link between development and climate mitigation. Access to energy services, like income, is distributed very unequally, with a strong correlation between the two.

Development economists have long promoted significant investments in “social overhead capital” such as the provision of energy services, in part because of the direct welfare effects of the services provided, but also because of their potential to crowd in other productive investments. Returns on these investments are likely to be highest in the early development stages, when basic networks are still incomplete. In low-income countries, basic services such as water, irrigation and transport account for most infrastructure spending, while in middle-income countries, telecommunications, and especially electric power, become more important. Once the social overhead capital is in place, more targeted policy incentives can support further diversification and technological upgrading. Indeed, a virtuous circle of strong investment, rising productivity, falling costs, and expanding incomes and markets, leading to further investments and increases in productivity, exhibits the mix of cumulative supply- and demand-side impulses essential to sustained development. Large public investments in areas such as energy services can play a catalytic role in this.

A major goal of any big public investment programme is to increase the return on private investments in new technologies by creating rents and market opportunities for the private sector (see chap. IV). As Albert Hirschman recognized long ago, the success of such a push is not measured solely by the speed with which cost advantages in the targeted sectors are realized, but also by the links those sectors establish backwards to suppliers and forward to new activities and markets that use their products, whose expansion could trigger new investment opportunities.² Indeed, a high density of such linkages among modern or modernizing sectors is an essential

dimension of development, and a key to sustained increases in incomes. Hirschman associated those linkages mainly with large-scale industrial investment, but he also recognized that the power sector had very strong linkage potential that could trigger cumulative development prospects.

The importance of electrification to rural development is well known. Major investments in rural electrification projects, mainly grid extensions, have been integral to successful growth experiences. In rapidly developing agricultural regions, electricity helps raise the productivity of local agriculture, industry and commerce by supplying motive power, refrigeration, lighting and process heating. Increased earnings from those activities, in turn, lead to greater household demand for electricity. Cheaper and better lighting can make education more productive, help build human capital, and raise output by extending the length of the workday and making working conditions more predictable.

ACHIEVING CONVERGENT ECONOMIC GROWTH AND ENERGY CONSUMPTION

Globally, about 31 million tons of oil equivalent are consumed daily as primary energy, equivalent to 55 kilowatt hours (kWh) per person per day. This consumption is distributed very unequally (see table II.2). In high-income countries, roughly coinciding with the membership of the Organization for Economic Cooperation and Development (OECD), average per capita consumption ranges from 100 to 300 kWh per day, divided roughly equally between household and commercial consumption. In the vast majority of developing countries, average per capita consumption is under 50 kWh per day. The exceptions are the countries of the Organization of the Petroleum Exporting Countries (OPEC), the newly industrialized countries and regions (Singapore, Republic of Korea, Hong Kong Special Administrative Region of China and Taiwan Province of China), and some emerging economies (such as South Africa). Most countries in sub-Saharan Africa and South Asia consume less than 20 kWh per capita per day. The differences are even wider in the consumption of electricity, the pre-eminent form of modern energy service, and the very symbol of modernity and affluence.

The threshold of 100 kWh per capita per day can be used as a convenient dividing line between energy poverty and energy sufficiency. Achieving this target worldwide would imply a significant expansion of energy infrastructure. Here is where the climate and energy agenda of developing countries begins to diverge from that of developed countries.

Table II.2 Per capita energy consumption, selected countries, 2008			
	<i>Population (millions)</i>	<i>Primary energy (kWh per capita/day)</i>	<i>Electricity (kWh per capita/day)</i>
Canada	33.3	254.98	46.72
Germany	82.5	129.53	19.50
Japan	126.5	124.85	22.31
Sweden	9.2	171.06	40.66
United Kingdom	61.3	108.40	16.64
United States	305.0	238.59	37.33
Russian Federation	143.2	152.85	17.48
Brazil	191.5	41.34	6.13
Mexico	110.6	52.02	5.32
Venezuela, Bolivarian Republic of	28.1	72.80	8.39
Nigeria	150.7	23.51	0.35
South Africa	49.3	86.89	12.90
Egypt	78.3	28.77	4.07
Bangladesh	145.5	6.12	0.63
India	1,190.9	16.61	1.48
China	1,328.3	50.77	6.71
Hong Kong SAR	6.9	65.05	16.19
Indonesia	235.0	26.94	1.57
Korea, Republic of	47.7	151.49	24.70
Singapore	4.8	123.66	22.74
Thailand	68.3	50.03	5.62
Sources: UN/DESA, based on primary energy data (Total Primary Energy Supply in Mtoe per year) and electricity data (electricity consumption in TWh per year) from International Energy Agency; and population data from United Nations Population Division, DESA.			

Developed countries have greater potential for energy conservation and energy efficiency, especially since most consume well over 100 kWh per capita per day; scaling down energy consumption could be consistent with the same or higher levels of income and well-being. In developing countries, in contrast, while energy efficiency is still important, it does not obviate the need for expansion of the energy infrastructure. Most countries will need to expand energy services to the threshold level of 100 kWh per day in order to meet their human development targets.

The second reason for divergence hinges on the question of affordability. Currently, the expansion in energy services in developing countries is

hindered by the fact that the vast majority of the population is too poor to afford these services without some form of subsidy. Even populations with incomes of \$3 per day would not be able to spend more than, say, \$0.30 per person per day on energy-related expenditures (electricity, cooking, heating, transport). Even if energy is priced as low as, say, \$0.05 per kWh, they would be able to afford only 6 kWh per day, comparable to the average in China or Brazil (see table II.2); the threshold of 100 kWh per day is well beyond their horizon.

This points to the need for a three-part agenda. At the aggregate level, it would make sense to set a minimum global target of 100 kWh per capita per day to overcome energy poverty. Second, energy efficiency measures should be instituted to ensure that this consumption level corresponds to the achievement of economic and human development targets. Third, at the most urgent level, there is a need to address “energy destitution”, the lack of access to modern energy services.

The faster-growing developing countries have been able to follow this trajectory with reasonable success. However, the example of China shows the potential problems. Since 2000, China has more than doubled its energy consumption, to 2.26 billion tons of oil-equivalent in 2009, according to the International Energy Agency (IEA)³—and to a great extent, it has done so by exploiting coal, the cheapest energy source but also the worst in terms of global warming impact per unit of energy. China has also become a world leader in wind and solar power, but these technologies remain far costlier than coal; much of China’s production of renewable energy technologies is for export, rather than for domestic use. For developing countries, relying heavily on high-cost renewable options could put modern energy services beyond the reach of many of their residents for years to come.

On the other hand, the energy infrastructure in some countries is so underdeveloped that it makes more sense to set up new renewable energy systems than to retool the existing infrastructure, or try to convert coal-based systems later on. Assuming catch-up growth and continuing rates of urbanization and industrialization, closing the gap between energy supply and energy demand in developing countries would require trillions of dollars of investment, even for low-cost options such as coal, and certainly well in excess of current energy investments in many developing countries. In the meantime, energy remains under-supplied and expensive in many areas, where people still rely primarily on traditional biomass fuels—wood, crop wastes and animal dung—for their energy needs.

For some rural areas, small-scale, decentralized renewable energy technologies now offer a cost-effective and sustainable approach to

electrification. The cost per customer for connection to the national grid can be very high in remote or low-density rural areas, creating a natural advantage for local renewables. Still, any big push into low-emissions energy sources is likely to require massive investments in developing wind, hydro and other renewable energy sources and connecting isolated areas with the main national grid. Rising demand for liquid fuels and gases might potentially be met through the development of a modern biomass fuels industry, which could simultaneously increase farm and rural industry employment and income. Renewable energies could also generate backward linkages, as the search for low-carbon inputs would provide incentives to innovate and explore new activities. The existence of these alternatives for economic and social development underlines the need to include energy considerations in development planning.

The energy investment push

Figure II.4 depicts both the historical evolution of the energy system and one possible future development path towards decarbonization. This scenario

Sources: Riahi et al., 2007; Riahi and Nakicenovic, 2007; and International Institute for Applied Systems Analysis, 2009.

requires transformation of the global energy system, including new energy technologies and practices, as well as changes in lifestyles and behaviour. It describes a future world that stabilizes concentrations of greenhouse gases just above current levels and thereby limits global average temperature change to about 2° C by the end of the century. The climate change implied by such a scenario would be uneven across the world, and many regions might significantly exceed the 2° C global average. Hence, even a global temperature increase of 2° C can lead to considerable local vulnerabilities and disruptions of ecosystems, water supplies and coastal communities (see chap. III). Nevertheless, a 2° C world would be spared the most severe adverse (and perhaps also irreversible) consequences associated with higher rates of climate change. Under this scenario, the world would transition towards sustainability as well as economic convergence and the fulfilment of the Millennium Development Goals in most of the world. This is very much in line with the vision outlined in the previous chapter.

The uncertainties about the nature of technological change and its impact on the climate call for the adoption of innovations as early as possible, in order to ensure lower costs and faster, wider diffusion. As noted above, there appear to be significant global mitigation opportunities that would cost less than €60 per ton of CO₂e. This potential could be larger, especially if the price of fossil fuels increases. In 2008 and again in 2011, for example, oil prices were well over \$100 per barrel. The IEA's *World Energy Outlook 2010* projects a rise in oil prices to \$120 per barrel (in 2009 dollars) by 2025 and \$135 by 2035 if no substantial energy policy changes occur, or \$105 and \$113, respectively, if countries pursue their pledged emissions reductions.⁴ In light of recent experience, it is all too easy to imagine prices going much higher than that. Higher prices for oil and other fossil fuels increase the monetary value of the energy savings from mitigation measures, thereby decreasing the net cost of those measures.

However, as the 2008 oil price spike showed, a substantial increase in oil prices can create serious problems for energy-importing developing countries, with adverse impacts on fiscal solvency and increases in the costs of basic needs such as food, transportation and energy. A prolonged escalation in energy prices would be costly in developmental terms for many countries. Thus the adoption of a purely price-based carbon market strategy would require subsidies to developing countries to offset such adverse impacts. In addition, adequate domestic measures will be needed to ensure that subsidies reach poor and vulnerable groups.

Putting a price on carbon could also trigger some of the technological, institutional and behavioural changes required for effective emissions

reduction, and given the low mitigation costs in developing countries, least-cost mitigation efforts would channel investment to these countries. However, these measures would have to be combined with a suite of compensatory policies to offset the social and economic costs of the price increase.

Technological learning and the change that it produces are essential for reducing mitigation costs and increasing mitigation potentials. To realize those benefits, “upfront” investments in new and advanced carbon-saving technologies will be needed, which would, after scale-up and adoption, lower mitigation costs and increase mitigation potentials. As chap. I suggests, these will initially have to be public investments. A recent study compared energy system investments throughout this century for two IPCC scenarios, A2 and B1.⁵ The former is a typical “business-as-usual” scenario, with a rapid increase of greenhouse gas emissions leading to a likely global temperature change of about 4.5° C in this century; B1 corresponds to a slower emissions path that keeps this century’s global temperature change under 3° C. The total investments under either scenario are in the range of \$20 trillion through 2030 and are slightly higher for B1, owing to the initial build-up of capital-intensive energy systems. Meeting a 2° C target would imply still higher start-up investment. However, in the long term, beyond 2030, the capital costs of ensuring the more sustainable future are significantly lower owing to induced technological change and learning. Over the entire 21st century, energy system investments are about \$40 trillion lower for the B1 scenario, compared to A2 (see figure II.5).

In other words, early upfront investments would enable potential reductions later as we move along the learning curves. Large investments would have to be made in developing countries in particular; indeed, again assuming that they will have the lowest costs, highest mitigation potentials, and largest opportunities for new markets, investments in the energy sector would likely be predominantly in those countries in the coming decades.

AN INTEGRATED APPROACH TO THE MITIGATION CHALLENGE

*Energy security*⁶

For many advanced countries, the future availability of oil has become a matter of concern and controversy. The IEA’s *World Energy Outlook 2010* predicts a total oil supply of 107 million barrels per day by 2035 under its highest-consumption, highest-price scenario, and 99 million barrels if current emission reduction pledges are pursued. High oil prices will be

Figure II.5
Energy systems investment, 2000-2030

Sources: Riahi et al., 2007.

Note: Please see text for explanation of scenarios.

needed, it warns, to keep demand within the range of supply. The IEA also warns that the size of “ultimately recoverable resources” of conventional and unconventional oil “is a major source of uncertainty for the long-term outlook for world oil production”.

Many energy experts hope that the supply of other basic fuels and energy sources—natural gas, coal, nuclear, hydropower—can be expanded even beyond current growth rates to compensate for possible shortfalls in the availability of oil. Still, without a radical shift in energy strategy, it will be difficult for these sources to fill the gap. This shift provides the opportunity to meet both climate and energy security goals in advanced countries.

Natural gas is the most attractive of the three fossil fuels from a climate perspective, because it emits the least amount of greenhouse gases per unit of energy. Nevertheless, gas is a finite commodity like petroleum, and many of the most prolific and easily accessible fields in North America, the North Sea and western Siberia have by now been largely depleted. Although new fields in eastern Siberia, offshore Iran, northern Alaska and Canada, and the Arctic Ocean await exploitation, the costs of developing these reservoirs

will be substantially greater than the costs for those now in production, and it is not clear how many of them will attract the high levels of investment needed to bring them online. Additional supplies could be extracted from nonconventional sources in North America and elsewhere, but at the cost of significant and controversial local environmental impacts, which are not yet fully understood. In sum, while it is reasonable to expect some increase in the availability of natural gas in the years to come, it is unlikely to compensate fully for the eventual shortfall in petroleum supplies.

Coal is the most abundant of the fossil fuels. The technology for using coal to produce electricity is very well developed, and its relatively low cost has made it especially attractive to developing nations such as China and India as a source of electric power. The IEA's *World Energy Outlook 2010* projects that global coal use will rise by nearly 60 per cent between 2008 and 2035 under current policies (though only by 20 per cent if countries adopt policies to match their emission reduction pledges and stated plans). Conventional use of coal releases more CO₂ per unit of energy produced than oil or gas; an increase in coal use of this magnitude will result in a significant worldwide increase in CO₂ emissions, undermining global efforts to slow the rate of climate change. Hence efforts to stem CO₂ emissions would preclude a greater reliance on coal. Making coal viable in this context would require the development of cleaner coal-based technologies, in particular carbon capture and sequestration, which does not appear likely to be ready for large-scale deployment in the near future.

Another possible substitute for oil is nuclear energy. Because nuclear energy releases no CO₂ emissions, some see it as an attractive alternative to fossil fuels. Nuclear energy, however, also entails many risks, as the world was reminded by the Fukushima disaster in Japan—and previously, by the Chernobyl disaster. There are also severe, extraordinarily long-run problems of safe management and disposal of nuclear waste. All of this has kept costs high compared with other sources of energy, discouraging governments and private utilities from building many reactors. The tempo of reactor construction may pick up in the years ahead in response to rising demand for CO₂-free electrical power, but it is difficult to imagine a scenario entailing enough new plants to raise nuclear power's share of total world energy significantly above its current level of 6 per cent. The unfolding reactions to Fukushima may even reduce the long-term role of nuclear power below that level.

The only sustainable solution to energy insecurity and climate threats is the rapid development of climate-friendly renewable sources of energy,

such as wind, solar, geothermal, and advanced biofuels. By the 2030s, renewable energy is projected to account for almost one-third of global electricity production, or one-sixth of global primary energy supply.⁷ These projections could be revised upward in response to efforts by the European Union and the United States, but it will take a major investment push to lift the share of renewables by more than a few percentage points. After the sharp fall in oil prices in late 2008, many governments and utilities indicated that they would not be able to proceed with ambitious plans to develop new renewable energy projects because of inadequate funding.

To fully realize the potential of renewable sources of energy, a number of technological hurdles must be overcome. Before wind and solar power can be used more widely, for example, it will be necessary to find better ways to store energy and release it at night or when the weather is cloudy or windless. More efficient transmission systems are also needed to carry electricity from areas of greatest wind and solar energy production to areas of greatest demand. Likewise, new methods are needed to convert waste plant matter into ethanol, so as to spare food crops and other valuable species. Sources of energy such as geothermal, tidal power, hydrogen, and nuclear fusion will require a visionary approach and even greater scientific and technological advancement. These advances, in turn, will require investments that are not currently forthcoming—and some of today's "visionary" technologies may turn out to be unworkable at any price.

Until these multiple challenges of energy supply are addressed, the world will continue to experience persistent energy insecurity, which will make it difficult to overcome recurring economic insecurity. In that context, it is imperative to reduce the world's reliance on fossil fuels, and increase reliance on renewable sources of energy. For high-income countries this will require action on:

- **Conservation:** efforts to reduce the consumption of fossil fuels, especially oil. This means, among other things, driving less, driving more slowly, carpooling more, trading in gas guzzlers for fuel-efficient cars, improving the energy efficiency of homes, businesses and electrical appliances of all types, and expanding public transportation.
- **Innovation:** developing ever more fuel-efficient vehicles, factories, appliances, and heating systems; moving to gas/electric hybrids, plug-in hybrids and all-electric cars; improving the efficiency and utility of wind and solar power; developing advanced biofuels derived from non-edible plants.
- **Investment:** greatly increasing public and private investment in energy efficiency,⁸ renewable energy sources and public transportation; creating

financial incentives for the development and utilization of energy alternatives, such as green bonds and a cap-and-trade system for carbon emissions.

Efforts along all fronts must start immediately if real progress is to be made. Renewable-energy investments have already risen significantly, from \$33 billion in 2004 to a record \$211 billion in 2010. China is a major driver of this growth, investing nearly \$50 billion in 2010 alone. Even the mistakes of European policy—unsustainably generous solar power subsidies, later rescinded—have spurred growth of capacity and reduced prices in photovoltaics, for which small-scale installations are now increasing rapidly.⁹ But a real transformation of energy systems will require far more; the sustainable scenario depicted in figure II.5 would require at least \$1 trillion per year over the coming decades.

Energy access

Given the overall low level of energy consumption in developing countries, the concept of energy security is predictably somewhat different than in more advanced economies. Access to modern energy services is unequal, notably between rich and poor and between urban and rural areas. Indeed, about 2 billion people, almost one third of the world population, have no access to modern energy; about 1.6 billion have no electricity, while 2.4 billion cook with traditional forms of biomass. As the United Nations Development Programme has noted, limited energy access is an important contributor to high levels of poverty in some sub-Saharan African countries. Yet this limited-access population makes up a vast potential future market for energy. Most live in rural areas; about 260 million are estimated to be urban dwellers. Expanding energy access to these populations would have a positive effect on economic activity and development.

Assuming an average connection cost for those excluded at \$1,000 per household (and a 20-year phase-in period) yields global investment needs of some \$25 billion per year over the next 20 years. This is a huge sum for the poorest of the developing countries, but a humble one compared with other requirements for global climate and development solutions. It pales beside the hundreds of billions recently spent by many industrialized countries to rescue the financial sector, automotive industry and other sectors of the economy. Still, only about \$4 billion, or 4 per cent of the total Official Development Assistance provided each year, now goes to energy needs.

Capacity expansion

Scenarios of future energy development also assume a substantial improvement of energy services, with developing countries as the largest future energy markets. Capacity expansion in the South (developing countries) is expected to be double that in the North (industrialized countries) over the coming decades, demonstrating how significant growing energy markets will be in the developing world. Capacity replacement is much larger in the North because of its huge existing stock of power plants and their substantial ageing. In business-as-usual scenarios with continuing reliance on fossil and nuclear energy, especially coal in the United States, China, India and Russia among others, the total new capacity to be installed is almost 50 terawatts electric (TWe) or 12 times the current global installed capacity. (A terawatt is a million megawatts, or a trillion watts; a terawatt of generating capacity is, roughly speaking, 1,000 large coal or nuclear plants, or 400,000 wind turbines). Even under these scenarios, developing countries would add renewable capacity through 2030 equivalent to all the power plants in the world today, and half as much again in additional nuclear plants. This presents important investment opportunities for the private sector, but in terms of climate mitigation, it would be dwarfed by the expansion of traditional fuel sources.

Climate stabilization scenarios reduce, but do not entirely eliminate, the need for capacity expansion and replacement in coming decades; the exact amount that is needed depends on the extent of energy efficiency initiatives, among other factors. Moderate stabilization targets, assuming substantial success in energy efficiency and conservation programmes, still entail many terawatts of new and replacement capacity—with the bulk of the investment in the South.

With so much expansion of energy systems slated to occur, there is a potential risk of locking in traditional technologies if the new investments in generating capacity do not use the best technologies. This risk should provide a huge incentive to attract capital to renewable energy and to support its extension to the developing world. On the other hand, there are real possibilities in developing countries of leapfrogging to the most advanced technologies. There is obvious potential for a virtuous growth circle (which also meets the climate challenge), in which a big public investment push in mitigation action leads to crowding in of private investment, technological upgrading and productivity growth.

Feed-in tariffs and renewable portfolio standards

Among the policy options that might promote a rapid transition to renewables, there has been particular interest in the feed-in tariff—a policy that obligates utility companies to purchase, at a legally mandated price per kWh (or “tariff”), energy “fed into” the grid from renewable sources by any individual or organization.

Feed-in tariffs have been used for over two decades and are now on the books in at least 45 countries and U.S. states. They were first developed in the United States under the Public Utility Regulatory Policies Act of 1978, which allowed connection of renewable generators to the grid and specified that they should be paid for the cost of generation that they avoided. In response, different states developed contractual arrangements, called “standard offer contracts”, to offer to renewable generators. The first was California’s Standard Offer No. 4, in 1984, which fixed the amount to be paid per kilowatt-hour for a long period (generally 10 years, in the context of a 30-year contract). The rate was based on the long-term avoided cost of conventional generation. These contracts led to the establishment of 1,200 megawatts of new wind power plants by the late 1980s, which have contributed about 1 per cent of California’s consumption for more than two decades. While the legal forms have changed, California has continued to experiment with other feed-in tariff options.¹⁰

Germany implemented its *Stromeinspeisungsgesetz* (the “law on feeding in electricity”) in 1991. Germany based its tariffs upon a fraction of the retail rate (that is to say, the price at which electricity was sold to consumers), not the wholesale rate (the cost at which utilities purchased electricity from other generators). Wind energy and solar energy were paid 90 per cent of the retail rate, and hydroelectric plants were paid 80 per cent of the retail rate.

However, even these rates were not sufficient to attract adequate financing. This was corrected in Germany in 2000 by the stipulation that renewable sources of electricity would have priority access to the grid for a host of environmental, social and economic reasons. Germany also set different tariffs for different technologies (based on the respective cost of generation plus a reasonable profit) and guaranteed them for 20 years. Many other countries have followed this model, called Advanced Renewable Tariffs.

For residential rooftop solar photovoltaic (PV), for example, Germany’s 2004 law offers €0.57/kWh, much more than for other sources. Similarly, the Canadian province of Ontario recently revised its laws to offer standard contracts differentiated by technology, size and application, including C\$0.80/kWh for residential rooftop solar PV.

In developing countries, the costs of most renewable options are far higher than the average retail price of electricity, which is often held quite low because so many people cannot afford higher rates. This creates a disincentive for producers, who fear future policy changes in case of large-scale uptake of renewable energy generation. In this regard, a feed-in tariff option can be successful in developing countries only if it is backed by an international guarantee and internationally funded subsidies for low-income consumers.

The feed-in tariff is just one of several policy options for inducing investments in renewable energy, which may be used alone or in combination. Other options include renewable portfolio standards, which require utility companies to supply a specified share of electricity from renewable sources; price mechanisms, which raise the price of carbon-based energy, for example, through a carbon tax or a cap-and-trade system; and direct or indirect support for the renewable sector through allocation of funds for research and development, subsidized credit or land, or even direct public investments.

In the United States, California—long an environmental leader, but also, by virtue of its size, one of the world's largest greenhouse gas emitters—has adopted several policies that have driven change in the private sector. Under the California Renewables Portfolio Standard (RPS), for example, requiring utilities to procure 20 per cent of their power from renewable sources by 2010, renewable capacity grew by 1,702 MW from 2002 to 2010, according to the California Public Utilities Commission. Utilities still fell short of the standard, procuring only 17.9 per cent of their power from renewables (excluding large hydroelectric) in 2010, according to state data, but that is still almost five times the share of electricity generated from renewables in the United States as a whole in 2009 (3.6 per cent). Another 889 MW of renewable capacity was expected to be added in California in 2011, and the state has approved a new RPS with a goal of 33 per cent renewables by 2020.¹¹

Research and development

Research, development and deployment (RD&D) are vital to the improvement of performance and the lowering of costs in the early stages of any technology. RD&D expenditures are ultimately a small factor in the cost improvements of technologies that have already found commercial niche markets, but in the earlier stages, RD&D accounts for a large share of performance improvements and cost reductions.

Research and development efforts that lead to diffusion of new and advanced technologies can address the double challenge of providing access to modern technology for those who have been excluded, while allowing further development opportunities among the more affluent. In the energy area, this could imply a shift from traditional fuels, in the case of those who are excluded from access, to clean fossils and modern renewable energy; and, in the more developed parts of the world, a shift from fossil energy sources to carbon-free and carbon-neutral energy services. In all cases, this means a vigorous improvement of energy efficiencies, from supply to end use, expanding shares of renewables, more natural gas and less coal, vigorous deployment of carbon capture and storage, and—depending on social acceptability, economic viability, and resolution of environmental risks—perhaps also nuclear energy.

All of these transformational changes in the energy system need to be empowered by vigorous RD&D efforts, investments, removal of barriers, provision of information and capacity-building. The latest trends are not entirely positive. In 2010, public sector support for R&D on renewables rose by 121 per cent, to \$5.3 billion, but corporate R&D dropped by 12 per cent, to \$3.3 billion. There are risks that progress on renewables could be hindered by fear of government cutbacks, plummeting natural-gas prices, and scepticism about the future of the market.¹² Yet, much greater investments are needed to assure the timely replacement of energy technologies and infrastructures.¹³

CONCLUSION

A more sustainable future requires large upfront investments, likely more than \$1 trillion per year from now to 2030, primarily targeting developing countries. Achieving a transition towards more sustainable development paths will also require substantial and complementary investment in energy RD&D.

Not only would these investments lead to carbon-leaner energy systems and a more sustainable development path, but in the long run (to 2050 and beyond), they would reduce costs compared with business-as-usual alternatives. The reason is that the cumulative nature of technological change translates the early investment in a lower-carbon future into lower costs of the energy systems in the long run, along with the co-benefits of stabilization. This points to the need for radical change in energy policies in order to assure that the investment effort will be adequate to our common future, and to promote accelerated technological change in energy systems and end uses.

NOTES

- 1 World Resources Institute, 2010. 'Climate Analysis Indicators Tool.' CAIT 8.0. <http://cait.wri.org/>.
- 2 Hirschman, Albert O., 1958. *The Strategy of Economic Development*. Yale University Press, New Haven, CT.
- 3 International Energy Agency, 2010. *World Energy Outlook 2010*. Paris. <http://www.worldenergyoutlook.org/2010.asp>.
- 4 Ibid.
- 5 Riahi, K., Grübler, A. and Nakicenovic, N., 2007. 'Scenarios of long-term socio-economic and environmental development under climate stabilization.' *Technological Forecasting and Social Change*, 74(7). 887–935. doi:16/j.techfore.2006.05.026.
- 6 This section draws substantially from Klare, M., 2008. 'Persistent energy insecurity and the global economic crisis.' Paper presented at the panel discussion on Overcoming Economic Insecurity, Second Committee, United Nations General Assembly, 11 November.
- 7 Electricity projection is from IEA (ibid.), New Policies Scenario; primary energy supply is based on an IPCC review of 164 scenarios from 16 large-scale integrated models that found more than half projected that renewables (including biomass) would contribute 17 per cent or more of the global primary energy supply in 2030: Intergovernmental Panel on Climate Change, 2011. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. (coordinating lead authors); Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow (eds.). Cambridge University Press, Cambridge, U.K., and New York.
- 8 As argued in a recent United Nations report, much if not most of the reduction of greenhouse gas emissions to meet climate change mitigation targets can be achieved by gains in energy efficiency. This would require giving sufficient priority to development of energy-efficient end-use technologies (automobiles, electrical equipment, heating systems, etc.). Hence, a mere focus on developing clean and renewable energy source will not suffice. See United Nations, 2011. *World Economic and Social Survey 2011: The Great Green Technological Transformation*, New York. http://www.un.org/en/development/desa/policy/wess/wess_current/2011wess.pdf
- 9 United Nations Environment Programme and Bloomberg New Energy Finance, 2011. *Global Trends in Renewable Energy Investment 2011: Analysis of Trends and Issues in the Financing of Renewable Energy*. UNEP Division of Technology, Industry and Economic, Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, and Bloomberg New Energy Finance. <http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2011>.
- 10 Rickerson, W., Bennhold, F. and Bradbury, J., 2008. *Feed-in Tariffs and Renewable Energy in the USA—a Policy Update*. Report sponsored by the Heinrich Böll Foundation, the North Carolina Solar Center, and the World Future Council. <http://archives.eesi.org/files/Feed-in%20Tariffs%20and%20Renewable%20Energy%20in%20the%20USA%20-%20a%20Policy%20Update.pdf>
- 11 California Public Utilities Commission, 2011. *Renewables Portfolio Standard Quarterly Report—1st Quarter 2011*. Sacramento, CA. <http://www.cpuc.ca.gov/NR/rdonlyres/62B4B596-1CE1-47C9-AB53-2DEF1BF52770/0/Q12011RPSReporttotheLegislatureFINAL.pdf>

54 • Climate Protection and Development

Data for United States as a whole are from Gelman, R. and Kubik, M. (ed.), 2010. *2009 Renewable Energy Data Book*. National Renewable Energy Laboratory, U.S. Department of Energy, Washington, D.C. http://www1.eere.energy.gov/maps_data/pdfs/eere_databook.pdf

- 12 United Nations Environment Programme and Bloomberg New Energy Finance, 2011 (ibid.).
- 13 See for further discussion and comparison of estimates, United Nations, 2011. *World Economic and Social Survey 2011*, ibid.