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Perspectives

Sustainable energy for developing countries

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Abstract

Overall, at least 1.6 billion people—one-fourth of the world's population—currently live without electricity and this number has hardly changed in absolute terms since 1970. And yet, the electricity required for people to read at night, pump a minimal amount of drinking water and listen to radio broadcasts would amount to less than 1 percent of overall global energy demand.

Developing and emerging economies face thus a two-fold energy challenge in the 21st century: Meeting the needs of billions of people who still lack access to basic, modern energy services while simultaneously participating in a global transition to clean, low-carbon energy systems. And historic rates of progress toward increased efficiency, de-carbonization, greater fuel diversity and lower pollutant emissions need to be greatly accelerated in order to do so.

To a significant extent, fortunately, the goal of reducing greenhouse gas emissions may be aligned with the pursuit of other energy-related objectives, such as developing indigenous renewable resources and reducing local forms of pollution. In the near term, however, there will be tensions. Sustainable energy policies are more likely to succeed if they also contribute toward other societal and economic development objectives. Governments should look across policies to maximize positive synergies where they exist and avoid creating cost-cutting incentives.

Keywords: Energy, services, policies, sustainable development, electricity, developing, emerging, economies, low-carbon

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1. INTRODUCTION

Since the dawn of the industrial age, the ability to harness and use different forms of energy has transformed living conditions for billions of people, enabling them to enjoy a level of comfort and mobility that is unprecedented in human history, and freed them to perform increasingly productive tasks. For most of the last 200 years, the steady growth in energy consumption has been closely tied to rising levels of prosperity and economic opportunity in much of the world. However, humanity now finds itself confronting an enormous energy challenge. This challenge has at least two critical dimensions. It has become clear that current patterns of energy use are environmentally unsustainable. The overwhelming reliance on fossil fuels, in particular, threatens to alter the Earth's climate to an extent that could have grave consequences for the integrity of both natural systems and vital human systems. At the same time, access to energy continues to divide the 'haves' from the 'have-nots.' Globally, a large fraction of the world's population—more than two billion people by some estimates—still lacks access to one or several types of basic energy services, including electricity, clean cooking fuel and an adequate means of transportation.

Of course, the need for a profound transformation of the world's energy-producing and using infrastructure has been widely recognized in the mounting concern about global climate change. Countless reports have been written on the subject of sustainable energy, but few have approached this specifically from the perspective of a developing country. In nations where a significant portion of the population still lacks access to basic energy services, the worry about long-term environmental sustainability is often overshadowed by more immediate concerns about energy access and affordability.

This report addresses the two-fold energy challenge that confronts developing and emerging economies—expanding access to energy while simultaneously participating in a global transition to clean, low-carbon energy systems.

At a macro level, the policy options recommended here will be familiar as similar prescriptions have been widely advocated in energy policy discussions generally and in the context of a variety of different country. However, these arguments have often been based on experience or evidence from wealthier, industrialized countries. To successfully implement a sustainable energy agenda, it will be essential for developing countries to design and implement policies that (a) are responsive to their particular needs and constraints and (b) advance the realization of many goals, including economic, social development, and environmental objectives.

2. HISTORIC ENERGY TRENDS

The energy use of human societies has historically been marked by four broad trends:

- Rising consumption as societies industrialize, gain wealth and shift from traditional sources of energy (mostly biomass-based fuels such as wood, dung and charcoal) to commercial forms of energy (primarily fossil fuels).
- Steady increases in both the power and efficiency of energy-producing and energy-using technologies.
- De-carbonization and diversification of fuels, especially for the production of electricity, throughout most of the 20th century.
- A reduction in the quantities of conventional pollutants associated with energy use.

Each of these trends has contributed to the shaping of our current energy situation. All will be important in determining the nature and magnitude of the sustainability challenge that humanity confronts in the decades ahead. In particular, much will depend on how the last three of the four trends described above interact with the first. In other words, the ability of developed and developing countries to manage the consequences of rising consumption and demand for commercial forms of energy seem likely to depend on whether it will be possible to greatly accelerate progress toward higher efficiency, more de-carbonization, greater fuel diversity and lower emission of pollutants.

2.1 RISING CONSUMPTION AND THE TRANSITION TO COMMERCIAL FORMS OF ENERGY

Before the industrial revolution, humans relied on natural energy flows and animal and human power for heat, light and work. Draft animals, wind and water were the only sources of mechanical energy. The only form of energy conversion (from chemical energy to heat and light) came from burning various forms of biomass. The per capita use of energy did not exceed 0.5 tons of oil-equivalent (toe) annually.

Between 1850 and 2005, overall energy production and use grew more than 50-fold—from a global total of approximately 0.2 billion

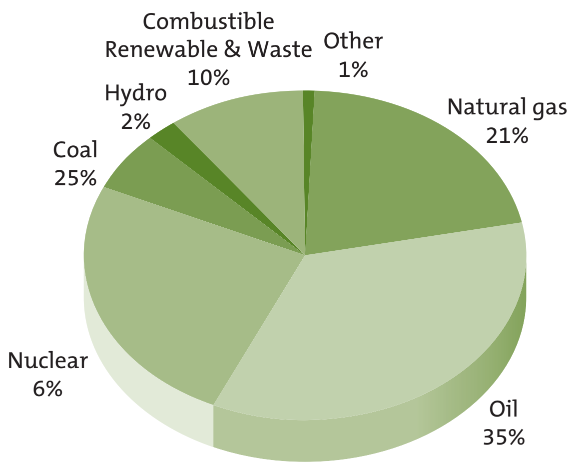

Figure 1. Share of World's Primary Energy Supply in 2005 (total=11.4 M toe). Source: IEA, http://www.iea.org/textbase/nppdf/free/2007/key_stats_2007.pdf, p.6.

toe to 11.4 billion toe (IEA, 2007). Most of this occurred in industrialized societies, which had come to rely heavily on the ready availability of energy. On a per capita basis, people in these societies now use more than 100 times the quantity of energy that was used by their ancestors before humans learned to exploit the energy potential of fire (UNDP, 2000, p. 3).

As societies industrialized, they not only began to use more energy, but also began to use energy in different forms, typically switching—as household incomes rose—from such traditional fuels as wood, crop residues and dung to such commercial forms of energy (i.e., fuels that can be bought and sold) as oil, natural gas, propane and electricity. Reliable estimates of the use of traditional waste and biomass are difficult to obtain, but these fuels are estimated to account for approximately 10 percent of overall primary energy use. Much of this use is concentrated in the rural areas of developing countries. More reliable statistics are available for the consumption of commercial energy, which grew rapidly during the second half of the 20th century.[1] Most commercial forms of energy are derived from fossil fuels (notably coal, oil and natural gas) and consumption of them has grown even faster—increasing roughly 20-fold in the 20th century alone. Non-renewable, carbon-emitting, fossil fuels now supply approximately 80 percent of the world's primary energy needs (see Figure 1).

A projection of the current trends suggests that overall energy use will continue to grow strongly—doubling or even tripling by 2050. More troubling from a sustainability perspective is that fossil fuel consumption could grow nearly as strongly as total energy consumption. This would mean that fossil fuels would continue to dominate the overall supply mix—again assuming a continuation of current, business-as-usual trends.

Of course, these are the outcomes that a policy agenda that is guided by climate concerns and other sustainability considerations presumably would seek to change. However, altering the present trajectory will require governments, businesses and individuals around the world to join in a concerted effort to accelerate the other historic trends discussed in the next subsections, particularly the trends toward higher efficiency and lower-carbon energy sources.

2.2 INCREASING POWER AND EFFICIENCY

Harnessing oxen increased the power available to human beings by a factor of ten. The waterwheel increased it by an additional factor of six and the steam engine by another factor of ten (UNDP, 2000, p. 3). Cumulatively, these innovations increased the power that was available to humans by a factor of 600. The development of the steam engine—initially powered by coal—was particularly important. It enabled the provision of energy services to become site-independent because coal could be transported and stored anywhere. Steam engines fuelled the factory system and the industrial revolution. Used later in locomotives and ships, these engines revolutionized transport as well (Grubler, 1998, p. 249). By the beginning of the 20th century, coal provided almost all of the primary energy needs of the industrializing countries.

Even as technologies like the steam engine vastly increased the power available to humans, improvements in energy-producing and -using technologies steadily increased the efficiency at which energy could be converted to different forms and used to deliver goods and services. For example, it has been estimated that the thermal efficiency of steam engines has increased by a factor of about 50 since 1,700, whereas the efficiency of lighting devices has increased by a factor of about 500 during the past 150 years (Ausubel and Marchetti, 1996). Large efficiency gains also resulted from the development of the internal combustion engine as a replacement for steam engines in many forms of transport (Grubler, 1998, p. 251).

Massive improvements in the efficiency of technologies and devices have facilitated continuing reductions in the quantity of energy required to produce a unit of goods and services in industrialized economies. This has resulted in the "decoupling" of economic output from energy consumption—two measures which, until recently, were assumed to grow more or less in lockstep with each other. Figure 2 shows that the rates of growth of primary energy use and gross domestic product (GDP) for member countries of the Organization for Economic Co-operation

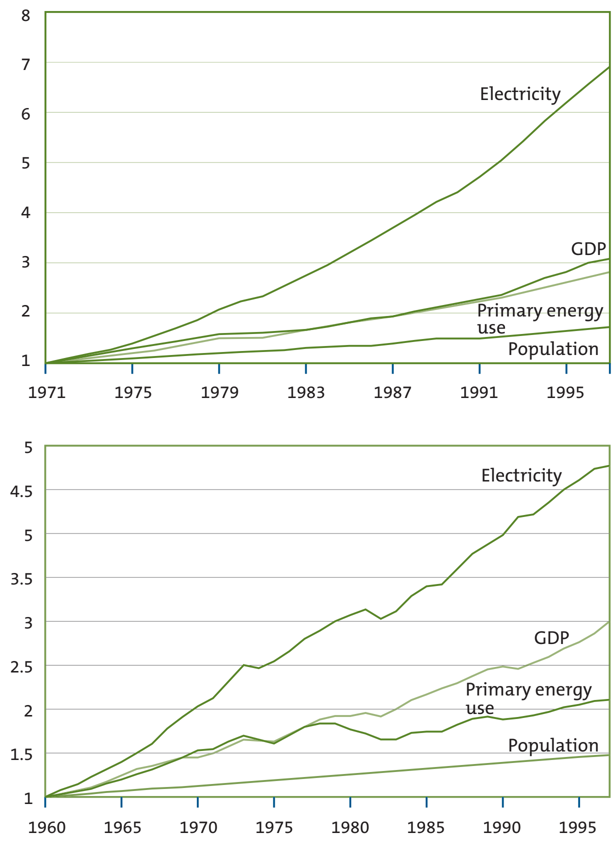

Figure 2. Changes in GDP, Population and Energy Use. Changes in GDP, Population, Primary Energy Use and Electricity Use in OECD countries 1960-97 (Figure 2A, upper panel), and in developing countries 1971-97 (Figure 2B, lower panel)
Source: Source: UNDP, 2000, Figure 1.1, p. 34 (upper panel) and Figure C.1 (d), p. 459. (lower panel)

[1] Starting around 1970, the global consumption of commercial forms of energy grew by approximately 2 percent per year. Global growth rates moderated somewhat in the 1990s with the economic contraction of a group of countries (primarily in Central and Eastern Europe and Central Asia) that were transitioning from centrally planned economies to market-based systems. Strong global growth resumed after 1998. Recently, high energy prices and recessionary pressures that have caused a diminution of global credit and an increase in the volatility of several major currencies may again be causing a global slowdown.

and Development (OECD)[2] were almost the same between 1960 and 1978, but then began to diverge, providing more output for less energy. A similar divergence appears in Figure 2B, which presents the same data for developing countries, although it occurs nearly 15 years later (in 1993).

Overall, the energy intensity of the OECD countries—where energy intensity is measured simply as the ratio of GDP to primary energy consumption—has been declining in recent years by an average rate of 1.1 percent per year. Interestingly, energy intensity has been falling even faster in non-OECD countries, presumably because many are in the process of modernizing from a fairly inefficient industrial base. However, it is worth emphasizing that electricity intensity throughout the world has not been declining. In fact, because of electricity's versatility, convenience and lack of emissions, its use as a share of total energy use has tended to rise as societies modernize and become wealthier. Consequently, the growth of electricity has been outpacing the rate of economic growth in all regions in recent years. This is relevant to the discussion of trends in electricity production in the subsection that follows.

2.3 DE-CARBONIZATION AND DIVERSIFICATION, ESPECIALLY IN THE PRODUCTION OF ELECTRICITY

Another historic trend that is likely to be relevant to future energy sustainability involves a change in the carbon content of fuels used as primary energy sources. The shift from wood and other traditional biomass fuels to a reliance on coal during the first part of the industrial age to, more recently, an energy mix that includes large shares of oil, natural gas and nuclear power, in addition to coal, has implied that there is a gradual reduction in the overall carbon intensity of the world's energy supply.[3] In fact, the ratio of tons of carbon in the primary energy supply to units of energy consumed globally has declined by about 0.3 percent annually since 1860, which is sufficient to reduce the overall ratio by 40 percent (Nakicenovic, 1996).

With regard to climate change, the trend toward lower carbon intensity during the second half of the 20th century has helped to slow the rate of increase of atmospheric concentrations of carbon dioxide. (In contrast, the earlier transition from traditional biomass fuels to fossil fuels had the opposite effect, despite an associated reduction in carbon intensity. The reasons are discussed in footnote 3.) In the three decades before 2000, the carbon intensity of the global economy—in kilograms of carbon (kgC) per U.S. dollar of gross world output (GWP)—declined from 0.35 in 1970 to 0.24 kg in 2000. This reduction is equivalent to an average annual decline in carbon intensity of approximately 1.3 percent. More recently, however, the rate of decline in carbon intensity has begun to slow and even reverse. Globally, carbon intensity per dollar of economic output has increased at a rate of approximately 0.3 percent per year since 2000 (Canadell/PNAS, 2007).

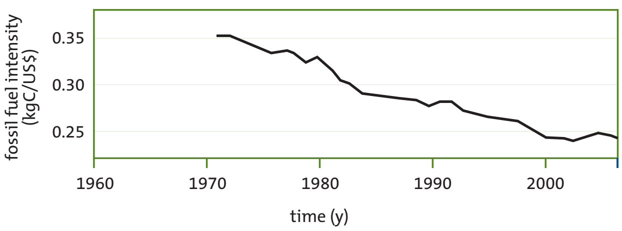

Figure 3. Declining Global Carbon Intensity. Source: Canadell, Josep G., etc., in PNAS, 2007, p. 18868.

It is unclear whether the last few years represent an anomaly and global carbon intensity, even without climate-related policy interventions, will resume the downward trend that was underway before 2000. Despite global warming concerns, higher prices and concern about the long-term supply of oil and natural gas are likely to prompt increased utilization of coal and unconventional oil resources (*e.g.*, tar sands and oil shale). This could substantially increase the carbon intensity of the global energy supply mix. Indeed, this may already be occurring to some extent.

Many experts believe that, in the long term, climate change and other concerns will necessitate a shift to natural gas and then to a hydrogen economy that is dependent on the introduction of non-carbon energy sources and the sustainable use of biomass (Ausubel, 1996, p. 4). Based on the historic rate of energy de-carbonization, this process could take 80 years to unfold in the absence of further policy interventions. It could take even longer if rising prices and oil and natural gas supply constraints, coupled with a lack of cost-competitive non-fossil-fuel alternatives, create countervailing pressures to move to more carbon-intensive fuels like coal.

A second distinct trend, and one that is linked to the gradual process of de-carbonization that is described above, began in the early 20th century and continues today. It is characterized by a proliferation of end-use technologies that rely on a diversity of fuels to generate electricity. Figure 4 shows the current and projected production of electricity by fuel for developing countries, based on the International Energy Agency's (IEA) 2005 reference scenario forecast. It suggests that production of electricity by developing countries will nearly triple during the next 25 years. Non-hydropower renewables are expected to increase their share of the total electricity supply mix from roughly one percent to four percent during that period. Overall, however, coal will continue to dominate and account for roughly half of the total production of electricity by developing countries in 2030. Of course, the IEA projections do not account for the effect of new policies that might be introduced to address climate change and other concerns during the decades ahead. Such policies could further expand the contribution of non-fossil primary energy sources to the world's electricity supply mix over the next several decades.

[2] The OECD was established in 1961. Its 30 member countries include the world's major developed economies.

[3] The ratio of hydrogen atoms to carbon atoms in wood is effectively 1:10. The ratio is between 1:2 and 1:1 in coal. It is 2:1 in oil and 4:1 in natural gas. However, not all sources of carbon have impact climate change equally. Provided that biomass feedstocks are managed sustainably, the carbon dioxide that is released by the combustion of biomass fuels is offset by an equivalent uptake of carbon dioxide from the atmosphere to support the growth of new biomass. As a result, there is, at equilibrium, no net change in atmospheric carbon dioxide concentrations. In contrast, the combustion of coal and other fossil fuels puts into the atmosphere carbon that has been stored—and thus kept out of circulation—for millennia. It therefore produces a net increase in atmospheric concentrations. Together, human activities, primarily fossil fuel combustion and land use changes, are believed to be responsible for an increase in atmospheric carbon dioxide concentration of approximately 40 percent since pre-industrial times (from roughly 270 parts per million around 1750 to 380 parts per million in 2005) (IPCC, 2007, *Fourth Assessment Report, Summary for Policymakers*, p. 5).

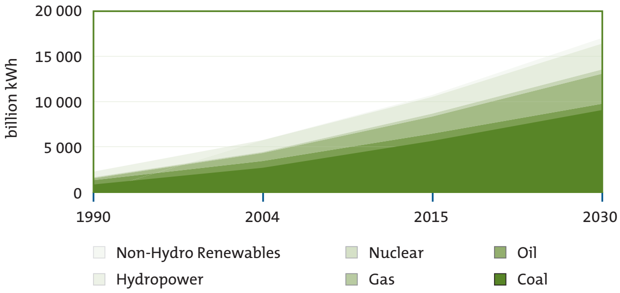

Figure 4. Electricity generation in developing countries: 2006 IEA reference case forecast. Source: IEA, *World Energy Outlook* 2006, p. 513.

An effective response to the threat of climate change will require a significant acceleration of the historic trends to de-carbonization and fuel diversification. This acceleration must take place globally. It cannot be restricted to the developed countries, but must be pursued with equal or even greater vigor in developing countries.

2.4 REDUCTION OF CONVENTIONAL POLLUTANTS ASSOCIATED WITH ENERGY USE

The archetypal symbol of the industrial age was the smokestack and, in many developing countries, large energy facilities continue to represent modernity and economic opportunity. However, with increasing affluence and a better understanding of the adverse environmental and human health impact of most conventional air pollutants, the public's willingness to accept dirty technologies has declined, especially during the last 30 years. The result has been a clear link in many countries between rising incomes and an increase in emphasis on environmental performance. Over time, energy end-use technologies (*e.g.*, cooking stoves, automobiles) and energy conversion technologies (*e.g.*, power plants) have become progressively cleaner, at least with respect to visible, local and immediately harmful pollutants.

In fact, the energy technology that has the most potential to immediately improve human health and well-being in many developing countries is relatively simple. It is the improved cooking stove. The use of such traditional fuels as wood and dung for cooking is inefficient and generates extremely high levels of indoor pollution. Accelerating the transition to more expensive, but far cleaner kerosene, liquefied petroleum gas (LPG), or electric stoves, would dramatically reduce the exposure to unhealthy levels of particulate pollution in many developing countries, particularly among women and children. Other sectors that offer great opportunities to reduce conventional levels of air pollutant emissions and to improve public health are transport and electricity production. More stringent pollution control requirements for automobiles, heavy-duty vehicles and equipment and power plants, in particular, would substantially improve air quality.

In some cases, technology improvements that reduce the emissions of conventional air pollutants (such as sulfur dioxide, nitrogen oxides, hydrocarbons and particulate matter) can be expected to also reduce emissions of greenhouse gases. A good example is the use of natural gas for the production of electricity. This became increasingly common in the United States in the 1990s. One reason is that natural gas plants do not require the same pollution controls that coal-fired plants do (*e.g.*, electrostatic precipitators, sulfur dioxide scrubbers, etc.). This has helped them to become competitive with coal-fired power stations in many countries that regulate conventional pollutant emissions. Some conventional pollutants, such as black carbon, directly contribute to global warming. In those cases, conventional emission controls can provide automatic climate co-benefits. In other cases, the relationship is more complicated. For example, sulfur particles have a cooling effect on the atmosphere. In general, most post-combustion conventional-pollutant control technologies do not reduce the emissions of carbon dioxide, the chief greenhouse gas. Moreover, agreements to reduce or control emissions that could disrupt global climate systems have proved to be difficult to negotiate.

Devising effective policy responses to a problem that is truly global and multi-generational in scale presents a challenge that is both unprecedented in the history of environmental regulation and daunting to developed and developing countries alike. The challenge for developing countries is greatly complicated by the need to expand access to essential energy services and to simultaneously provide low-cost energy for economic development.

3. THE ENERGY CHALLENGE

Global consumption of commercial forms of energy has increased steadily over the last four decades and has been recently marked by especially dramatic growth rates in many developing countries. Yet, stark inequalities persist throughout the world in the access to modern energy services. Between 1970 and 1988, the developing countries' share of global primary energy consumption rose from approximately 13 percent to about 30 percent. In 2005, the non-OECD countries accounted for just over half (52 percent) of global primary energy consumption. This increase in energy consumption has not, however, resulted in a more equitable access to energy services on a per capita basis. In 2005, the average per capita consumption of energy in the OECD countries was more than four times the per capita average in all non-OECD countries, and nearly seven times the per capita average in Africa (IEA, Key Energy Statistics 2007, p. 48).

Overall, at least one quarter of the world's 6.6 billion people are unable to take advantage of the basic amenities and opportunities made possible by modern forms of energy. The inequities in per capita use of electricity are even greater than the inequities in per capita use of primary energy. In 2005, the average citizen in the OECD countries used 8,365 kwh of electricity. In contrast, the average citizen in China used 1,802 kwh and the per capita average for the rest of Asia was 646 kwh. The per capita average use of electricity in 2005 in Latin America and Africa were 1,695 kwh and 563 kwh respectively.

Energy Service/Development Need	Typical energy services	Electricity demand kWh/month per household
Lighting	5 hours/day @ 20 W/household	2.0-6.0
Radio/Music	5 hours/day @ 5 W/household	2.0-6.0
Communications	2 hours/day @ 10 W/household	2.0-6.0
Potable Water	Community electric pump providing 5 liters/day/capita	2.0-6.0
Basic Medical Services	2.5 kWh/day for 100 households	0.5-1.0
Education	2.5 kWh/day for 100 household	0.5-1.0
Income generating productive uses	5 kWh/day for 10 households	0.0-20.0
TOTAL	—	3.0-30.0

Table 1. Typical Electricity Requirements for Off-Grid Populations in Developing Countries. Source: Adapted from Table 1, (G8 RETF, 2001, p. 23).

These regionally or nationally aggregated figures mask even starker within-country disparities, since the energy consumption patterns of elites in many developing countries are similar to those of the general population in developed countries. In fact, although it has been estimated that developing countries were spending as much as $40 to $60 billion annually on electricity systems by the end of the 20th century (G8, RETF, 2001), approximately 40 percent of the population in these countries remained without access to electricity. This means that the number of people throughout the world who had no access to electricity has hardly changed in absolute terms since 1970 (UNDP, 2000, p. 374). Not surprisingly, the rural poor in developing countries account for the vast majority (nearly 90 percent) of households that have no access to electricity.

Consequently, the most immediate energy priority for many developing countries is to expand access. In fact, providing safe, clean, reliable and affordable energy to those who currently have no access to such is widely viewed as essential in order to progress toward other development objectives. Although there was no specific chapter on energy in Agenda 21 (1992) and no specific United Nations Millennium Development Goal (2000) on energy, the access to basic energy services is directly linked to most social and economic development targets that were outlined in the Millennium Declaration (WEHAB Working Group, 2002).

The immediate obstacle to access to energy for many poor households and governments in developing countries is a lack of financial resources. Moreover, where access to energy is lacking, other urgent human and societal needs also are often not met, meaning that energy needs must compete with other priorities. Fortunately, people need only a relatively modest amount of electricity to be able to read at night, pump a minimal amount of drinking water and listen to radio broadcasts (G8-RETF, 2001). In other words, it is possible to greatly improve the quality of life for many poor households with a level of energy consumption that is far below that of the average citizen in an industrialized country.

To pay for even basic services, however, households need income-generating opportunities. These also require energy. Table 1 below shows typical electric service requirements for off-grid households in developing countries, assuming an average household size of five persons. It has been estimated that basic household services, along with commercial and community activities (*e.g.*, rural clinics and schools), can be provided for an average of just 50 kilowatt-hours (kWh) per person annually. (Note that this figure includes only basic electricity needs. The energy requirements of cooking and transportation are not included).

An estimated 1.6 billion people worldwide lack access to electricity. Providing basic electricity services to these people at an average annual consumption level of 50 kWh per person would increase the global end-use demand for electricity by roughly 80 billion kWh per year. This is less than one-half of one percent of global annual electricity production in 2004 (estimated at 18,235 billion kWh) and less than one-fifth of the expected annual increase in global electricity production for the next two decades, according to the IEA's 2006 reference case forecast for 2004–2030.

Besides a need to expand access, many developing countries face at least two other immediate energy-related challenges.

The first and most pressing issue for many oil-importing countries is economic. A rapid rise in world oil prices has led to a steep and, for some countries, increasingly unmanageable increase of their import bill for energy commodities. For example, the value of India's oil imports increased by more than 20 percent in a single year, from $33 billion in 2006 to an estimated $40 billion in 2007.[4] The Economic Research Service of the U.S. Department of Agriculture has stated, "For oil-importing developing countries, the $137 billion increase in the energy import bill in 2005 far exceeded the $84 billion of official development assistance they received."[5] Moreover, oil prices have continued to rise substantially since 2005, adding further to this financial burden.

For many smaller and poorer countries, the combination of rapidly rising energy prices and a recent, similarly precipitous escalation of world food prices are generating concerns about internal economic and political stability. For these countries, diversifying the domestic energy resource base and reducing the demand for imported fuels would bring a host of benefits, not only by freeing scarce resources for domestic investment, but also by reducing long-term exposure to financial and humanitarian crises that now loom in many parts of the world.

A second, important energy-related challenge is environmental. As noted in a previous section, energy use in many developing

[4] Source: http://www.upiasiaonline.com/Economics/2007/12/11/india_and_china_lose_with_high_oil_prices/6010/
[5] Source: http://www.ers.usda.gov/AmberWaves/February08/Features/RisingFood.htm

countries is a significant and immediate cause of high levels of air pollution and other forms of environmental degradation. Energy-related emissions from power plants, automobiles, heavy equipment and industrial facilities are largely responsible—especially in major cities—for levels of ambient air pollution that routinely exceed the health thresholds set by many developed countries, and sometimes by an order of magnitude. In both urban and rural areas, indoor air pollution caused by the use of traditional fuels for cooking and space heating daily exposes billions of people, especially women and children, to significant cardiovascular and respiratory health risks. In many cases, adverse environmental impacts begin well upstream of the point of energy end-use. The extraction of commercial fuels like coal and oil is often highly damaging to local ecosystems and becomes an immediate cause of land and water pollution. Meanwhile, reliance on traditional fuels, such as wood, can produce its own adverse impacts.

It is expected that the longer-term, climate change that is caused by energy-related emissions will pose many risks to developing countries. Even though emissions in developed-country are overwhelmingly responsible for current levels of heat-trapping gases in the atmosphere, numerous analyses conclude that the myriad burdens of global warming are likely to fall disproportionately on developing countries. This is because developing countries are likely to be more sensitive to such adverse impacts as the effects on water resources and agricultural productivity. They are also more likely to lack the financial and institutional means to implement effective adaptation measures.

Because it is believed that developing countries account for a large and growing share of overall greenhouse gas emissions, active participation by such countries in the efforts to de-carbonize the world's energy systems is essential as a matter of self-interest and also to help to avert a global environmental catastrophe.

Fortunately, the goal of reducing greenhouse gas emissions may be aligned to a significant extent with the pursuit of such other energy-related objectives as the development of indigenous renewable resources and the reduction of local forms of pollution. However, there will be tensions in the near term. This is particularly likely if policies designed to discourage the use of carbon-intensive conventional fuels, many of which implicitly or explicitly have the effect of raising energy prices, are seen as conflicting with the goal of expanding access to essential energy services for the poor or promoting economic development or both. Thus, the pursuit of a sustainable energy agenda for developing countries requires leveraging the positive synergies of efforts devoted to achieving other societal and economic objectives, while minimizing potential conflicts between different public goals.

How this may be accomplished by well-designed policies is discussed in a later section of this report. However, it is useful to first review some of the technology options available to developing countries that seek to meet their growing energy needs in a global environment that is marked by increasingly intractable environmental and resource constraints.

4. THE TECHNOLOGY CHALLENGE

The various energy supply technologies that will probably be used in a carbon-constrained future have been extensively reviewed elsewhere. The usual list includes renewable energy technologies (*e.g.*, wind, solar and biomass), nuclear technology and advanced fossil-fuel systems with carbon capture and sequestration. Natural gas systems are widely viewed as a crucial 'bridge' technology. In addition, energy efficiency is often cited as a critically important and an often lower-cost complement to supply side improvements.

In principle, the same supply- and demand-side options are available to all countries. Nevertheless, some options, especially technologies that are in very early stages of commercialization or require very large, initial capital investments or substantial outside expertise to operate, are likely to face additional obstacles to their use in developing countries.

For purposes of this report, we focus on renewable energy technologies because they can be particularly attractive in dispersed, 'off-grid' applications. Therefore, they represent important options for rural areas that lack electricity transmission and distribution infrastructures. Other low-carbon supply technologies are reviewed briefly (at the end of this section), while energy efficiency is covered as part of the policy discussion in the section that follows.

A number of renewable energy technologies have been so improved that they can now provide electricity at a lower cost than other supply options wherever extension of the grid is prohibitively expensive or uneconomic. There are six broad categories of renewable energy technologies. They are biomass, wind, solar, hydro, geothermal and marine. They can be tapped by using a variety of conversion technologies or processes to produce a range of energy services, including electricity, heat (or cooling), fuels, mechanical power and illumination. The competitiveness of different renewable technologies in different settings depends on their cost and performance, as well as the local cost and availability of fossil-based energy. All of these factors still vary widely and depend strongly on local conditions.

For example, many renewable energy sources are inherently intermittent. Thus, their integration into a unified electricity grid can pose challenges, especially on a large scale, and may make them less competitive with conventional generating systems.[6] In dispersed, off-grid applications, intermittency may pose less of a problem and renewable technologies may be more cost-effective than the next available conventional option. In addition, the modularity of many renewable energy technologies facilitates their deployment in relatively small increments. This can be advantageous in cost and risk to many developing countries.

[6] In the longer term, the development of cost-effective storage systems can overcome this drawback of renewable technologies like wind and solar.

		Current Energy Costs		Potential Future Energy Costs	
Source	**Units**	**Low**	**High**	**Low**	**High**
Biomass-Ethanol	$/GJ	8	25	6	10
Bio-diesel	$/GJ	15	25	10	15
Geothermal-heat	c/kWh	0.5	5	0.5	5
Biomass-Heat	c/kWh	1	6	1	5
Geothermal-electricity	c/kWh	2	10	1	8
Large Hydro	c/kWh	2	10	2	10
Small Hydro	c/kWh	2	12	2	10
Solar low-temperature heat	c/kWh	2	25	2	10
Wind electricity	c/kWh	4	8	3	10
Biomass-Electricity	c/kWh	3	12	4	10
Marine-current	c/kWh	10	25	4	10
Solar Thermal Electricity	c/kWh	12	34	4	20
Marine-Wave	c/kWh	10	30	5	10
Solar PV electricity	c/kWh	25	160	5	25
Marine-ocean thermal	c/kWh	15	40	7	20
Marine-tidal	c/kWh	8	15	8	15

Table 2. Current and Projected Future Costs of Renewable Energy Technologies. Source: (adapted from UNDP, 2004, Table 7, p. 50). For comparison, typical (wholesale) electricity production costs in many developed countries in recent years have been on the order of 2–4 c/kWh; retail prices have been on the order of 8 c/kWh; prices in off-grid niche markets have been on the order of 14 c/kWh and peak power prices have typically ranged from 15–25 c/kWh (G8, RETF, 2001).

In general, the costs of most forms of renewable energy have declined substantially in recent decades. In the early 1990s, only hydropower was competitive with electricity generated by conventional power plants for on-grid applications. However, expanding markets and experience-proven cost reductions have since made wind and geothermal power competitive or nearly competitive with other, conventional sources. Solar photovoltaic technology remains more expensive, but can compete in some off-grid niche market applications. These comparisons are, of course, based on narrow criteria of strict cash flow and ignore such other advantages as environmental benefits, which renewable technologies can confer (G8 RETF, 2001, p.16-17).

Table 2 shows current and projected future costs for selected renewable technologies. The figures are somewhat dated, but indicate the extent to which additional experience, larger-scale deployment and continued technology improvement may reduce future costs. The prospects for continued cost reductions are promising in view of the recent rapid growth in renewable energy markets. During the past several years, the global rate of increase in installed wind and photovoltaic capacity has averaged as much as 30 percent per year, creating some of the world's most rapidly expanding markets for energy technology.

For comparison, typical (wholesale) electricity production costs in many developed countries in recent years have been on the order of 2–4 c/kWh; retail prices have been on the order of 8 c/kWh; prices in off-grid niche markets have been on the order of 14 c/kWh and peak power prices have typically ranged from 15–25 c/kWh (G8, RETF, 2001).

An expectation of declining costs in the future due to greater field experience and larger-scale deployment is not unique to renewable energy technologies. They would apply also to other relatively new, low-carbon technology options, such as carbon capture and sequestration. Figure 5 compares the decline in unit costs for wind and photovoltaic technology in the United States and Japan to the historic decline in the prices of gas turbines. The figures show that the declines were more rapid at first for gas turbines, but slowed as the technology matured. This is typical of maturing technologies.

All renewable energy sources can be converted to electricity. In principle, energy can always be converted from one form to another. In actual practice, however, there will be some forms that will be preferred due to cost-effectiveness. Table 3 suggests some specific near-, medium-, and long-term options for supplying basic energy needs in rural areas using low-carbon technologies. The optimal mix of options in different settings will depend on costs, scale, location, timing and availability of local resources and expertise and a host of other factors. In general, a greater diversity

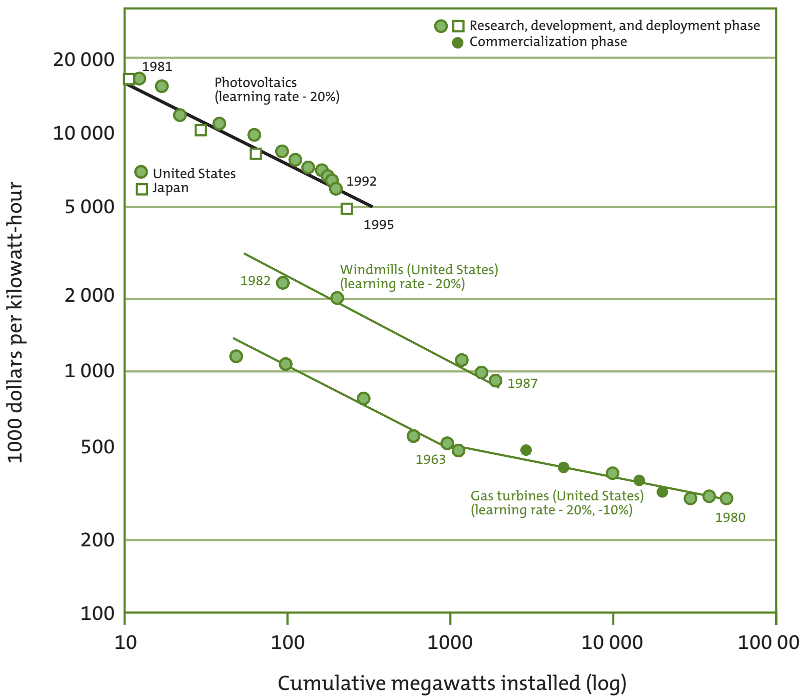

Figure 5. Experience curves for photovoltaics, windmills, and gas turbines in Japan and the United States. Source: UNDP, 2000, Figure 12.1, p. 436.

Energy Source /service	Present Options	Near Term Options	Medium Term Options	Long Term Options
Electricity	Grid-based or no electricity	Natural gas combined cycles, biomass gasifiers coupled to internal combustion engines, wind, photo-voltaics, small hydro for remote applications.	Biomass gasifiers coupled to micro-turbines; mini grids with combinations of photovoltaics, wind, small hydro, batteries.	Grid-connected photovoltaics and solar thermal, biomass gasifiers coupled to fuel cells and fuel cell/turbine hybrids.
Fuel	Wood, charcoal, crop residues, animal dung	Natural gas, liquid petroleum gas, producer gas, biogas.	Syngas, dimethyl ether.	Dimethyl ether from biomass with electricity as a co-product.
Cogeneration	—	Internal combustion engines, turbines.	Micro-turbines with integrated combined cycles.	Fuel cells, fuel cell/turbine hybrids
Cooking	Woodstoves	Improved wood-stoves, liquid petroleum gas, biogas.	Producer gas, natural gas, dimethyl ether.	Electric stoves, catalytic burners.
Lighting	Oil and kerosene lamps	Electric lights	Fluorescent and compact fluorescent lamps	Improved fluorescent lamps, compact fluorescent lamps
Motive Power	Human, and animal power	IC engines, electric motors	Bio-fueled prime movers, improved motors	Fuel cells
Process heat	Wood, biomass	Electric furnaces, cogeneration, producer gas, natural gas/solar thermal furnaces.	Induction furnaces, biomass/solar thermal furnaces.	Solar thermal furnaces with heat storage.

Table 3. Technological Options for Rural Energy. Source: Adapted from table 10.3, UNDP. 2000, p. 380.

of supply options will help to reduce exposure to resource and technology risks. Of course, there are also trade-offs to consider. Some standardization can help to reduce deployment costs and make it easier to develop the local expertise required to operate and maintain new technologies and systems.

Along with a need to extend basic electrical services to rural areas, many developing countries face a rising demand for grid-connected power to meet industrial and manufacturing energy needs and to provide electricity in fast-growing urban areas. In countries that have access to substantial coal supplies, conventional coal-fired steam-electric power plants are often the cheapest near-term option for the addition of large-scale, grid-connected generating capacity. However, such investments risk locking-in decades of high carbon emissions and, unless modern pollution controls are used, substantial emissions of conventional air pollutants. These economy-environment trade-offs are difficult to resolve, especially for poorer countries that have pressing near-term needs for low-cost power. For those countries, assistance from developed countries will be essential to offset the additional costs and technology demands of more expensive, but cleaner and lower-carbon, technologies.

Shorter-term, commercial alternatives to high-emitting conventional coal plants include such renewable technologies as wind and biomass;[7] higher-efficiency conventional coal plants (*e.g.*, super-critical and fluidized bed systems); nuclear power and, if natural gas is available, integrated, combined-cycle gas turbines. In the long-term, advanced coal technologies, such as integrated, combined-cycle gasification systems, coupled with carbon capture and sequestration must be successfully commercialized to make continued reliance on coal resources compatible with global carbon limits.

In comparison to the main non-renewable, low-carbon, electrical generating options, modern natural gas systems are relatively clean and efficient and can be cost-competitive where ample supplies of natural gas are available. They can also be deployed relatively quickly and in small (←100 MW) increments. In contrast, nuclear technology is far more demanding. China and India are poised to make substantial investments in nuclear power during the next few decades. However, this technology is unlikely to be attractive to smaller developing countries in the short- to mid-term because of the operational and waste management challenges it presents and the high initial investment required. Advanced coal systems with carbon capture and sequestration are in an even earlier stage of the research, development and deployment trajectory. Because of the high capital cost and the relatively unproved nature of the advanced coal systems, most analysts believe that developed countries will need to take the lead in demonstrating and commercializing this option.

As noted in an earlier section, the mix of technologies and fuels used to meet electricity needs has become more diverse over time. In contrast, the transportation sector has remained, with few exceptions, overwhelmingly dependent on petroleum fuels. This poses a problem to the environment as transportation accounts for roughly one-quarter of global energy-related carbon dioxide emissions. Further, the reliance on petroleum fuels fails to address the issue of energy and economic security despite recent trends in world oil markets. The rapid growth in vehicle ownership and overall travel are potential problems for many developing countries that already are contending with high levels of urban air pollution and seeing a sharp rise in expenditures for imported oil.

In the short- to medium-term, developing and developed countries have two primary options for advancing sustainability

[7] In addition, concentrating solar-thermal technology for the production of electricity has recently attracted renewed attention, with demonstration projects planned or underway in several countries.

objectives in the transportation sector: (1) improving vehicle performance by improved efficiency and emissions controls and (2) promoting sustainable, low-carbon biofuels as an alternative to petroleum-based fuels. Both options have drawn increased attention in recent years. A number of countries with large vehicle markets, including China and India, have adopted more stringent emissions standards and are considering the adoption of automobile fuel economy standards. At the same time, global interest in biofuel development has intensified, due in part to the adoption of aggressive fuel mandates in developed countries like the United States. Brazil is already a world leader in this area, having successfully developed a major domestic sugar cane ethanol industry that is economically competitive with conventional gasoline.

The current worldwide boom in biofuels is proving to be a mixed blessing at best, especially in many developing countries where biofuels are blamed for contributing to accelerated rates of deforestation, habitat destruction and high food prices. These are significant issues that should be addressed expeditiously by a thoughtful re-examination and reform of current biofuel policies in the developing world and also in the developed countries that are behind much of the recent drive to expand global production. In the long run, the viability of biofuels as an alternative to oil, and the ability to reconcile or minimize the conflicting interests of food production and habitat preservation, will depend on successful commercialization of improved feedstocks and conversion technologies. In general, such improvements as the ability to cost-effectively convert ligno-cellulosic feedstocks to ethanol would also greatly enhance the net environmental benefits and greenhouse gas reductions achieved by switching from conventional fuels to biofuels.

5. POLICIES AND ACTIONS

The energy challenges that developing countries face are significant and increasing. Further, it is clear that developing countries will be unable to avoid the potentially large and adverse consequences without concerted policy interventions by developing and developed countries alike.

This section focuses on a relatively short list of policy actions that will help developing countries to avoid or minimize such consequences. None are easy to implement. All require the active engagement of all sectors of society, including individual consumers and local communities, non-governmental organizations, private businesses and industry, the science and technology research community, governments, intergovernmental institutions and charitable organizations. Developing countries must take the lead in charting new energy courses for themselves. However, developed countries must stand ready to provide support, recognizing that they have a vital stake in the outcome. These policy actions include:

- Promoting energy efficiency and adopt minimum efficiency standards for buildings, appliances and equipment, and vehicles.
- Reforming and re-directing energy subsidies.
- Identifying the most promising indigenous renewable energy resources and implementing policies to promote their sustainable development.
- Seeking developed-country support for the effective transfer of advanced energy technologies, while building the indigenous human and institutional capacity needed to support sustainable energy technologies.
- Speed the distribution of clean, efficient, and affordable cook stoves.

Before proceeding to a more detailed discussion of these policy recommendations, a caveat on the need for harmonized policies and holistic approaches should be repeated. First, as noted in the introduction, sustainable energy policies are more likely to succeed if they also contribute to other societal and economic development objectives. Second, governments should review policies to maximize positive synergies where they exist and to avoid creating cost-cutting incentives. In responding to various pressure groups, governments often adopt conflicting policies that undermine each other, at least in part. For example, government efforts to promote energy efficiency can be undercut by subsidies that tend to promote increased consumption.

Harmonization is not always possible due to political or other reasons. Thus, it may not be possible to pursue a comprehensive set of policies all at once. Nevertheless, governments should recognize that maximum benefits can be achieved by an approach that considers the interactions of different policies, leverages multiple opportunities where possible and responds to the specific needs and constraints of individual countries.

5.1 ENERGY EFFICIENCY

Assessments of the cost of mitigating climate-change consistently find that energy efficiency improvements offer the largest and least costly emissions-reduction potential, while providing such important ancillary benefits as energy cost savings, reductions in emissions of conventional pollutants, a reduction in the dependence on imported fuels and improved economic competitiveness. Energy efficiency can be especially important in rapidly industrializing countries as a way to manage rapid demand growth, improve system reliability, ease supply constraints and allow energy the production and distribution infrastructure to 'catch up.'

As discussed earlier, historic trends reveal steady progress toward improved energy efficiency and lower energy intensity (where intensity is measured by the amount of energy required to deliver a unit of goods or services).

This historic rate of improvement can be expected to continue. Nevertheless, without policy intervention, such improvements are unlikely to keep pace with the continued growth in demand, especially in countries that are still in the early stages of industrialization. Moreover, experience shows that market forces by themselves often fail to exploit all cost-effective opportunities to improve energy efficiency.[8]

Countries like the United States have significant untapped energy efficiency potential. The U.S. economy, as often noted, is only half as efficient as the Japanese economy. In other words, the United States consumes twice as much energy per dollar of GDP as Japan. However, the opportunities are also great in some rapidly industrializing economies. China, for example, consumes nine times as much energy per dollar of GDP as does Japan. Overall, a recent assessment of global efficiency opportunities by the McKinsey Global Institute (2007) indicated that the average annual rate of decline in global energy intensity could be raised in a cost-effective way to 2.5 percent per year. This would be essentially double the recent global rate of decline, which has been averaging approximately 1.25 percent per year. This is a significant finding as it confirms that even relatively small changes in year-to-year improvement of energy efficiency can produce a wide divergence of outcomes over time.

Although it might seem insensitive to recommend energy conservation to countries that consume so little by global standards, the historical record indicates that small, incremental and cumulative improvements in efficiency over long periods can deliver enormous benefits by making the economies of countries less wasteful, more productive and more competitive. The potential benefits of such improvements are very significant in countries that have a rapidly growing demand for new infrastructures, buildings, appliances and equipment. It is usually much easier and more cost-effective to create a high level of efficiency at the outset than to improve efficiency later. Moreover, policies that "ride the waves" of grand transitions (in the sense that they are consonant with other major societal or technological changes) are less likely to encounter friction than those that run counter to them. In most situations and all countries, it is essential to have programs that promote more efficient use of energy (G-8 RETF, 2001, p. 5).

Governments have important roles to play in promoting energy efficiency and conservation. Efficiency standards for appliances, equipment and automobiles have proved to be extremely cost-effective in many developed countries and are often relatively easy to implement compared to other policies, particularly if they can be harmonized with the standards adopted in other large markets. Efficiency standards or codes for buildings, especially commercial buildings, are extremely important because of the long useful life of most structures. However, to be effective, countries will need to educate architects and builders and develop the means to monitor performance and enforce compliance with the codes. By setting a floor or baseline for energy efficiency, minimum standards can ensure that there will be substantial energy savings in the future.

To secure additional benefits and ensure that manufacturers continue to innovate, other policies and incentives are needed to generate a demand for products that perform above the minimum standards. For example, governments can adopt labeling requirements and pro-active public procurement policies. Intergovernmental and non-governmental organizations and charitable associations can encourage or require the use of more efficient equipment. In some countries, utility companies have been successfully enlisted to help promote efficiency by end-use customers. There is a substantial history of such programs in the United States. However, there are also examples in other countries (text box A describes a utility-led initiative in India). Energy-efficiency or 'demand-side management' programs can provide a number of benefits in developing countries, including lower costs to customers, an fewer electrical supply problems, greater system reliability and a more moderate growth in demand.

5.2 SUBSIDY REFORM

Although energy subsidies have declined during the last decade in many parts of the world, subsidies for fossil fuels still amount to tens of billions of U.S. dollars in developing countries.

BOX A. A UTILITY-LED EFFICIENT LIGHTING PROGRAM IN BANGALORE, INDIA

The Bangalore Electric Supply Company (BESCOM), a distribution company that serves the Bangalore metropolitan area in the state of Karnataka recently partnered with the International Institute for Energy Conservation to implement a program to replace inefficient incandescent light bulbs with compact fluorescent lights (CFLs).

The program was motivated in part by the need to address peak power shortages.

Within the developing world, the BESCOM Efficient Lighting Program (BELP) was innovative for several reasons: The program was undertaken on a substantial scale so that distribution utilities everywhere could witness its implementation and impact.

- Over nine months, BESCOM's monitoring and verification program indicated that 100,000 customers bought an average of two CFLs. The estimated program benefits included a 300-percent increase in CFL sales, a reduction of 12 megawatts in peak-power demand, energy savings of 10 megawatt-hours and a total of 100 tonnes of carbon dioxide reductions.
- The utility and industry formed a novel and replicable partnership, in which BESCOM used its billing and collection system to pass on energy savings to customers and CFL vendors agreed to meet international product specifications and provide improved warranties.
- Except for the program design, which was funded by the U.S. Agency for International Development, all marketing costs were borne by BESCOM, demonstrating that subsidies are not always necessary.

[8] A recent report by the McKinsey Global Institute found that half of all growth in global emissions could be avoided at a negative net cost by using energy efficiency measures. Specifically, the report stated that a global investment of $170 billion US per year in energy efficiency would yield $900 billion US in benefits annually by 2020, providing an average internal rate of return on investment of 17 percent per year. See: http://www.mckinsey.com/mgi/publications/Curbing_Global_Energy/index.asp

The BELP program was widely viewed as a success and subsequently served as a model for lighting programs sponsored by other companies. In addition, the Ministry of Power's Bureau of Energy Efficiency (BEE), which implements the Energy Conservation Act of 2001, recently announced a bulk purchase program to further reduce the price of CFLs and invited distribution utilities in India to participate. Several vendors have agreed to reduce their prices by an across-the-board carbon financing mechanism, and BESCOM has continued to scale-up its program.

Cumulatively, these subsidies are less than the taxes imposed on such fossil fuels as petrol (G-8 RETF, 2001). However, they have several effects that undermine, rather than bolster, sustainable energy objectives. First, by artificially reducing the price of certain fuels, they distort the market and encourage inefficient levels of consumption (that is, consumption in excess of what the society would use if it was necessary to pay a price that was based on market demand or on real costs). Second, fossil fuel subsidies make it more difficult for energy efficiency and cleaner sources of energy to compete.

The usual justification for subsidies is that they help the needy. In fact, many developing-country governments rely on subsidies largely because they lack other reliable mechanisms to make transfer payments to the poor. However, even as a mechanism to alleviate poverty, the use of subsidies is unsound. Because it is often difficult or impossible to restrict the use of subsidies to the neediest households, most of the benefit typically goes to wealthier households, which can afford a higher level of consumption.

Of course, fossil fuel subsidies are not restricted to developing countries. They are provided in many countries. They are also addictive and those who benefit from them are usually unwilling to give them up. Thus, analysts may conclude that subsidies should be eliminated or phased out. However, this is difficult for politicians who must renew their mandates periodically.

Thus, reforming and re-directing energy subsidies, if necessary, over time rather than all at once, may be a more realistic strategy for developing countries than attempting to abolish all subsidies simultaneously. For example, a gradual reduction in subsidies for conventional fossil fuels could be used to provide new subsidies for more sustainable forms of energy or more efficient technologies. Alternatively, public resources that are conserved by reducing subsidies could be directed toward other societal needs.

Where there is concern that poor households will be unable to access basic energy services if they are required to pay the full market price, it might be feasible to provide subsidies of up to only a certain level of consumption. This is more likely to be practicable for electricity than for portable fuels like petrol or kerosene. For example, low-income households could be offered reduced electrical rates for the first increments of consumption. In summary, creative policy approaches are needed to reconcile the differing interests of energy access expansion and the promotion of sustainable energy outcomes. The research community and non-governmental organizations (NGOs) should respond to this challenge and explore possible solutions, including new mechanisms for transferring aid to poor households to enable them to meet their basic needs.

Of course, in the longer-run, energy prices for fossil fuels should not only be subsidized, but also increased to reflect environmental and public health externalities that are not presently recognized by the marketplace. In principle, monetizing positive and negative externalities and ensuring that they are included in energy prices is an elegant way to address many issues of sustainability. Without this step, the market will tend to over-allocate resources where there are negative externalities (such as pollution) and under-allocate resources where there are positive externalities (such as improved energy security).

The difficulties associated with internalizing externalities are essentially parallel to those associated with removing subsidies, with the added complication that it is often difficult to place a precise monetary value on certain impacts. Figure 6 illustrates the results of one attempt by the European Commission to quantify the external costs of global warming, public health, occupational health and material damage associated with different ways of generating electricity. It shows that the ignored costs that are associated with coal, lignite and oil often greatly exceed the current cost differential with many renewable technologies. However, there is considerable uncertainty about the specific number for external costs that should be assigned to any technology.

These difficulties are not insurmountable. Governments are continually forced to make decisions based on reasonable judgment and negotiated in a political process in the face of uncertainty. In practice, the greatest difficulty is likely to be political. Raising energy prices is almost always very unpopular with business leaders and the public. There will be objections that higher energy prices may harm consumers and the economy, particularly competitive industries and low-income households.

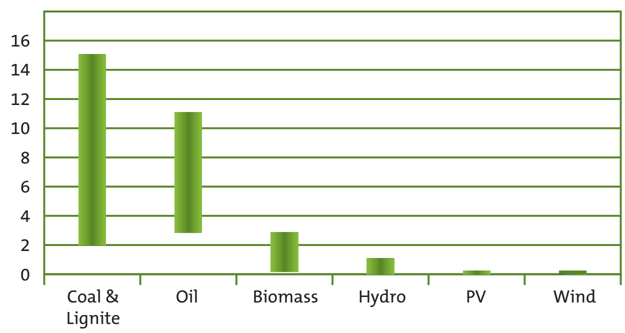

Figure 6. External Costs of electricity production in the EU in Eurocent/kWh. Source: Data from the European Commission-ENERGIE Programme (European Union 5th Research and Technological Development Framework Programme). G-8 RETF, 2001, Figure 4, p. 19.

As in the reduction or removal of subsidies, any effort to internalize externalities must deal with the conflicting desires to raise prices for many conventional forms of energy and to expand access for the poor. (This general point applies whether government seeks to internalize externalities by a tax or by environmental regulation.) Because of the parallel situations, some of the approaches used in subsidy reform may be helpful, including the use of a gradual approach and offsetting the impact on poor households by other forms of assistance. If the mechanism used to internalize externalities is an emissions tax, the additional public revenues can be used to provide increased support for social services or other (non-energy) necessities, or to subsidize other forms of consumption that primarily benefit the poor.

5.3 INDIGENOUS SUSTAINABLE RESOURCES

Many developing countries have abundant renewable energy potential and could benefit from the positive economic spillovers generated by renewable energy development, especially in underserved rural areas where decentralized, small-scale renewable energy technologies are likely to be competitive with conventional alternatives.

In most cases, however, government policies and public support will be necessary to take advantage of these opportunities. The World Bank has concluded that incentives are usually required to motivate the private sector to invest in providing services to the remote and underdeveloped areas where the poor reside. There is a case for providing intelligently designed incentives and/or subsidies for the development and use of appropriate technologies in these areas, preferably in ways that are targeted, simple, competitive and time-limited (G8 RETF, 2001).

Incentives or subsidies alone will not always suffice to overcome market barriers, especially for risky projects in less accessible areas of developing countries. In those cases, direct financial support from the government or outside groups or institutions may be necessary to implement renewable energy projects. There is ample precedent for such interventions. International aid organizations and other entities have invested millions of dollars in sustainable energy projects in developing countries. However, the record if success for such investments is decidedly mixed. Many projects have failed over time as a result of inadequate attention to practical problems, local conditions and a need for ongoing maintenance and operational expertise.

Because of the enormity of the challenge in relation to the resources available, it is essential that future efforts are more successful than in the past. This can be accomplished in part by taking greater care in the design and implementation of projects and by ensuring that the skills and financial resources needed to sustain new energy installations are in place. For its part, the research community should put greater emphasis on developing renewable energy technologies that are robust and well-adapted to the specific conditions found in developing countries. In addition, researchers and advocates must avoid the tendency to understate costs or to minimize potential problems with the technologies that they develop. Other aspects of this challenge are discussed in subsequent sections, which address the importance of expanding and improving international technology transfer initiatives and the need to build institutional and human capacity.

BOX B. USING RURAL COOPERATIVES FOR PV ELECTRICITY IN BANGLADESH

The Grameen Bank of Bangladesh, a world-renowned micro-lending agency, established a non-profit subsidiary, Grameen Shakti, in 1996 to administer loans for photovoltaic solar home systems to serve those who had no access to electricity. Initially, Grameen Shakti found that long distances, poor transport infrastructure, periodically flooded and impassable roads, low literacy rates, lack of technical skills and transactions based on barter contributed to high transaction costs and difficulty in building consumer confidence in their product. In 1998, a Global Environment Facility (GEF) grant enabled Grameen Shakti to offer improved credit terms to its customers and install thousands of systems. It also found that a critical mass of installations in an area (of the order of 100 systems) built consumer confidence, making it easier and less time consuming to expand the customer base (G8, RETF, 2001). Grameen Shakti now expects to be able to draw additional financing for scale-up activities from commercial banks.

It is obvious that government support is required to demonstrate new sustainable energy technologies and in the early stages of deployment described above. However, government involvement is needed even more in the early stages of research and development (R&D). Not surprisingly, developed countries have historically taken the lead in energy R&D spending because they have had the resources to do so. This will likely continue. However, this does not mean that there is no role for developing countries. Some of the larger developing countries have sufficient resources to permit them to invest significantly in technology. Others can participate by targeting investments and/or working cooperatively with other countries or institutions to ensure that their R&D efforts address the specific opportunities and constraints that apply in developing countries. Investment in energy R&D can also be seen as a way to build indigenous human capital in science and engineering. Brazil, for example, has nurtured a viable domestic biofuels industry through all stages of technology development, deployment and commercialization (see Box C).

However, governmental support for energy R&D is declining in all countries (UNDP, 2000, p. 448). In view of the challenges, this trend must be reversed because only governments take a long enough view (in the order of decades) to support the long-term investments in energy R&D that are needed to fully commercialize new technologies.

BOX C. NATIONAL ALCOHOL PROGRAM IN BRAZIL

When concerns about gasoline (petrol) shortages emerged in the first half of the 20th century (1896–1943), many European nations experimented with programs to blend gasoline and alcohol. However, as supply concerns faded, so did these programs. Brazil's earliest attempts to introduce blended automotive fuels occurred in 1903. However, a full-scale biofuel effort did not begin until 75 years later when the National Alcohol Program (Pro-Alcool) was launched in 1975 in response to a dramatic rise in international oil prices and the resulting adverse balance of payments.

At various times, Brazil's Pro-Alcool program has favored the use of neat hydrated alcohol (96 percent ethanol, 4 percent water) and gasohol (74 to 78 percent gasoline and 22 to 26 percent anhydrous ethanol), both of which are produced from sugar cane. Brazil now has the largest program of commercial biomass utilization in the world (UNDP, 2000, p. 229). Although automobiles that run on hydrated alcohol are no longer produced in Brazil, those that run on blends sustain an annual production of 200,000 barrels of ethanol per day. From 1975 to 1989, the value of the oil imports that were replaced by this production was about $12.5 billion US, although investments in the program during the same period did not exceed $7 billion US (Rosa and Ribeiro, 1998, p. 466). The value of oil imports displaced reached $40 billion US during the first 25 years of the program's operation.

Brazil's program has brought many social, economic, and environmental benefits. It has created significant numbers of skilled and semi-skilled jobs, played a significant role in developing a strong agro-industrial base, reduced urban environmental pollution by reducing carbon monoxide emissions and improved the global environment by curbing carbon dioxide emissions. Subsidies for this program were gradually reduced and then eliminated completely in 1999. Not surprisingly, the program seems to flourish most when international oil prices are high and international sugar prices are low.

5.4 TECHNOLOGY TRANSFER AND DEVELOPMENT OF HUMAN AND INSTITUTIONAL CAPACITY

Substantial efforts to facilitate technology transfer from developed countries to developing countries are essential to the achievement of global sustainability objectives. This is widely acknowledged and was affirmed most recently at the December, 2007, UN Conference on Climate Change in Bali. At that conference, developing-country negotiators called for language that explicitly linked mitigation action by developing countries to "measurable, reportable and verifiable" support for technology, finance and capacity-building.

Accordingly, Decision 1(d) of the Bali Action Plan[9] calls for enhanced action on technology development and transfer to support action on mitigation and adaptation, including the consideration of:

- Effective mechanisms and enhanced means for the removal of obstacles to, and provision of, financial and other incentives for the scaling up of the development and transfer of technology to developing countries to promote access to environmentally sound technologies.
- Ways to accelerate deployment, diffusion and transfer of affordable environmentally sound technologies.
- Cooperation in R&D of current, new and innovative technology.
- The development of effective mechanisms and tools for technology cooperation in specific sectors.

While the current situation requires more technology transfer, it also demands that technology transfer be done better. In the past, too many well-intended projects have failed to live up to expectations. To ensure that rural areas of developing countries do not become graveyards for sustainable energy technologies, sustained attention must be paid by both host and donor nations to the human and institutional capacities needed to support these technologies on a long-term basis (UNDP, 2000, p. 441).

Research shows that technology transfer is more successful and more likely to produce innovation when the host institution has the requisite technical and managerial skills. Thus, there is an urgent need to develop skills to produce, market, install, operate and maintain sustainable energy technologies in developing countries. Ensuring that as much of this capacity-building as possible takes place in local communities and that companies based in the host country have the potential to provide additional benefits in local job creation and economic development because project developers and operators are likely to be more effective if they have close ties to the population that will use the technology. One potentially promising approach to capacity building involves the development of regional institutes that can provide training in basic technology skills to local organizations and individuals drawn from the local population. Such institutes could also help to provide independent assessments of alternative technologies and policy choices and explore practical strategies for overcoming real-world barriers to further deployment of sustainable energy technologies (UNDP, 2000, p. 441; Martinot *et al*, 2002). The Consultative Group on International Agricultural Research (CGIAR) has successfully used this approach to disseminate technological and scientific advances in agriculture to developing countries. This may provide a promising model for the energy field.

In summary, successful technology transfer and a worldwide expansion of the human and institutional capacities needed to implement sustainable technologies are essential elements of an effective global response to the energy challenges that we face. To meet these challenges, developed countries will need to follow through on current commitments and work closely with developing countries to make the most effective use of scarce resources. Developing countries must not be passive bystanders in that process. They have everything to gain by leveraging future investments to build their indigenous human

[9] Source: http://unfccc.int/files/meetings/cop_13/application/pdf/cp_bali_action.pdf

and institutional capacities and by taking the lead in adapting and improving sustainable energy technologies to suit their particular needs.

5.5 CLEAN, EFFICIENT COOK STOVES

The rationale for immediate policy action to accelerate the transition from traditional cooking methods to the use of clean, efficient cook stoves is based on public health and welfare concerns. Therefore this recommendation stands somewhat apart from the others discussed here, which tend to be motivated by broader environmental and energy security concerns.

Improved cook stoves are worth mentioning, however, because they offer enormous public health and welfare benefits at a relatively low cost. It has been estimated that exposure to indoor pollution from the use of fuels like wood and dung for cooking and space heating causes as many as 1.6 million deaths annually throughout the world, primarily women and young children (WHO, 2002). In addition, the need to gather fuel can cause local environmental degradation and take up great amounts of time, particularly for women and girls that might otherwise be available for more productive activities. A shift away from traditional fuels for cooking could marginally increase demand for commercial fuels like propane, natural gas or electricity. The change would be quite small in relation to overall energy requirements and more than justified from a social welfare perspective. Various programs have been instituted to distribute improved cook stoves to poor households in rural areas. One is described in Box D.

BOX D. CERAMIC CHARCOAL STOVES IN KENYA

The Kenya Ceramic Stove (jiko) is one of the most successful cook stove initiatives in Africa (UNDP, 2000, p. 198). Between the mid-1980s and the mid-1990s, more than 780,000 of these stoves were distributed. Today, some 16 percent of rural households in Kenya also use these more efficient jiko stoves.

The program promotes a stove that is made of local ceramic and metal components by the same artisans who make traditional stoves. The new stoves do not differ radically from traditional all-metal stoves, except that their energy efficiency is close to 30 percent. The remarkable feature of this program is that it has received no government subsidies. This lack of subsidies has forced private entrepreneurs to undertake the production, marketing and commercialization of the stove at prices that Kenya's low-income households can afford. The project has been successfully replicated in Malawi, Rwanda, Senegal, Sudan, Tanzania and Uganda (UNDP, 2000, p. 198).

However, the stove still requires charcoal, which must be produced and transported. Charcoal production has been very inefficient historically and will need attention if the program is to reach its full environmental potential.

6. CONCLUSION

For the past 10 to 15 years, the energy sectors in most countries have been in turmoil. Many developing countries have been attempting to restructure their energy sectors, but are finding it difficult to implement reforms. The reasons include the multiplicity of actors involved, the changing perceptions of the relative roles of the market and governments, and the accumulation of policies of past decades, many of which may have made sense when they were proposed, but now impose unsustainable burdens. Meanwhile, a sharp run-up in world energy prices over the last two years and growing concerns about the supply of conventional petroleum (and natural gas, in some parts of the world), combined with projections of continued strong growth of demand globally and greater awareness of the threats posed by climate change, have brought a heightened sense of urgency to national and international energy policy debates.

The current energy outlook is challenging to say the least. Whether governments are chiefly concerned with economic growth, environmental protection or energy security, it is clear that a continuation of current energy trends will have many undesirable consequences at best, and risk grave, global threats to the well-being of the human race at worst.

The situation in developing countries is in many ways more difficult than that for developed countries. Not only are there obvious resource constraints, but also a significant part of the population may lack access to basic energy services.

Yet, developing countries also have some advantages. They can learn from past experience, avoid some of the policy missteps of the last half century and have an opportunity to "leapfrog" directly to cleaner and more efficient technologies. Fortunately many essential elements of a sustainable energy transition can be expected to mesh well with other critical development objectives, such as improving public health, broadening employment opportunities, nurturing domestic industries, expanding reliance on indigenous resources and improving a country's balance of trade.

This does not mean that cleaner, more efficient technologies will usually be the first choice or that difficult trade-offs can always be avoided. In the near term, many sustainable energy technologies are likely to remain more expensive than their conventional counterparts. Even when they are cost-effective, as is already the case for many efficient technologies, powerful market failures and barriers often stand in the way. Changing the incentives and overcoming those barriers is now more a question of political will and coordination than one of adequate resources (at least at the global level).

This doesn't make the task any easier. In surveying the current landscape, one can find ample justifications for a profoundly pessimistic view—or an equally optimistic view. Which outlook proves more accurate will depend to a large extent on how quickly developed and developing countries recognize and begin to act upon their shared stake in achieving positive outcomes that can be managed only by working together.

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