Chapter 21

Energy research and technology for a transition toward a more sustainable future

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Note: This chapter is a commentary on chapter 20.

The last fifty years of unprecedented development in the world have improved the human condition enormously but at the same time have resulted in widening gaps between rich and poor and in adverse environmental impacts on all scales, from indoor air pollution to climate change and biodiversity loss. Current patterns of development are thus clearly unsustainable. We need a fundamental paradigm change to produce a shift toward more sustainable development paths. This includes affordable access to adequate energy services. In her contribution to the present book, Annette Schavan also calls for fundamental innovations to help achieve structural changes in society, the economy, institutional structures, and in lifestyle and consumption patterns.

The recent financial crisis and the ensuing ever-deeper economic depression are no doubt going to bring additional hardship, especially to those without access to basic human needs. A predominant social issue that is increasingly becoming a major preoccupation for world leaders is how to address social inequality and poverty, especially in the developing world (Karekezi and Sihag, 2004). The longer the economic crisis deepens, the more threatened those living in poverty will be.

In response to the call to fight social inequality and poverty, world leaders endorsed the United Nations Millennium Development Goals (MDGs) as agreed upon by the Millennium General Assembly of the UN in 2000 and further advanced at the World Summit on Sustainable Development in 2002. The MDGs include eight specific goals but the primary objective is to halve extreme poverty by 2015 (Elliot, 2005). It is becoming increasingly evident that at current trends this goal will not be achieved even decades later in the poorest countries and regions of the world. Thus, it is urgent that significant effort is devoted toward the achievement of the MDGs.

Currently, it is estimated that about 2.6 billion people live on less than USD 2 a day and up to 3 billion on less than USD 2.5 per day (Chen and Ravallion, 2008; World Bank, 2008) – 75 % of whom reside in rural areas (IADB, 2005). Furthermore, it is estimated that 1.4 billion people live in extreme poverty (World Bank, 2008). This estimate is an upward revision from the previous one of 1 billion people living in extreme poverty. This trend underscores the importance of increasing efforts to meet the MDGs.

Affordable access to modern energy services has a significant role to play in meeting development goals as it is a fundamental prerequisite for reaching virtually all MDGs. However, modern energy services in the majority of developing countries are characterized by inequality of access, notably between the poor and the affluent, but also between rural and urban areas. At the national level, this is demonstrated by the low levels of modern energy in the primary energy supply mix, and by low electrification and low electricity consumption levels.

About 2 billion people or approximately a third of the world's population are without access to modern energy and about 1.6 billion are without access to electricity – the very symbol of affluence and modernity – while about 2.4 billion still cook with traditional forms of biomass (Nakicenovic *et al.,* 1998; Saghir, 2005; UN-Energy, 2005). Limited access to cleaner energy services supplied by modern energy carriers is an important contributor to rising levels of poverty in some sub-Saharan African countries (UNDP, 2007; Takada and Fracchia, 2007).

It is estimated that the cost of connecting a household without prior access to electricity is in the order of USD 1000 (Goldemberg, J., personal communication), resulting in total capital needs of about USD 500 billion, assuming an average of four persons per household and two billion people without access. Distributed over twenty years, this translates into annual investment requirements of some USD 25 billion. This represents a huge investment that is lacking, yet it does not appear excessive in comparison to the gigantic scale of the government guarantees and debt cancellation in the financial sector since the economic crisis emerged. To be effective, this kind of investment would have to be enhanced initially by a certain level of free energy for the poorest, say 700–1000 kWh per year or about 2–3 kWh per day (WGBU, 2009).

Thus, there is a clear need to embark on a new development path toward sustainable and affordable access to adequate energy services. Fortunately, many policies and measures directed toward increasing access to modern energy services have multiple benefits for other development goals, from the reduction of indoor air pollution and its assaults on human health to reductions of greenhouse gas emissions.

Some may argue that this transformation toward more sustainable development paths and energy patterns in the world will be difficult to achieve because falling consumer demand leads to a vicious circle that results in ever-decreasing employment reducing further the demand for traditional goods and services.

At the same time, this crisis of the 'old' is an opportunity for the 'new' to emerge. It is an opportunity that needs to be seized and should not go to waste. Joseph Schumpeter referred to paradigm-changing transformations of this kind as 'gales of creative destruction' (Schumpeter, 1942). As old techno-economic and institutional development paths encounter their limits, the chances for fundamentally new development paths to emerge and eventually diffuse become more likely.

Decarbonization of the global economy toward a carbon-free future is such a paradigm-changing transformation. It appears to be a must, given the ever-more-threatening manifestations of global climate change. In her contribution to the present book, Annette Schavan quotes the unequivocal message of the IPCC Fourth Assessment Report (IPCC, 2007) that climate change is accelerating and is almost certainly largely caused by humans. Anthropogenic greenhouse gas emissions over the last two centuries, since the beginning of the industrial revolution, have increased atmospheric concentrations of carbon dioxide from some 280 ppm to over 380 ppm today. The IPCC estimates that the global average surface temperature has increased by some 0.8 °C during the last century. Annette Schavan also observes that the negative effects of climate change can already be felt, and quotes the Federal Chancellor, Angela Merkel, saying that determined action from the international community is required to promote innovation and technological developments to support climate protection.

The necessary change toward wider access to modern energy services together with climate protection and decarbonization of the global economy is effectively blocked today by the addictive dependence on fossil energy sources. This explains the need for the Schumpeterian 'gales of creative destruction'. Today, 80 % of global energy comes from fossil sources, and this situation needs to be reversed so that 80 % of energy would be carbon-free or carbon-neutral well before the end of the century. The old energy systems need to be replaced by innovative, environmentally and climate-friendly alternatives. In parallel, the reliance on inadequate, traditional energy by the poor, which constitutes some 10 – 20 % of primary energy today (see Fig. 1), also needs to be replaced by modern renewable and other clean energy sources as well as efficient end-use devices from modern stoves to advanced lighting, communication and information technologies. For that to occur, we need vigorous private and public research and development efforts and partnerships in order to create the necessary scientific foundations for the paradigm-changing transformations. In this context, Annette Schavan argues that we need science and research to gain a better understanding of the complexity of the processes and interactions within the climate and the Earth system. She further argues that the important aim is to create fundamental innovations to help achieve structural changes in society, the economy, institutional structures, and in lifestyle and consumption patterns. We need to establish a foundation for the deployment and adoption of new systems and services that lead toward complete decarbonization of the global economy, and that involve all the world's population, from those without access to energy today to those living in affluence at high levels of consumption.

In other words, research and development (R&D) that lead to the diffusion of new and advanced technologies and practices represent a possible solution to the double challenge of providing development opportunities to those who are excluded and allowing for further development benefitting the more affluent. As Annette Schavan points out, this needs to occur without risking irreversible changes in ecological, biophysical and biochemical systems. As regards energy, this implies a shift from traditional energy sources to clean fossils and modern renewable energy in the case of those currently excluded from access, and a shift from fossil energy sources to carbon-free and carbon-neutral energy services in the more developed parts of the world. In all cases this means a vigorous improvement of energy efficiency, from

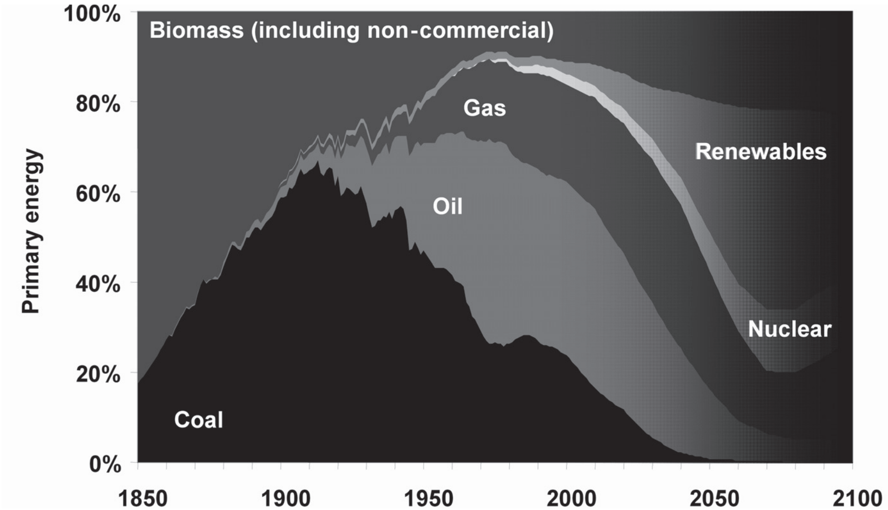

Fig. 1. History and possible future of global primary energy showing the relative shares of the most important energy sources. The future developments are consistent with stabilization of global temperature increase at about 2 °C above preindustrial levels. (*Sources:* Riahi and Nakicenovic, 2007; IIASA, 2007)

supply to end use, expanding shares of renewables, more natural gas and less coal, vigorous deployment of carbon capture and storage, and in some cases – where it is socially acceptable and economically viable – also nuclear energy.

Figure 1 shows the historical evolution of global primary energy and one possible future development path toward decarbonization. It is an illustration of the needed transformational change of the global energy system. New energy technologies and practices but also changes in lifestyles and behaviour are prerequisites in order to shift the energy system from its current dependence on fossil energy toward complete decarbonization well before the end of the century.[1]

This particular scenario describes a future world that stabilizes concentrations of greenhouse gases just above the current levels and thereby limits the temperature increase to about 2 °C. Even a global temperature increase of 2 °C would lead to significant disruptions of natural ecosystems, threatening water availability and communities in coastal areas (IPCC, 2007). The poor and those who are excluded would bear the brunt of such changes. Nevertheless, a 2 °C world would probably avoid the most severe adverse – and perhaps also irreversible – consequences associated with higher magnitudes of global warming. Therefore, this particular scenario can be characterized as a transition toward sustainability that enables the

[1] This will require vigorous introduction of carbon-free sources of energy and carbon capture and storage (CCS) from fossil energy, and perhaps also biomass, in order to reduce carbon emissions to zero or even turn them negative toward the end of the century.

fulfilment of the MDGs through provisioning energy services in most of the world while simultaneously avoiding more drastic climatic changes (UN-Energy, 2005).

The current investments in the global energy system are estimated at some USD 500 billion per year (Nakicenovic and Kimura, 2005). This includes investments in energy production, conversion and distribution but excludes most of the end use such as vehicles, heating systems or industrial facilities. Adding end-use investments would bring the estimate to some USD 750 billion per year. The sustainable scenario depicted in Figure 1 would require at least twice this investment effort during the coming decades to the tune of about USD 1 trillion per year or about USD 20 trillion until 2030. In comparison, the investments needed to provide access to modern forms of energy to the two billion people currently living without it are relatively small, at about USD 25 billion per year or about USD 500 billion until 2030.

The nature of technological change and the associated deep uncertainties require that innovations are adopted as early as possible in order to lead to lower costs and wider diffusion in the following decades. The longer we wait before introducing these advanced technologies, the higher the required emissions reduction will be. At the same time, we may miss the window of opportunity for achieving substantial cost reductions through technological learning as a function of cumulative experience and investments. This requires research, development and deployment (RD&D) as well as investments in order to achieve accelerated diffusion and adoption of advanced energy technologies.

Current global energy research and development (R&D) trends are unfortunately going in the opposite direction. Public annual expenditure in this area in OECD countries has declined to some USD 8 billion today from about USD 12 billion two decades ago, while private ones are estimated to have declined proportionally and are now about four times the public efforts (IEA and OECD, 2008). This means that today we are investing less than USD 10 per person in the world per year in energy-related R&D activities. Many studies indicate that this sum needs to increase by at least a factor of two to three in order to enable the transition toward new and advanced technologies in the energy systems (Bierbaum *et al.,* 2007). However, it needs to be noted that Finland, Japan and Switzerland constitute important exceptions with substantially higher public and private spending on energy R&D efforts. In her essay, Annette Schavan suggests 3 % of gross domestic product (GDP) as a goal for future R&D efforts. Tripling global energy R&D and assuming the current 4 % share of global energy in total R&D efforts translates into some 1.5 % of global GDP.

As mentioned, the required investments in energy systems, an estimated USD 20 trillion needed between now and 2030, are at least a factor of a hundred greater than the needed R&D efforts. This translates into about twice the current level of investment, with most of the requirements being in developing parts of the world. To achieve a transition toward more sustainable development paths substantially larger investment in energy infrastructures and energy R&D is needed. All told, R&D efforts need to be tripled and energy investments at least doubled in order to assure the timely replacement of energy technologies and infrastructures.

The salient finding of a number of recent integrated assessment studies is that the additional costs needed to achieve a more sustainable future and climate stabilization are relatively small in comparison to these overall investment needs. Often they are 'negative', namely lower than those projected by traditional scenarios of future developments, sometimes called business-as-usual (BAU) scenarios. However, attaining a more sustainable type of future requires higher 'up-front' investments until about 2030. The great benefit of these additional investments in a future characterized by carbon-leaner energy systems and a more sustainable development path is that in the long run (by 2050 and beyond) the investments would be substantially lower compared to the BAU alternatives. The reason for this is that the cumulative nature of technological change translates the early investment in decarbonization and a sustainable energy future into lower costs of the energy systems in the long run, along with the co-benefit of climate stabilization. This all points to the need for radical change in energy policies to assure sufficient investment in our common future. Accelerated technological change in energy production and end use needs to be promoted. In other words, the global financial and economic crisis offers a unique opportunity to invest in new technologies and practices that would generate employment and affluence in most parts of the world. Seizing this chance today would pave the way for the eradication of poverty as well as a more sustainable future with lower rates of climate change. The crisis of the 'old' is a historic chance to sow the seeds of the 'new'.

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