HEINRICH BÖLL STIFTUNG

Systems for Change: Nuclear Power vs. Energy Efficiency + Renewables?

“We know the country that harnesses the power of clean, renewable energy will lead the 21st century.”
President Barack Obama, State of the Union Address,
February 2010

Hypothesis

Continued investment in nuclear power, in particular new nuclear power plant projects, constitutes a significant barrier for the necessary shift toward a sustainable and intelligent energy-services economy based on energy efficiency and renewable energy sources.

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Introduction

US President Obama's speech of 16 February 2010 on energy in Maryland[1] sets the tone. The possible future, he says, is "a future in which renewable electricity is fueling plug-in hybrid cars and energy-efficient homes and businesses" and "in which we're exporting home-grown energy technology instead of importing foreign oil." And in order to get there, he says, more is needed:

> We'll need to make continued investments in advanced biofuels and clean coal technologies, even as we build greater capacity in renewables like wind and solar. And we're going to have to build a new generation of safe, clean nuclear power plants in America.

Efficiency, renewables *and* nuclear power. French President Sarkozy agrees with his US counterpart and on 9 June 2009 he stated: "We will take a turn on renewable energies that is as significant as the one General de Gaulle took on nuclear in the 1960s. It is not one or the other. It is one and the other."[2] Sarkozy announced that for each euro spent on nuclear, a euro will be spent on renewable energy. He also clarified the political agenda on the issue. The investment parity is meant to "preserve a consensus on nuclear and get those that are opposed to nuclear to tolerate it."[3] What has been known for 65 years as the French Atomic Energy Commission has been renamed Atomic and Alternative Energy Commission (Commissariat à l'Energie Atomique et aux Energies Alternatives).

Nuclear power as a "bridging technology"? Germany's conservative coalition government has announced that it plans to extend the operation of its remaining 17 nuclear power plants beyond the deadlines that are defined in the still valid nuclear phase-out legislation. According to the coalition agreement between the two government parties, "the lion share" of the additional utility profits from plant life extension shall be taxed by the government and reinvested in renewable energies and energy efficiency in particular. The explicit prohibition of nuclear new built shall remain untouched. Chancellor Angela Merkel's government and her own party are split when it comes to the implementation of the agreement. Environment Minister Norbert Röttgen stated that the challenge is to shift "quasi entirely to renewable energies" and he stresses that he does not know "anybody in the coalition that says: Nuclear is our technology of the future."[4] Röttgen wants the nuclear phase-out to be accomplished by 2030 – about eight years later than the timeframe under the current legislation, when reactors reach about 40 years in age and renewables are supposed to cover 40% of the electricity, up from 16% today. The German minister points out that "a lot of nuclear electricity and a lot of eco-electricity don't fit together as economic concepts."[5]

Fit or don't fit together? Germany is likely the most interesting case when it comes to the analysis of potential complementary or contradictory aspects of nuclear and efficiency+renewables-based energy systems. The German Federation of Municipal Enterprises (VKU) – a powerful association of

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[1] Remarks by the president on Energy in Lanham, Maryland (16 February 2010), http://www.whitehouse.gov/the-press-office/remarks-president-energy-lanham-maryland

[2] Le *Monde* (9 June 2010); in fact, it was not de Gaulle that launched the first large nuclear power plant program but Prime Minister Messmer in 1974.

[3] Ibid. One should add that the "consensus" on nuclear power was never a public opinion consensus but rather an agreement by the major political parties.

[4] *Frankfurter Rundschau* (19 February 2010), http://www.fr-online.de/in_und_ausland/wirtschaft/debatte_energie_der_zukunft/?em_cnt=2331965&

[5] Ibid.

1,350 companies that covers over half of the country's end-users in the electricity and heat sectors – is concerned about the consequences of the planned delayed phase-out of nuclear power. VKU's executive director, Hans-Joachim Reck, declared in a press statement:[6]

> The negative implications for competition and for the conversion of the energy system toward decentralization and renewable energies are entirely blanked out. […] It is counterproductive to discourage investments of municipal utilities into efficient and future-oriented energy generation.

Municipal power plant investments in Germany in the order of €6.5 billion would now have to be reassessed, and even the economic viability of already implemented projects would be threatened, VKU added.

Many systemic issues have not been thoroughly investigated yet when it comes to compatibility or incompatibility of the centralized nuclear approach versus the decentralized efficiency+renewables strategy. What are the consequences for grid development or how do choices on grid characteristics influence power-generation investment strategies? To what extent is the unit size co-responsible for structural overcapacities and thus a lack of incentives for efficiency? How do government grants/subsidies stimulate long-term decision-making? Will large renewable power plants reproduce the same system effects as large coal/nuclear plants?

The present report presents the basic situation and raises questions that urgently need to be addressed. Successful energy policy will have to address the energy service needs of people in a much more efficient way than has been done in the past, as increased competition for ultimately finite fossil fuel leads to higher energy prices for all. For too long, energy policies have aimed at "supply security" of oil, gas and kilowatt-hours, rather than general access to affordable, reliable and sustainable services like cooked food, heat and cold; light; communication; mobility; and motor torque.

The outcome is well known. Even in industrialized countries with established nuclear power programs like the United States, France and the United Kingdom, fuel poverty has become a severe problem and is rising rapidly. The acronym EWD has been created: It stands for Excess Winter Deaths. A European project[7] has shown that the number of people that die during the winter because they cannot afford to heat their homes appropriately has become statistically highly significant. EWDs vary from 10% in Paris to 30% in Glasgow. In the United Kingdom, it is estimated that 15,000 people die in winter in addition to the normal mortality rate due to consequences of fuel poverty. In nuclear France, close to eight million households, about 28% of the total, spend over 10% of the budget on energy (including transport). Since 2005 about three million French families have been eligible for the Tariff for Primary Necessities, another recent invention that provides a subsidized lower tariff for low-income families.

It is obvious that nuclear power did not lead to broad-scale and just access to energy services in the countries that opted for nuclear energy. But is a nuclear strategy actually counterproductive for the development of a clean-energy service future based on efficiency+renewables? There is strong

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[6] VKU, press release 2/10 (19 January 2010).

[7] European fuel Poverty and Energy Efficiency, see http://www.precarite-energetique.org/

evidence that this is the case. As *Time* magazine commented on President Obama's nuclear loan-guarantee decision: "Eventually, extravagant government largesse might create a nuclear rebirth of sorts – but it might end up strangling better solutions in their cribs or prevent them from ever being born."[8]

Nuclear vs. Renewable

Amory Lovins:[9] "But nuclear power is about the least effective method: It does save carbon, but *about 2 to 20 times less per dollar and 20 to 40 times less per year than buying its winning competitors."*

Bill Keepin and Gregory Kats:[10] Improving electrical efficiency is nearly seven times more cost-effective than nuclear power for abating CO_2 emissions, in the United States.

Environment California:[11] "Per dollar spent over the lifetime of the technology, energy efficiency and biomass co-firing are five times more effective at preventing carbon dioxide pollution and combined heat and power is greater than three times more effective" than nuclear power.

Warwick Business School:[12] The undermining of other technologies means that nuclear power is not complementary to other low-carbon technologies. This refutes the argument that all low-carbon technologies should, and are able to, be harnessed together so that they can harmoniously work together to reducing carbon dioxide emissions. On the contrary, the government has to make a choice between a nuclear future and one dominated by renewable generation and the more efficient use of energy.

Duke University: [13] "Solar photovoltaics have joined the ranks of lower-cost alternatives to new nuclear plants," John O. Blackburn, professor of economics.

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[8] *Time* magazine (18 February 2010).

[9] Amory B. Lovins, "Proliferation, Oil, And Climate: Solving For Pattern"; Lovins' expanded version of essay "Proliferation, Climate, And Oil: Solving For Pattern," *Foreign Policy* (17 January 2010).

[10] B. Keepin and G. Kats, "Greenhouse Warning. Comparative Analysis of Nuclear and Efficient Abatement Strategies," *Energy Policy* 15:6 (December 1988): pp. S38-S61.

[11] Travis Madsen, Tony Dutzik, Bernadette Del Chiario, and Rob Sargent, *Environment California: Generating Failure: How Building Nuclear Power Plants Would Set America Back in the Race Against Global Warming* (November 2009).

[12] Catherine Mitchell and Bridget Woodman, *New Nuclear Power: Implications for a Sustainable Energy System* (Warwick Business School: March 2006).

[13] Nuclear Energy Loses Cost Advantage, Diana S. Powers, New York Times, July 26, 2010

Overview and Trends

Energy demand and the impact of a carbon- and resource-constrained world

The last few years have seen unprecedented changes in the energy sector. The markets – in particular for oil but with a knock-on effect to the other energy sources – have been extremely volatile. By mid 2008, the price of oil was close to $150 per barrel – an eightfold increase from a decade earlier. However, within a few months, the high prices had accelerated global economic problems, resulting in a price collapse to around $30 per barrel. In all energy sectors, the global recession has depressed energy consumption and, remarkably, 2009 was the first year since the end of World War Two that global electricity consumption has fallen.

However, globally, traditional energy "forecasts" anticipate rapid increases in energy demand, driven primarily by the need to fuel the growing economies in Asia, and particularly China, and to a lesser extent India. The International Energy Agency (IEA) assumes in its Reference Scenario of the 2009 World Energy Assessment that global energy demand will increase by 40% by 2030. Within this scenario, Chinese energy consumption effectively doubles between 2007 and 2030, while in the European Union demand increases by only 1%, and in the United States by less than 5%. The Reference Scenario adopted by the IEA is not a sustainable one, but is an extension of current national policies. There is no doubt that development along this pathway would lead to unparalleled and catastrophic changes in the atmosphere, with the IEA suggesting that the "the CO_2 concentration implied by the Reference Scenario would result in the global average rising by up to 6 degrees Celsius."[14]

The climate impact is not the only – or even necessarily the most pressing – problem associated with the Reference Scenario. The question of the midterm availability of suitable resources and the associated impact on the physical availability and prices for consumers is pressing, especially for liquid fuels. In recent years, the IEA has decreased the 2030 estimates for oil demand in its Reference Scenario. In the 2004 *World Energy Outlook*, global oil demand was expected to grow at an annual rate of 1.6% per year, reaching 121 million barrels per day (mb/day) in 2030, compared to current annual growth-rate scenarios of 1% per year, leading to 105 mb/day in 2030. The IEA has in particular altered its assumptions for consumption of oil in OECD countries with a 17-mb/day difference between the 2004 and 2009 scenarios. The lower oil demand still, however, leads to serious questions of resource availability due to a combination of overall increase in demand (as current demand is 76 mb/day). An assessment by the UK Energy Research Centre in 2009 estimated that the average rate of decline from fields that are past their peak of production is at least 6.5%/year globally, while the corresponding rate of decline from all currently-producing fields is at least 4%/year. To maintain the current levels of output, 3 mb/day of new capacity would be required each year, or the equivalent of the production of Saudi Arabia every three years.[15]

Therefore, from a security of supply and climate security system perspective, the current energy system and the policies that shape it are highly unsustainable. Regardless of the type of energy

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[14] IEA, *World Energy Outlook* 2009, p. 44.

[15] UKERC, *Global Oil Depletion, An Assessment of the Evidence for a Near-term Peak in Global Oil Production* (August 2009).

system envisaged, new investment will be required to meet predicted increases in demand for the exploitation of new energy sources and to replace existing infrastructure and facilities. The IEA estimated that the investment cost for its Reference Scenario will be in the order of $26 trillion between 2008 and 2030, or an annual requirement of $1.1 trillion – 1.4% of global GDP per year. Over half of this cost would be for the power sector. Importantly, the IEA has also undertaken a scenario in which emissions from the energy sector are reduced so as to fall within the 2 degree target. The investment costs associated with this "450 Scenario" are significantly higher than for the Reference case and would require an additional $10.5 trillion. However, the IEA also calculates that the 450 Scenario will result in a reduced energy cost of around $8.6 trillion by 2030 and a total savings over the lifetime of the structures of $17 trillion.

It is clear that a new direction is needed to create a sustainable and secure energy sector and that the current policies and market trends in place around the world must radically and rapidly change. In the long term, a low-carbon and environmentally secure energy sector is possible and will be cheaper than attempting to continue business as usual. However, just switching from a highly polluting to a less-polluting energy source will not result in a sustainable energy sector. Instead, there also needs to be systemic change that places far greater emphasis not only on the efficiency of the system as it relates to energy use, but also on its production, transformation and transmission, which are often overlooked.

Transforming the energy-supply options

Global energy consumption has increased as a result of the increase in population and per capita energy use. The figure below shows the extent to which global energy consumption has increased over the last two centuries, with a doubling between 1800 and 1900, and an eightfold increase in the last 100 years. As noted by the IEA and others, this trend is expected to continue as less-developed countries seek to increase the standard of living of their populations and enable them to have even basic energy services. Currently, around a quarter of the world's population lack access to electricity-based services and there is a fivefold per capita difference between energy consumption in OECD and developing countries. The figure also shows the extent to which commercial fossil fuels – those from coal, gas and oil – have contributed to this gap. While the global annual population growth rate has slowed in recent years to 1.3%, the UN's medium fertility scenario envisages that the population will not peak until after 2200, when it will have reached 10 billion, up from today's 6 billion level.[16]

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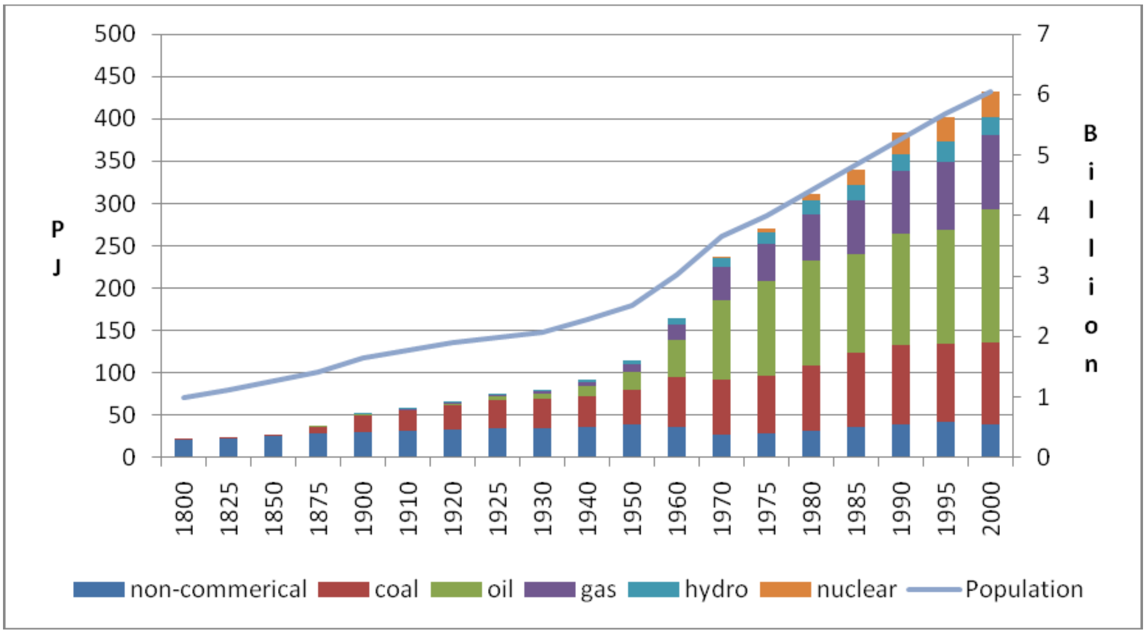
[16] UN, Six Billion (2004), http://www.un.org/esa/population/publications/sixbillion/sixbilpart1.pdf

Figure 1: Growth in Global Energy Demand



Source: Arnulf Grübler, 2008.[17]

Historic and projected development of renewables

Renewable energy was for centuries the main energy source for the human race, initially through the burning of biomass – particularly wood – but then through the exploitation of water and wind power. However, over the last centuries the reliance on renewable energy has declined as the ability to harness energy from fossil fuels developed. The use of fossil fuels, in particular in the form of coal, oil and then gas, has enabled energy to be released on an unparalleled scaled. This is because they are relatively energy-dense and therefore, despite the energy consumed in their processing and transportation, the consumer can obtain large quantities of usable energy.

However, in the last few years this trend has started to reverse in certain regions and sectors. Most notable has been the EU power sector. In Europe €13 billion of wind investment was made in 2009, which led to wind power installations accounting for 39% of new installations – the second consecutive year in which more wind power was installed than any other generating technology. Furthermore, renewable power installations in general accounted for 61% of new installations in 2009. The EU power sector continues its move away from coal, fuel oil and nuclear, with each technology continuing to decommission more than it installs.[18]

Figure 2 shows how a similar trend is developing within the global power sector. In 2009 new investment in sustainable energy was $162 billion (7% down from the record 2008 figure of $173 billion, as a result of the global economic crisis).

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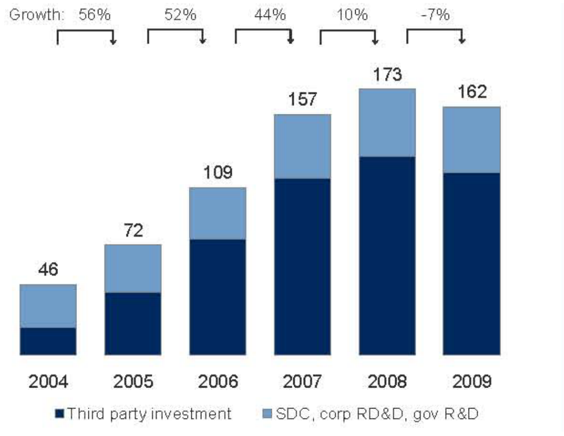
[17] Arnulf Grubler, “Energy transitions,” in *Encyclopaedia of Earth*, ed. Cutler J. Cleveland (Washington, DC: Environmental Information Coalition, National Council for Science and the Environment, 2008).

[18] EWEA, *More Wind Power Capacity Installed Last Year in the EU Than Any Other Power Technology*, European Wind Energy Association (February 2010).

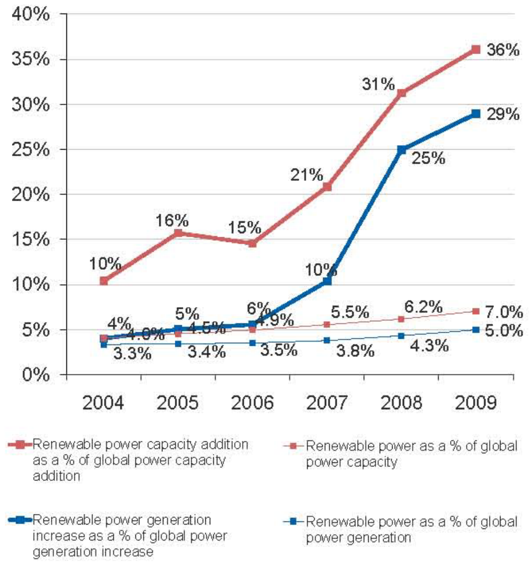
Figure 2: New Financial Investment in Clean Energy by Sector: 2004-2009 (US$bn)



Source: UNEP et al., Global Trends in Sustainable Energy Investment, 2010[19].

However, this was still the second highest annual investment total ever (and four times that seen in 2004) and spending on new capacity (including large hydro as well as other renewable) was for the second year running bigger than the investment in new fossil fuel capacity. As a consequence, as can be seen in Figure 3, 36% of the total increase in the installed capacity of the power sector was renewable (excluding large hydro), however, its total contribution to the global electricity consumption , is still relatively low at only 5%.

Figure 3: Global Growth of Renewable Energy in the Power Sector (excluding Large Hydro)



Source: UNEP et al., Global Trends in Sustainable Energy Investment, 2010.

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[19] SDC = small distributed capacity: New investment volumes adjusts for re-invested equity. Total values include estimates for undisclosed deals (source New Energy Finance)

Hydropower

The development and widespread use of electricity has resulted in considerable use of hydropower, which in 2009 produced around 3,200 terawatt hours (TWh) of electricity per year (an equivalent of 740 million tons of oil equivalent – mtoe). As a contribution to the global energy mix, this equates to around 15% of electricity. The installed capacity of hydropower is 923 gigawatts (GW) and is by far the largest of the renewable sources. However, there are significant differences in the environmental impacts and acceptability of hydropower. This particularly relates to the size of hydropower facilities.

Despite having many of the most accessible and economical large hydro sites in operation, particularly in North America and Europe, there has not been a significant increase in the use of hydropower. In fact since 2000 the global output of hydropower has increased by only 20%, which is below the rate of increase in electricity consumption as a whole. Consequently, hydropower's contribution to global electricity consumption has declined from 17% in 2000 to little over 15% in 2009, according to the BP Statistical Review of World Energy. Under the IEA's Reference Scenario, the electricity production from hydropower is expected to increase by around 50%, although its relative contribution will fall to nearly 14%. Even in the 450 Scenario, it is expected to provide only around 19% of electricity by 2030.

Scenarios by other organizations also indicate that there will be no significant increase in output from the hydro sector. Greenpeace's Energy Revolution scenario assumes even less installed capacity from hydropower than the IEA's Reference Scenario.[20] However, assessments do show that the potential from hydropower is potentially much larger. The World Energy Assessment estimates that the economic potential is approximately 8,100 TWh, the technical potential some 14,000 TWh and the gross theoretical potential around 40,000 TWh.[21] Reaching many of these levels would potentially bring large and, to many, unacceptable environmental and social consequences, and therefore will not be undertaken. However, some expansion could be achieved through smaller run of the river power plants or increased efficiency of existing facilities.

Figure 4 shows the relative importance of hydropower in the global electricity supply mix over time. Importantly, despite its relatively good economic performance, the expansion of hydro-generated electricity has not kept pace with the sector as a whole and its relative contribution continues to fall.

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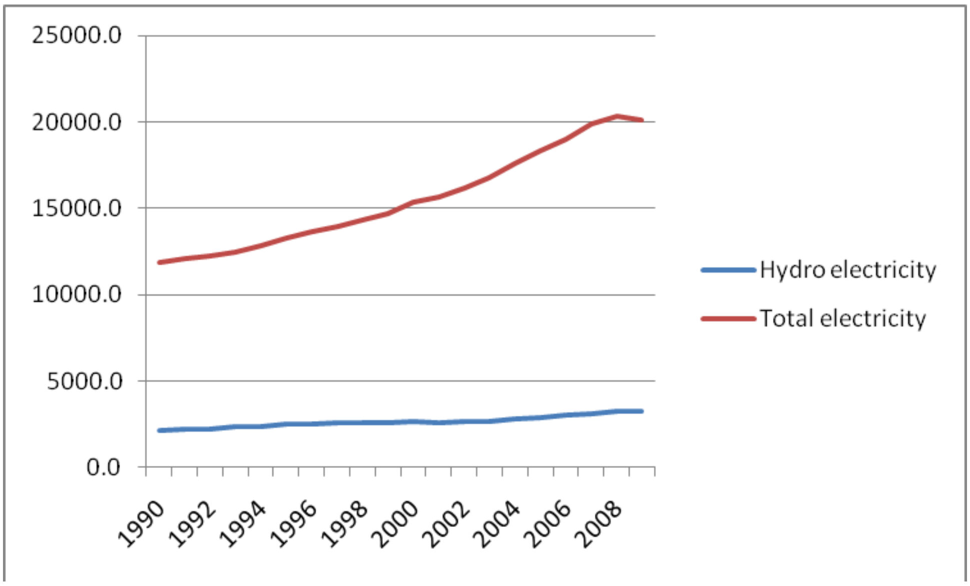
[20] Greenpeace, *Energy Revolution, Global Energy Scenario* (DLR, Institute of Technical Thermodynamics, Department of Systems Analysis and Technology Assessment, European Renewable Energy Council, and Greenpeace International, 2008).

[21] WEA, "Chapter 4: Energy Resources," in: *World Energy Assessment: Energy and the Challenge of Sustainability* (United Nations Development Programme, 2004).

Figure 4: Global Electricity and Hydropower Production (TWh)



Source: BP, 2010.[22]

Wind power

As noted, the commercial use of wind has increased rapidly in a number of countries in recent years. The figures below show both the increase in installed capacity over the last decade and also the breakdown of installed capacity across the globe. Over the past decade, the annual global growth rate has reached 30%. This trend is expected to increase, in particular with measures to improve energy security and climate security relying on wind power. The Global Wind Energy Council envisages that there will be an increase in wind energy from the 2008 level of 261 TWh to 680 TWh in 2012, which in total would contribute to 42% of the Annex 1 commitments under the first commitment period of the Kyoto Protocol. Furthermore, the GWEC estimates that under a more ambitious scenario, wind power could provide between 21 and 34% of the required emission reductions for developed countries, as outlined by the IPCC when calling for a 25 to 40% reduction. This would require around 1,000 GW of installed capacity by 2020, which would represent a slowing down of the current global growth rate.[23] However, other scenarios give, in some cases, much lower levels of installed capacity for wind power in 2020: The IEA suggests around 650 GW in their 450 Scenarios and Greenpeace around 900 GW.

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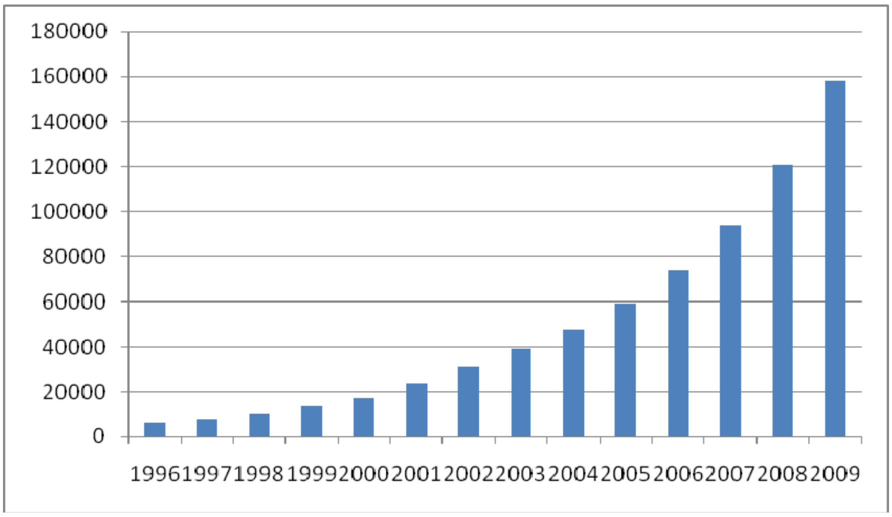
[22] BP, *Statistical Review of World Energy* (June 2009).

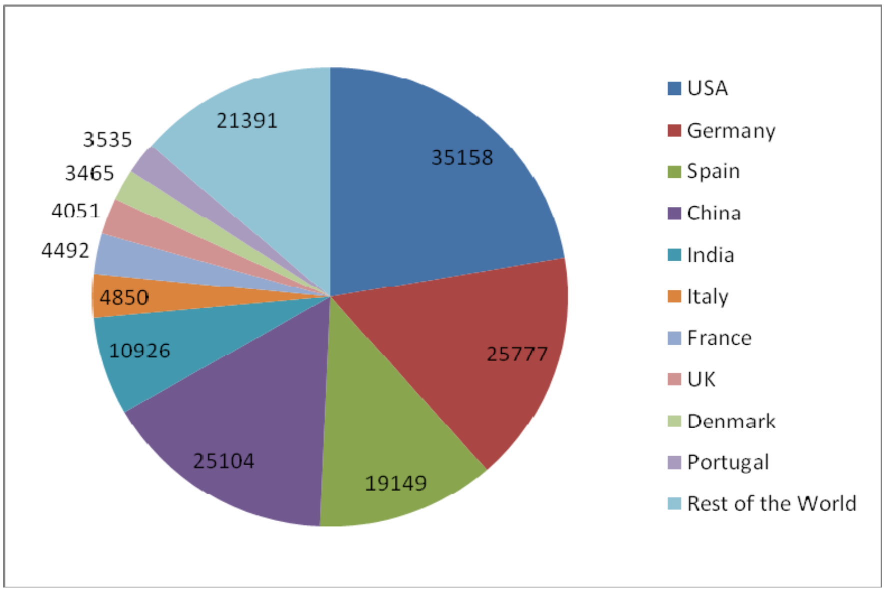
[23] GWEC, *Wind Power is Crucial for Combating Climate Change* (Global Wind Energy Council, December 2009).

Figure 5: Accumulative Global Wind Power Capacity (MW)



Source: Global Wind Energy Council, 2010.[24]

Figure 6: Installed Capacity of Wind Power Plants in 2008 (MW)



Source: Global Wind Energy Council, 2010.

Solar power

There are two basic types of solar technologies for electricity production: concentrated solar power, which concentrates solar heat to create steam and to drive turbines and then create energy in a more conventional way; and solar photovoltaic (PV), which converts the sun's energy directly into electrical current. Solar energy is also used, on a far wider scale, to heat water and buildings – solar thermal. The development of these technologies has followed quite distinctive pathways. The larger, more centralized concentrated solar power so far has experienced more of a "boom and bust" pathway (figure 7), while figure 8 shows the more steady development of solar PV.

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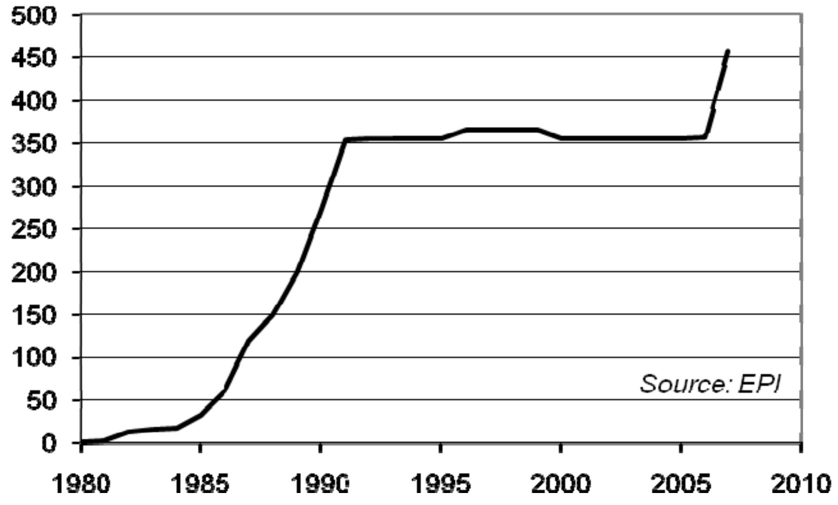
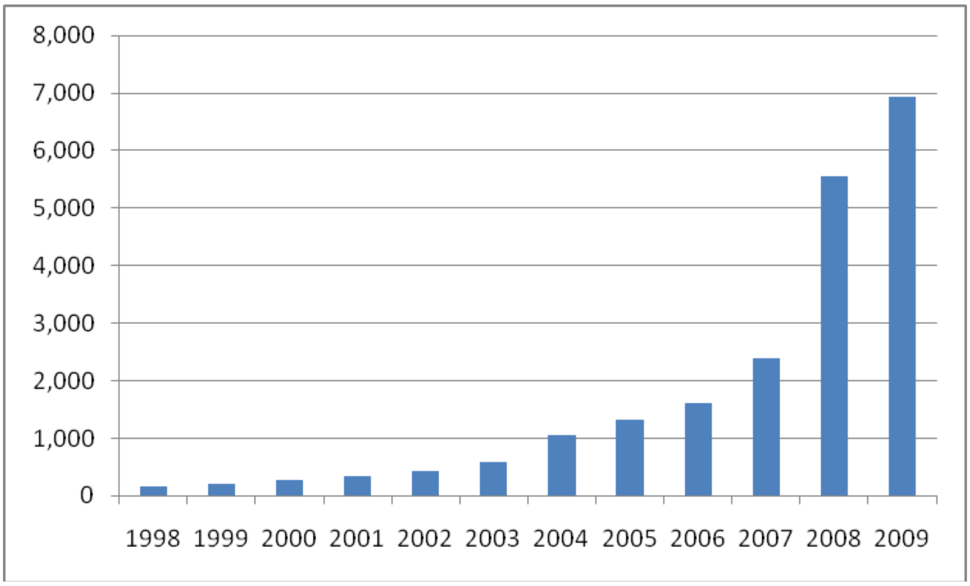
[24] GWEC, "Global Installed Wind Power Capacity: 2008/9" (Global Wind Energy Council, February 2010), http://www.gwec.net/fileadmin/documents/PressReleases/PR_2010/Annex%20stats%20PR%202009.pdf

Figure 7: World Installed Concentrating Solar Thermal Power Capacity 1980-2007 (MW)



Source: Earth Policy Institute, 2009.

Figure 8: World Annual Solar Cell Production 1998-2009 (MW)



Source: Earth Policy Institute, 2010 and www.renewableenergyworld.com (for 2009).

The last few years have seen a breakthrough in the economics and deployment of solar PV. Technology breakthroughs and the introduction of larger production facilities have resulted in considerably cheaper PV modules, with PV's installed costs falling from $7 per peak watt in 2008 to around $5 in 2009 and as low as $3 per watt installed for some utility scale projects[25]. This fall in prices is leading to wider deployment, which in turn is leading to lower prices, a virtuous circle. Until recently, Germany has been the major driver of this growth in deployment, in 2009, it installed 3800 MW of new capacity and by the end of the year operated a cumulated capacity of just under

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[25] Clean Energy Trends 2010, by Ron Pernick and Clint Wilder, Clean Edge

10,000 MW of PV. For the first six months of 2010 alone, the Federal Network Agency expects an increase of more than 3,000 MW.[26]

As of 19 July 2010, it has become possible to monitor real-time generation of solar power on the German national grid, which in the following weeks could be seen to regularly exceed 5,000 MW injection around midday (see Actual Solar Power Generation).

However, other countries, notably, China, Italy, Japan, Spain and the US are expected to require 60% of the growth in installed capacity in 2010. The falling production prices are leading to new claims that solar PV now has similar grid costs to nuclear power. A report prepared by John Blackburn, a professor of economics at Duke University, suggests that a "historic crossover," will occur whereby the costs of solar photovoltaic systems have declined to the point where they are lower than the rising projected costs of new nuclear plants.[27] Furthermore, one of the leading solar PV companies in the UK, a country not known for its sun exposure, has stated that they believe that by 2013 electricity from domestic PV will have a similar production price (grid parity) to that consumers are paying for their electricity[28]. While others suggest that parity in Europe may not be achieved until 2020, even this later date would be at best occur at the same time as the start up of a new nuclear reactor that were ordered today.

Historic and envisaged development of nuclear power

The first nuclear reactor was connected to a power grid in 1954 in what was then the Soviet Union. The rise in the numbers of operating units was uninterrupted for 35 years until the end of the 1980s. By 1989 there were a total of 424 reactors operating in the world. A historic peak was reached in 2002 with 444 units, five more than the 439 operating reactors as of August 2010. The International Atomic Energy Agency (IAEA) lists 61 reactors as under construction (as of August 2010), 13 of which have been listed for over 20 years and many have encountered significant delays.[29] In fact, for the first time since the beginning of the commercial use of nuclear energy, no new unit was connected to the grid in 2008. Since the grid connection in August 2007 of the Romanian Cernavoda-2 unit (after 24 years of construction), only five new reactors (one each in China, Japan and Russia and two in India) have started up, while five units were taken off the grid in 2008 and 2009. Total installed capacity has slightly decreased, in spite of widespread "uprating" [30].

In 2009 the 370 GW of nuclear capacity generated about 2,600 TWh - a 1.3% decline, the third in a row - that is about 13% of commercial electricity or 5.5% of commercial primary energy, or between 2% and 3% of all energy in the world – all on a downward trend.[31]

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[26] Federal Network Agency, Press Release, 27 July 2010

[27] Nuclear Energy Loses Cost Advantage, Diana S. Powers, New York Times, 26 July, 2010

[28] Jeremy Leggett, "I accept George Monbiot's £100 solar PV bet", The Guardian, 9 March 2010

[29] For a detailed analysis, see Mycle Schneider, Steve Thomas, Antony Froggatt, and Doug Koplow, *The World Nuclear Industry Status Report 2009*, commissioned by the German Environment Ministry (Paris: August 2009), available in English and German at http://www.bmu.de/english/nuclear_safety/downloads/doc/44832.php

[30] Capacity increase at existing facilities by technical means (steam generator replacement, turbine refurbishment, etc.).

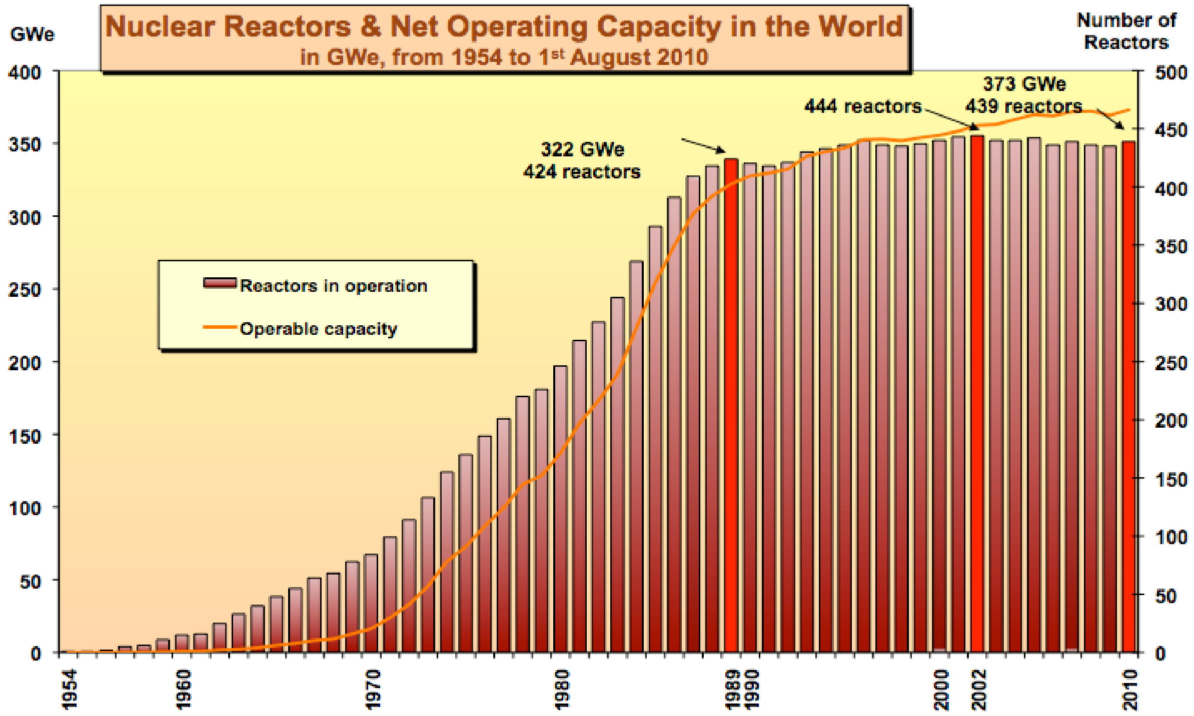
[31] We use the term "commercial" here in order to clarify that the energy statistics do not generally take into account non-grid connected power or non-commercial biomass for example that contribute a substantial share of the energy supply in many parts of the world.

In spite of the real-term decline in the role of nuclear energy, projections for a massive development by the IAEA and the OECD's International Energy Agency have been increasingly optimistic. The IAEA anticipates 473 GW of nuclear capacity in its "low" scenario and, with admirable precision, 747.5 GW in its "high" scenario by 2030. The IEA's *World Energy Outlook* 2009 has added another 10% to its projected installed nuclear capacity to reach 475 GW by 2030 in its Reference Scenario. In its 450 Scenario (climate stabilization scenario) the IEA envisages, similar to the IAEA "high" scenario, to more than double the current nuclear capacity and power generation by 2030. The IEA states:

> A nuclear renaissance is possible but cannot occur overnight. Nuclear projects face significant hurdles, including extended construction periods and related risks, long licensing processes and manpower shortages, plus long-standing issues related to waste disposal, proliferation and local opposition. The financing of new nuclear power plants, especially in liberalised markets, has always been difficult and the financial crisis seems almost certain to have made it even more so. The huge capital requirements, combined with risks of cost overruns and regulatory uncertainties, make investors and lenders very cautious, even when demand growth is robust.[32]

Neither the IAEA nor the IEA demonstrate how these "significant hurdles" could be overcome in order to justify these significant expansion projections. In fact, in a recent report, the Basel-based think tank Prognos[33] suggests that the number of operating reactors is likely to decrease by 29% by 2030 if compared with the spring 2009 level. Prognos estimates that only 35% of the projects announced by the World Nuclear Association for 2030 will materialize – not enough to compensate for aging reactors being taken off the grid.

Figure 9: World Nuclear Reactors and Capacity 1954-2010 (GW)



©Mycle Schneider Consulting *Sources: IAEA-PRIS, MSC, 2010.*

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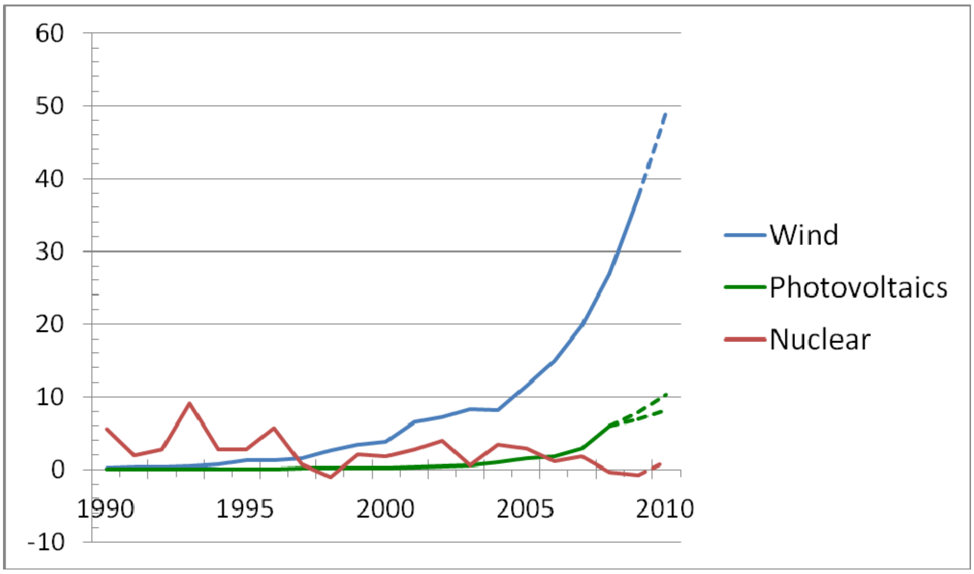
[32] IEA, *World Energy Outlook* 2009, p. 160.

[33] Matthias Deutsch et al., *Renaissance der Kernenergie*, commissioned by the Federal Radiation Protection Office (BFS), Prognos, Berlin/Basel, September 2009.

Comparison of nuclear to renewables

Figures 10 and 11 show the net additions to the grid from new renewables (not including large hydropower) and nuclear and the contributions of all so-called low-carbon energy sources to the global electricity mix. Although at first glance these figures may appear contradictory, they are two sides of the same narrative. Figure 10 details the net additions to the grid over the global grid over the last two decades. The size of the individual stations, coupled with the closure of reactors, is why the nuclear trend-line lacks an overall direction, but it could be summarized to an average net annual additional capacity of around 2 GW per year in the beginning of the period, compared to a global installed capacity of some 370 GW. However, this trend has stagnated or decreased since 2005. Over the same period, wind power has increased its capacity by over 10 GW on average per year, with capacity additions steadily increasing to reach over 37 GW in 2009.

Figure 10: Net Additions to Global Electricity Grid from New Renewables and Nuclear 1990-2010 (in GW)



Source: Amory Lovins, 2010.[34]

It is important to also look at the actual electricity generated by the different non-fossil fuel sources, as is mapped out in figure 11. This shows the extent to which, despite the recent growth in new renewables, their contribution, compared to nuclear power and large hydro, is small. However, as this situation will change, as seen in figure 17. The IEA assume that in their 450 Scenario that by 2030, the use of hydropower will be double the current level of nuclear power, while wind power would produce an equivalent amount as would other renewable sources[35].

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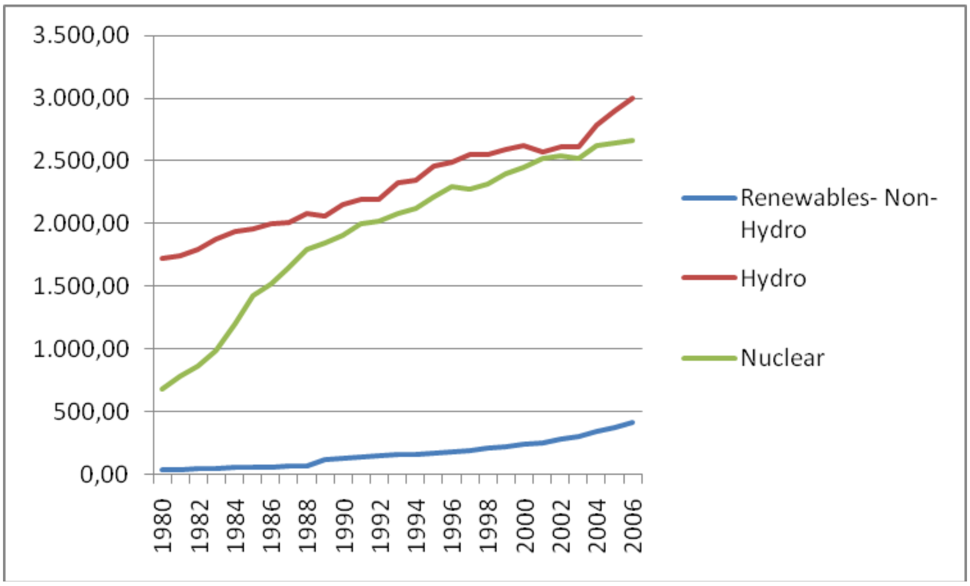
34 Amory Lovins, Personal communication to the authors (2010).
35 IEA, *World Energy Outlook* 2009, table 9.2, p. 324.

Figure 11: Electricity Production from Non-Fossil Fuel Sources



Source: Earth Policy Institute, 2009.

Systemic Issues

"If someone declares publicly that nuclear power would be needed in the baseload because of fluctuating energy from wind or sun in the grid, he has either not understood how an electricity grid or a nuclear power plant operates, or he consciously lies to the public. Nuclear energy and renewable energies cannot be combined."

Siegmar Gabriel
then Federal Environment Minister of Germany[36]

The policy decision to develop nuclear power and/or energy efficiency+renewables is far from limited to the choice of technological options. The decisions are often triggered, or at least heavily influenced, by pre-existing political systems, decision-making processes, market structure and heavy infrastructure. On the other hand, basic system decisions, like centralized or decentralized power generation, have a significant impact on the flexibility and competitiveness of the energy technologies and systems. For example, while there is no doubt that combined heat and power (CHP) is a much more efficient way to provide heat- and electricity-based energy services than separate generation, it is difficult for CHP to compete with *existing* centralized and often oversized power plants or *existing* natural gas networks.

In many developing countries, very many of those infrastructural decisions have yet to be made. Consequently, it is of utmost importance to assess the implications of these basic system choices. Industrial countries illustrate the outcome of past strategic choices. Unfortunately, while there are numerous successful local and regional cases, there is no "good" example for a successful national energy policy that provides affordable, sustainable energy services. All countries have implemented policies that have serious drawbacks, and major "repair jobs" are necessary in order to address the defaults.

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36 Deutscher Bundestag, 16. Wahlperiode, 211. Sitzung (Berlin: 19 March 2009).

The French centralized system

France, for example, governed by a very centralized political system, quite naturally has always been looking for centralized answers to energy-supply challenges. Nuclear power was a logical choice of top-down decision-making and the result of the total absence of a willingness by the central state to share political power on energy issues with regional or even local governments. Like a steamroller, the state-sponsored nuclear logic wiped out small and medium-sized industries trying to develop new and renewable energy sources. In a similar way, efficiency efforts have been often suffocated. By the mid 1980s, it had become clear that the state utility EDF had massively overbuilt (in the order of 16 nuclear power plants). Instead of adjusting the equipment planning, the state dismantled most of the Energy Efficiency Agency and EDF went for two strategic choices: long-term electricity export agreements and widespread promotion of electric space and water heating. This strategy has led to the single most significant barrier for the development of energy efficiency+renewables in France. Hundreds of thousands of buildings have been built without chimneys, thus without a low-cost opportunity to switch to a less wasteful and polluting heat sources than electricity. In recent years the tendency has even increased and around 75% of all new French homes are equipped with electric space heating. There are cases where new urban heating networks pass by electricity-heated buildings without any chance of hooking them up because of what is felt as disproportionate investment costs.

The other side-effect of the massive thermal use of electricity – almost half of the residential power consumption in France – is the spectacular increase of the winter peak load that exceeds now three times the lowest load-day in summer. The result is a considerable increase in fossil fuel use for power generation (an increase of about 25% since 1990), the restart of up to 40-year-old oil-fired power plants and the rapidly increasing import of electricity, in particular coal-fired power from Germany. In fact, in January 2010 France was a net importer of electricity – after October 2009 the second net import month in 27 years.

The energy efficiency+renewables efforts in France have remained severely underdeveloped. Logically, per capita electricity consumption is significantly higher than the EU average or in a country like Italy, which abandoned nuclear power after the Chernobyl disaster. In 2008 Spain added more wind power capacity (4,600 MW) than France had installed in total by 2007 (4,060 MW).

The idea that the French nuclear system has led to a low carbon content of its economy is wrong. As new figures published by the French government[37] illustrate, taking into account the net carbon content of imported goods (minus the carbon content of exported items), per capita greenhouse gas emissions (2005) increase from 8.7 t to 12 t of CO2equivalent and thus almost reach the level of coal-based Germany.[38] France has a large trade deficit while Germany has been the world's leading export nation until China took over in 2009.

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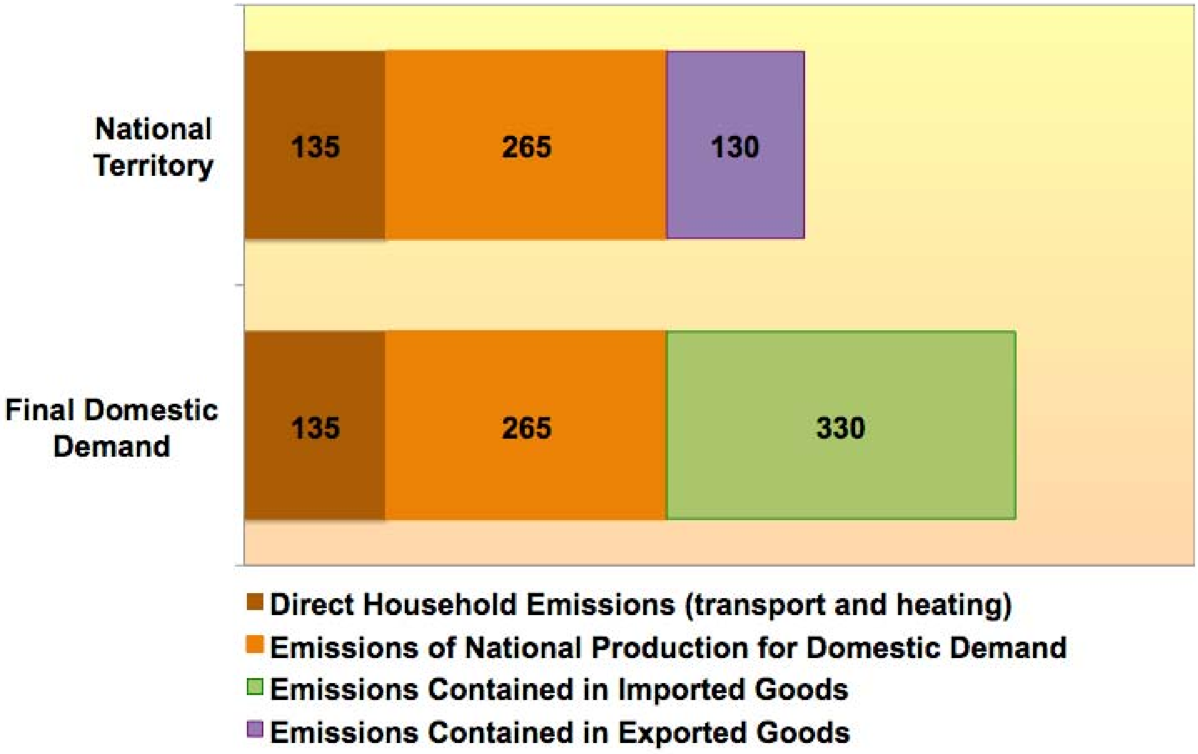
[37] Ministère de l'Ecologie, "L'empreinte carbone de la demande finale intérieure de la France", August 2010

[38] For year 2001, the Norwegian Carbon Footprint Calculator indicates 13.1 t of CO2eq for the six greenhouse gases for France and 15.1 t of CO2eq for Germany, see http://carbonfootprintofnations.com

Figure 12: Greenhouse Gas Emissions Due to Final Consumption in France (in t of CO_2eq.)[39]



Source; Ministry of Ecology, August 2010

The German case illustrates an entirely different strategy. While nuclear power has provided up to 30% of the electricity, the country has always heavily depended on coal and lignite. In 2000 the government signed an agreement with the nuclear utilities and in 2002 legislated for the phase-out of nuclear power. In parallel, in 2000 feed-in tariff legislation was passed. It introduced guaranteed prices for renewable electricity producers and market stimulation programs have been introduced to foster the penetration of renewable energies in the heat market. The combination of a clear planning horizon for the phase-out of nuclear power and strong stimulation for the development of renewable energies created a phenomenally dynamic environment. Regional energy agencies under *Länder* (state) authority were instrumental in engineering the implementation. The total energy provided by renewable energies has tripled since the end of the 1990s, hundreds of thousands of jobs have been created and renewable energy technologies have become a top export branch.

However, not everything has gone well. While the generation of renewable electricity, mainly wind, increased by about 70 TWh – or a factor of five between 1990 and 2007 – total electricity consumption increased by over 12%, or almost 68 TWh, during the same period. As a result, the CO_2 emissions of the German power-generation sector was identical in 2007 and 1990. That is a particularly shocking result as the unification of East and West Germany led to a "natural" decrease

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[39] note that this calculation only takes into account CO_2, CH_4 and N_2O

of the carbon content *and* power consumption in the east due to the simple shutdown of outdated power plants[40] and industries.

Energy analysts and environmental organizations have been pointing out this problem for some time, but neither the previous Grand Coalition nor the new conservative government have been able to implement even the minimum efficiency requirements under EU legislation. At the same time, the potential extension of the operation of German nuclear power plants threatens the restructuring of the energy system in the country. A comprehensive analysis by Joachim Nitsch, commissioned by the German Environment Ministry, concluded in 2008[41]:

> In case of the lifetime extension of nuclear energy, the current planning for the construction of new fossil fuel plants would have to be entirely revised in order not to threaten the 30% target for renewable energy for 2020. The CHP target could not be reached. The necessary structural change of the power supply towards significantly increased electricity efficiency, a significantly higher share of CHP and a high expansion dynamic for renewable energy would be fundamentally put into question. Thus the energy system would be hardly in a position to fulfil the climate protection target of an 80% CO_2 emission reduction until 2050.

The significant expansion of renewable energies in the power sector does not necessitate additional, large baseload capacities that operate all year round with high load factors, but rather flexible, middle-load plants that can adapt to various types of intermittent power plants.[42] “The lifetime extension of nuclear power plants would leave electricity quantities in the market that otherwise would be successively replaced by combined heat and power,” stresses the Wuppertal Institute.[43] At the same time, continued operation of nuclear plants would also hinder the extension of urban heating systems.

Direct competition between renewable electricity and nuclear and other “baseload” power leads more and more to absurd market situations. In Germany the injection of renewable electricity has a legal priority over nuclear and fossil power. But in October 2008 wind energy generation was so high that some of the non-renewable electricity had to be “sold” for “negative” prices on the power market because nuclear and coal fired power plant output could not be reduced quickly enough. This situation appeared in spite of the fact that 8 GW of nuclear capacity was off-line for maintenance.[44] Since then, negative electricity prices, which are legal in Germany only since September 2008, have become an increasingly frequent phenomenon on the German power market. In the six months between September 2009 and February 2010, power prices dropped into the red

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[40] The oldest coal-fired power plant in East Berlin operating in 1989 dated from 1919.

[41] Joachim Nitsch, “Leitstudie 2008 - Weiterentwicklung der Ausbaustrategie Erneuerbare Energien vor dem Hintergrund der aktuellen Klimaschutzziele Deutschlands und Europas”, commissioned by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (October 2008).

[42] Note that in fact all power plants are more or less intermittent, including nuclear plants that are not only down for several weeks per year for refueling but also many of which that have experienced extensive repair or upgrading outages exceeding one year.

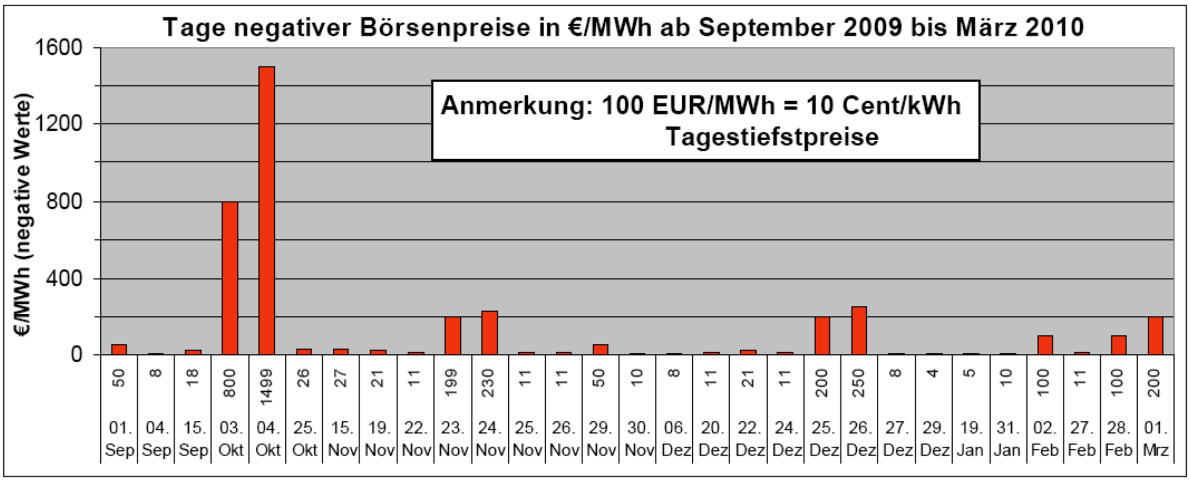
[43] Manfred Fischedick et al., “Hindernis Atomkraft – Die Auswirkungen einer Laufzeitverlängerung der Atomkraftwerke auf erneuerbare Energien”, commissioned by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Wuppertal Institut, April 2009).

[44] Ibid.

on 29 days (see following figure). Negative prices reached stunning levels: on 4 October 2009 a power producer had to pay up to €1,500/MWh (15 cents/kWh) to get rid of its electricity.

In fact, the German nuclear phase-out strategy is perfectly complementary to the introduction of a highly flexible system based on the intelligent combination of distributed energy sources.

Figure 13: Negative Electricity Prices on the German Power Exchange



Sources: H. Alt, "Warum negative Strompreise an der Strombörse?", FH-Aachen, March 2010

Spanish renewables hitting the current ceiling?

In Spain, in the early morning of 24 February 2010, the transmission system operator Red Eléctrica (REE) ordered 800 MW of wind power to stop generating electricity for several hours. This was because at 1:30 am, wind power was delivering 11,961 MW (44.5% of the 26,674 MW demanded at that time). However, after an intervention from REE, the wind power output was lowered to 10,852 MW. Wind generation remained below the amount it could have delivered until 6:30 am, when demand started to increase. However, during the period of decreased wind output, nuclear generation remained unchanged.

A new approach

One of the most significant system issues is the effect of the insistence on centralized power plants – whether extended operation or new built – on innovation. This is not only relevant for technological aspects of power and heat generation but in particular for innovative linkages of decentralized energy use and load management in virtual power plants. As the Galvin Electricity Initiative, founded in 2005 by former Motorola Chairman Robert Galvin, points out:

> Aging, unreliable, inefficient, insecure and incompatible with the needs of a digital economy, the U.S. electric system is in dire need of modernization. With technology that pre-dates the 1950s, the system includes decades-old equipment on the verge of failure. While these parts can and will be replaced, the situation presents the nation with an unprecedented opportunity – a chance to also reinvent and change America's electric grid in ways that are profoundly beneficial to consumers, the environment and the economy. (…)The industry,

> however, has failed to spawn significant innovation in more than 50 years, largely due to a regulatory structure not attuned to the needs of the 21st century.[45]

This verdict could be applied to the European grid as well as to many other industrialised countries in the world.

Virtual Power Plants (VPP) – the clustering and central management of decentralized (distributed) generation units like small-scale renewables and CHP – are one of the most promising concepts of the electricity future. A further expansion of this approach is the inclusion of decentralized storage capacities, like car batteries or renewable energy-system backup storage. This is literally the opposite of the nuclear power vision. Power consumers use a power switch that triggers the generation and use of energy according to optimized grid conditions (demand/supply balance/price). Power consumers turn into producers and the term *prosumers* was born. The bulk of investment into new generation capacity in a country like Germany is now done by households and not by utilities anymore. In order to allow for this development, the grids will have to be adapted significantly. The European Regulators Group for Electricity and Gas stated in a public consultation paper[46]:

> Future electricity networks will be required to connect generators of many different technologies and sizes, at all voltage levels, some of them highly controllable and others with their output strongly dependent on the instantaneous physical availability of their renewable primary energy resource (e.g., wind generation). […] Significantly more system monitoring and intelligent control will need to be introduced to securely meet the demand for energy with the optimum level of generation and network capacity. This will be achieved by the evolution of electricity networks – in short smart grids.

The key difference to traditional power transport and distribution systems is the adaptation of a sophisticated communications network to the electricity network. A significant challenge will be the integration of these communication systems at medium- and low-voltage levels and the organization of their synergies with smart metering on the consumer side. In order to make this work, not only do new electronic systems have to be deployed but also regulation has to be adapted. And the faster one wishes for the introduction of smarter grids, the more regulators are requested "to find ways of encouraging an adequate level and scope of more radical innovations while providing an appropriate degree of protection of customer interests and economically-effective development of the network."[47]

Non-nuclear Italy was a precursor in smart metering. Already in 2006 the regulators announced the mandatory installation of smart meters for all consumers by the end of 2011. However, Sweden implemented the technology faster and reached 100% coverage by July 2009. Now the country is helping neighbouring Denmark, Finland and Norway to speed up installation.[48] Nuclear France will

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[45] The Galvin Initiative, "Transforming the Grid: An Executive Summary", see http://galvinpower.org/about-galvin/transforming-grid

46 ERGEG, "Position Paper on Smart Grids – An ERGEG Public Consultation Paper" (Brussels: 10 December 2009).

47 Ibid.

48 *Technology Action Plan – Smart Grids*, report by Italy and South Korea to the Major Economies Forum on Energy and Climate (December 2009).

only start a test phase in 2010 with 300,000 smart meters in two regions. In the meantime the European Smart Metering Industry Group (ESMIG) has grown from five founding members in 2008 to a membership of 32 in July 2010, federating the largest electronics and telecom companies in Europe. Most industrialized countries have now demonstration projects underway and some developing countries are preparing for introduction. In March 2010 the US Agency for International Development published “A Smart Grid Vision for India’s Power Sector”.

The household appliances industry is making fast progress. Whirlpool was the first company to announce that all of their household appliances with an electronic component will be smart grid capable by 2015.

Various models of developing distributed power with a share of renewable energies are already being implemented. Virtual Power Plant and micro-grid projects that significantly reduce transmission and distribution losses are being built up in several countries[49]. In May 2010 the Galvin Electricity Initiative launched the Microgrid Hub: “Smart microgrids are an ideal way to integrate renewable resources on the community level and allow for customer participation in the electricity enterprise. They form the building blocks of the Perfect Power System”.[50] The Perfect Power System, developed by the Initiative, is the “innovative business and technology blueprint for the ultimate smart grid”. The University of Illinois’ Institute of Technology has recently entered the implementation phase for a real size demonstration project on the university campus.

The July 2010 Washington Clean Energy Ministerial has launched the “International Smart Grid Action Network (ISGAN) to accelerate the development and deployment of smart electricity grids around the world”. However, the term “smart grid” is being used in many ways. The key question will be whether some of its components (smart metering in particular) are being implemented as convenient complement to the old macro top-down system or whether they are developed in order to make use of their full potential. This would necessarily mean to shift towards a micro-grid based power system. Where possible, these micro-grids would most likely be connected to clusters in order to increase complementarities and system stability.

Much like France, the United Kingdom envisages smart grids as an upgrading of the current network rather than a tool for a profound shift toward an efficiency+renewables economy. On the contrary, the UK Department of Energy and Climate Change is even counting on a continuous increase in consumption.

> By 2050 we will need to produce more electricity than we do today but must do so largely without emitting greenhouse gases. We will need to generate electricity from low-carbon sources such as renewables, nuclear and fossil fuel plants fitted with carbon capture and storage.[51]

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[49] See for example Dardesheim in Germany and the “Power Matching City” Hoogkerk in the Netherlands. In the US, the California Energy Commission (CEC) recently approved the proposal of the University of California in San Diego for the Renewable Energy Secure Communities (RESCO) grant to develop and demonstrate integration of on-site renewable energy production using geothermal, heat pump technology and treated wastewater, solar voltaic, wind energy combined with on-site storage alternatives, lighting and air conditioning building retrofits and electric vehicle charging stations.

[50] http://galvinpower.org/microgrids

51 http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/network/smart_grid/smart_grid.aspx

While significant knowledge gaps remain, there is overwhelming evidence that some of the systemic effects of a nuclear-power-based electricity infrastructure include barriers to the development of an efficiency+renewables-based energy service society and, in some cases – especially as the level of renewable energy increases – the fact that both approaches exclude each other.

The Timing of Investment

Imperative of rapid climate change action

There is a growing, and now near universal, consensus that human-induced greenhouse gas emissions, particularly carbon dioxide (CO_2) from the energy sector, are altering the global climate. The *Fourth Assessment Report* from the Intergovernmental Panel on Climate Change stated that "warming of the climate system is unequivocal" and that there was a more than 90% probability that this was a result of human activities since the start of the industrial revolution. During the 20th century, global temperatures increased by 0.6 degrees Celsius. Continuing along the current trajectories of energy and land use will increase the concentrations of greenhouse gases in the atmosphere to such a point that by the end of this century, temperatures might increase by an additional 6 degrees. This would have catastrophic consequences for the human race and the earth's ecosystems.

To avoid the most dangerous consequences of climate change, the international community has set a "2 degree target," whereby emissions would be reduced to try and ensure that the global average temperature does not increase by more than 2 degrees Celsius above pre-industrial levels. This target has been endorsed by a large number of international bodies and fora, including the European Union, the International Panel on Climate Change and most recently the Copenhagen Accord, which states: "We agree that deep cuts in global emissions are required according to science, and as documented by the IPCC *Fourth Assessment Report* with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity."[52]

In order to meet this target, there must be a dramatic cut in greenhouse gas emissions of more than 80% by 2050. In many ways more important than the long-term target are those for the short-term. Rapidly changing technology or behaviour will demonstrate the viability of reducing emissions and avoid locking in investment in high energy-consuming/high emissions pathways. However, delays in reducing emissions lead to much larger requirements for cuts at much higher cost in the future.

Lead times for scaling up new technologies, experiences and expectations

Nuclear power

Given the need for rapid emission reductions, the time needed to introduce new technologies on a mass scale is an important and highly underestimated factor. There are two major phases for the commissioning of new energy-generating facilities: the pre-development phase and construction.

The pre-development phase can include a wide variety of consultations and potentially involves obtaining the necessary construction and operating licenses, local and national consent, as well as raising the financing package. In some cases, the deployment of a new technology may be sped up as generic safety assessments are made, or alternatively, the pre-development phase may take longer due to local site conditions or new issues coming to light. The IEA has estimated a pre-

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[52] Copenhagen Accord, drawn up at the UN Framework Convention on Climate Change, 15th Session (Copenhagen: 7-18 December 2009).

development phase of approximately eight years for nuclear power.[53] However, this includes the time it takes to gain political approval and it assumes an existing industrial infrastructure, workforce and regulatory regimes. In the case of the United Kingdom, then Prime Ministry Tony Blair announced that nuclear power was “back with vengeance” in May 2006, but it was some years before the pre-development phase for nuclear power even began.

Nuclear power has a history of delays in construction, and analysis undertaken by the World Energy Council[54] has shown the global trend in increased construction times for nuclear reactors. The significant increase in construction times from the late 1980s until 2000 was in part due to changes in political and public views of nuclear energy following the Chernobyl accident, with subsequent alterations in the regulatory requirements. As we have shown in the *World Nuclear Industry Status Report 2009*,[55] calculating a global average construction time – it would be around nine years for the 16 most recent grid connections – does not make much sense because of the differences between countries. The construction period for four reactors started up in Romania, Russia and Ukraine lasted between 18 and 24 years. In contrast, it took hardly more than five years on average to complete the 12 units that were connected to the grid in China, India, Japan and South Korea.

Increases in construction times can be seen in various countries across the world. In Germany, in the period from 1965 to 1976, construction took 76 months, increasing to 110 months in the period from 1983 to 1989. In Japan average construction time in the period from 1965 to 2004 was in the range of 44 to 51 months. Finally in Russia, the average construction time from 1965 to 1976 was 57 months, then from 1977 to 1993 it was between 72 and 89 months, but the four plants that have been completed since then have taken around 180 months (15 years),[56] due to increased opposition following the Chernobyl accident, economic constraints and the political changes after 1992.

Table 1: Construction Time of Nuclear Power Plants Worldwide

Period of reference	Number of reactors	Average construction time (months)
1965-1970	48	60
1971-1976	112	66
1977-1982	109	80
1983-1988	151	98
1995-2000	28	116
2001-2005	18	82
2005-2009	6	77

Sources: Clerici, 2006; IAEA.[57]

The first of the latest design of reactors, the so-called Generation III+ reactors, is under construction in Finland.[58] At the time of the ordering of Olkiluoto-3 in December 2003, the contract called for the

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[53] IEA, Nuclear Power in the OECD (International Energy Agency, 2001).

[54] World Energy Council, Alexandro Clerici, and ABB Italy, “European Regional Study Group – The Future Role of Nuclear Energy in Europe” (13 June 2006); and, for post-2000 figures, calculation based on PRIS database, http://www.iaea.org/programmes/a2/index.html

[55] Mycle Schneider et al., *The World Nuclear Industry Status Report 2009*.

[56] World Energy Council et al., “European Regional Study Group” (2006).

[57] Ibid. The 2005-2009 range does not include the completion of the Cernavoda 2 unit in Romania, which took 279 months due to an extended break in construction.

plant to be on-line by 1 May 2009. However, the latest completion date is now at least three and a half years late and close to 100% over budget (current estimates suggest that by completion, the total will reach €5.7 billion or more, compared to an original estimate of €3 billion). The second Generation III+ reactor, also an EPR as in Finland, is under construction in France. After three years of construction, Flamanville-3 is now officially at least two years behind planning and €2 billion over budget. As a consequence of the building problems, the credit agency Standard & Poor's downrated nuclear builder AREVA[59].

Given the complexities and costs associated with construction, reactors tend to be built in series rather than parallel, i.e., constructors will wait until one reactor is completed until starting the next. Consequently, it will take a number of additional years for a new fleet of reactors to be fully operational.

The construction of large numbers of reactors around the world would bring experience, which would, under normal technological deployment conditions, lead to accelerated diffusion rates and lower costs. To date, accelerated deployment rates have not occurred with nuclear power, in part due to the complexity of the technology, the associated supply chains and the variety of the technologies deployed. One of the cost and financing papers prepared for the *Stern Review* (the UK government's review of the economic impact of climate change) stated that:

> The costs of energy production and use from all technologies have fallen systematically with innovation and scale economies in manufacture and use, apart from nuclear power since the 1970s.[60]

This can be illustrated by the two largest nuclear programs in the world: the United States (figure 14) and French ones (figure 15). Both show large increases in construction costs, despite considerable construction experience. In the case of the United States, over the 25-year period the cost per installed kW increased approximately fivefold, while in France more than a threefold cost was accrued. The data for the United States also shows, in pink, the projected costs for nuclear power plant, which includes assessments from independent and Wall Street analysts of over $10 000 per installed KW. What is also remarkable in France was that this was recorded for one company, as only the state-owned company was in a position to build and operate reactors.

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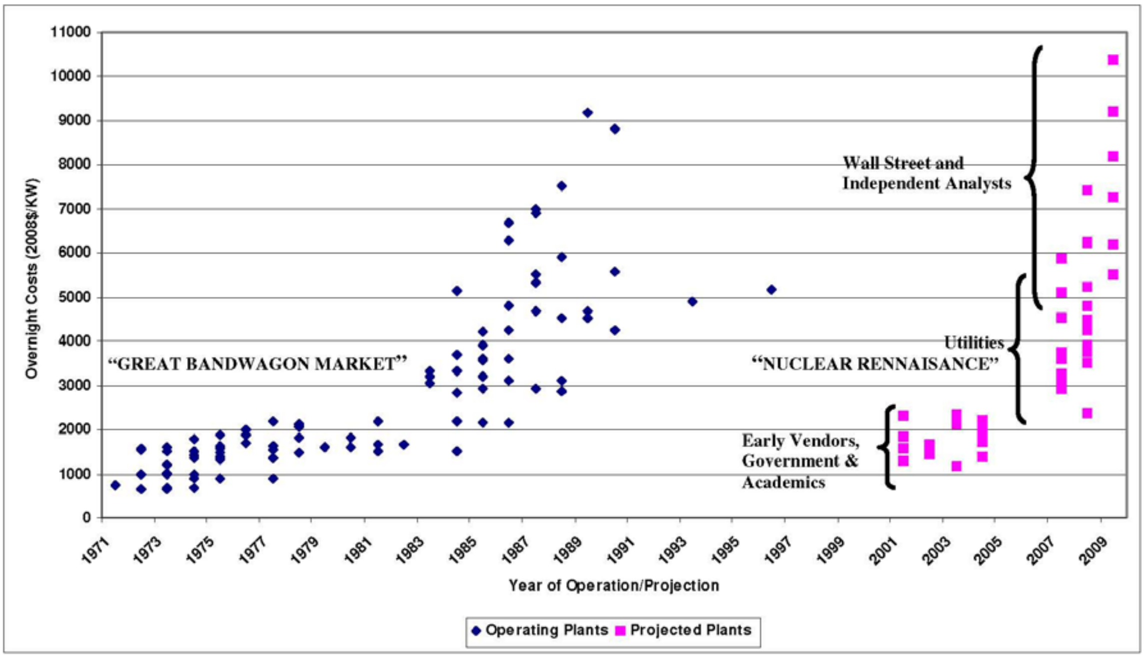
58 For more information, see paper by Steve Thomas, "The Economics of Nuclear Power", (2010), www.boell.de

[59] from A to BBB+

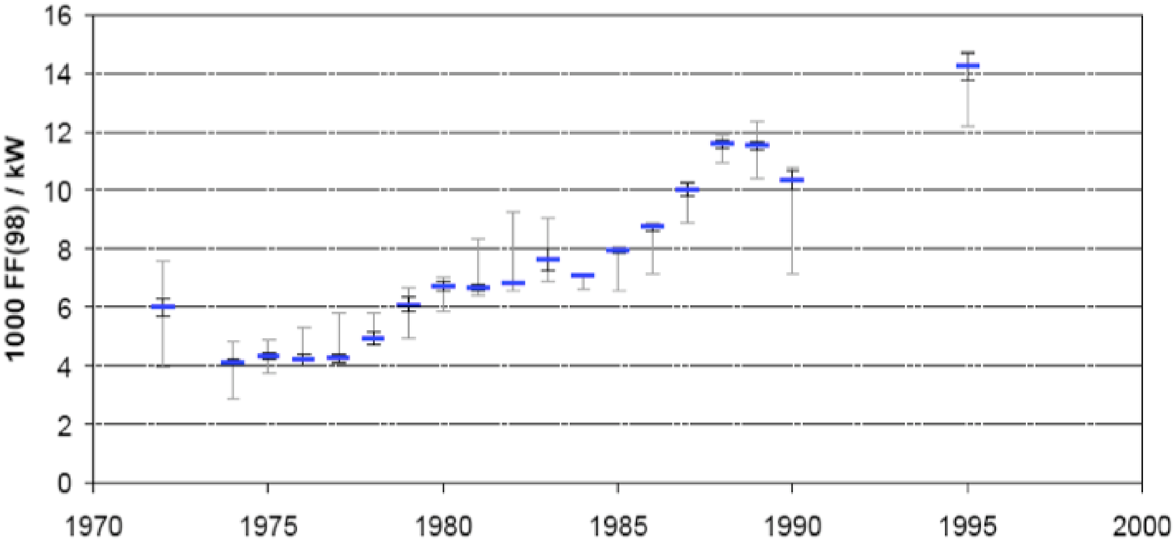
60 Dennis Andersen, "Cost and Finance of Abating Carbon Emissions in the Energy Sector," supporting paper for the *Stern Review* (Imperial College London: October 2006), p. 18.

Figure 14: Investment Cost Evolution ("Learning Curve") of US Nuclear Power Plants



Source: Cooper, 2009.[61]

Figure 15: Investment Cost Evolution ("Learning Curve") of French Nuclear Power Plants



Source: Arnulf Grübler, 2009.[62]

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[61] Mark Cooper, *The Economics of Nuclear Reactors: Renaissance Or Relapse?* Mark Cooper is Senior Fellow for Economic Analysis Institute for Energy and The Environment (Vermont Law School, June 2009).
[62] Arnulf Grübler, *An Assessment of the Costs of the French Nuclear PWR Program 1970–2000* (6 October 2009).

Various reasons have been put forward for the relatively low or negative learning rate relating to the manufacture of nuclear power plants, including the relatively small, post-1970s reactor ordering rate; the interface between the complexity of the nuclear power plant and the regulatory and political processes; and the variety of designs deployed.[63] While some of these factors may be overcome in the future, the UK government's Performance and Innovation Unit also highlighted a number of areas in which future nuclear power plants may not exhibit comparable learning rates to other technologies, including:

- Nuclear power is a relatively mature technology and, therefore, a dramatic "technological stretch" is less likely than in other technologies;
- The relatively long lead times for construction and commissioning mean that improvements derived by feeding back information from operating and design experiences on the first units are necessarily slow;
- The scope for economies of scale is narrower in the nuclear case than for renewables, due to the latter's smaller initial scale and wider potential application (in types and numbers).

Furthermore, the industrial issue has radically changed since nuclear construction peaked around 1980. Many of the leading organizations in the nuclear industry in 1980 have moved away completely from the nuclear business, having amalgamated with others in the nuclear field or redirected their business approach to activities related to decommissioning and waste management, where there has been an increase in activity in the last few years. This has resulted in a smaller group of companies in fewer countries with the capability of managing the construction of a complete nuclear power plant.[64]

The nuclear manufacturing industry is clearly in a state of profound reorganization and upgrading. Investments in heavy-equipment manufacturing capacity are very capital extensive. Manufacturers will not go ahead with investments worth hundreds of millions of dollars if they do not have firm orders for several years ahead.

Renewables

As figure 16 shows, the lack of a positive learning effect and the negative impact on the economics in the nuclear sector have not proven to be applicable to renewable energy technologies. The further diffusion of wind power, solar electricity and ethanol has in all cases led to a significant reduction in installation or production costs.

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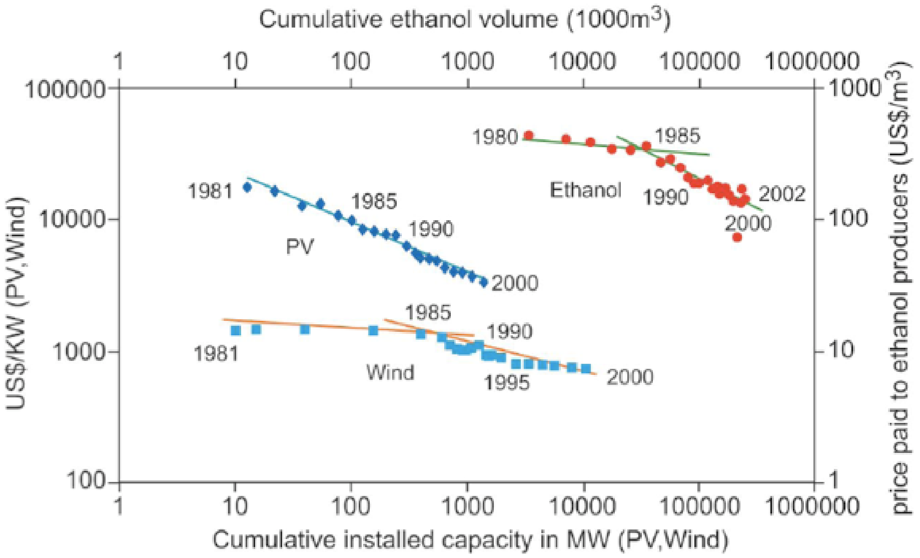
63 Performance and Innovation Unit (PIU), "Energy Review Working Paper, The Economics of Nuclear Power" (PIU, 2002).

64 IAEA, *International Status and Prospects of Nuclear Power* (2008).

Figure 16: Technology Learning Curves



Source: IPCC Fourth Assessment Report, Report 3, Mitigation of Climate Change.

In 2002 the UK Government's Performance and Innovation Unit estimated what the production costs for various supply options in 2020 might be. This can be seen in table 2, where nuclear power costs are significantly higher than onshore wind and offshore wind costs and are in a similar range to energy crops and wave power.

Table 2: Electricity Fuel Source Cost Projections in 2020

Technology	Cost in 2020 - p/kWh	Confidence in Estimate	Cost Trends to 2050
Conventional Fuels			
Coal (IGCC)	3.0-3.5	Moderate	Decrease
Gas (CCGT)	2.0-2.3	High	Limited decrease
CCS	3.0-4.5	Moderate	Uncertain
Large CHP (gas)	Under 2	High	Limited decrease
Micro CHP (gas)	2.5-3.5	Moderate	Sustained decrease
Nuclear	3.0-4.0	Moderate	Decrease
Renewables			
Onshore wind	1.5-2.5	High	Limited decrease
Offshore wind	2.0-3.0	Moderate	Decrease
Energy crops	2.5-4.0	Moderate	Decrease
Wave	3-6	Low	Uncertain
Solar PV	10-16	High	Sustained decrease

Source: PIU, 2002.[65]

Recent years have seen an increase in opposition to wind power in some counties, which has led to the cancellation and delays of projects. In the United Kingdom in 2009, only 25% of proposed onshore wind power sites were given the local approval necessary – a fall from 63% in 2007. The government's Renewable Energy Strategy, published in July 2009, set a target of 14 GW of installed capacity for onshore wind by 2020. Onshore in the United Kingdom, as of mid 2010 there are 3.2 GW

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[65] PIU, "The Energy Review: Performance and Innovation Unit," The Cabinet Office (February 2002), p. 199.

installed, 0.8 GW being built and 3.4 GW under construction – which makes 7.4 GW total, or just over halfway to the target. However, there are another 7.4 GW in planning – enough to reach the target in time if approved.[66] Even larger offshore projects can be done quickly, relative to nuclear power plants. In January 2010, the UK government announced plans for 32 GW, to complement the 8 GW currently under development. These are expected to be in operation by 2020.

It is important to note the differences in the construction of a wind farm compared to conventional power stations. The European Wind Energy Association likens the construction of a wind farm to the purchase of a fleet of trucks, as they noted that the turbines will be purchased at a fixed cost agreed in advance and that a delivery schedule will be established. The electrical infrastructure can also be specified well in advance. There may be some variable costs associated with the civil works, but this cost variation will be very small compared to the cost of the project as a whole.[67] The construction time for onshore wind turbines is relatively quick, with smaller farms being completed in a few months, most within a year. The wind industry has turned the speed advantage of implementation into a major marketing tool.[68]

Opportunity Costs

Assessments by the International Energy Agency and others show two important and somewhat conflicting trends. Firstly, that there will need to be unprecedented levels of investment in the energy sector over the next decade. This is as a result of a number of trends:

- growing demand from developing countries, particularly in the urban environment ;
- the need to retire large numbers of electricity-generating plants in OECD countries as they reach the end of their operating lives and, in some cases, due to the introduction of environmental protection legislation;
- depletion of existing energy reserves and the opening up of new energy reserves and sources.

Secondly, however, there has been a reduction in investment in the energy sector over the last couple of years due to: less availability and higher cost of capital, lower energy demand as a result of the global recession and lower energy prices leading to higher levels of financial uncertainty. With many analysts now predicting the end of the global recession, the conditions that slowed or halted investment may be fully or partially removed. As a consequence, increased investment in the energy sector is both likely and is being encouraged. However, despite the stated economic recovery, capital will be limited, in particular for public sector investment. Furthermore, there will be considerable competition for investment funds between sectors.

Assuming that there is an acceleration of investment in the energy sector, then decisions on what types of investment are to be made now will determine the type of energy sector that will operate for a generation. The figure below shows the scale of investment needed in the energy-related

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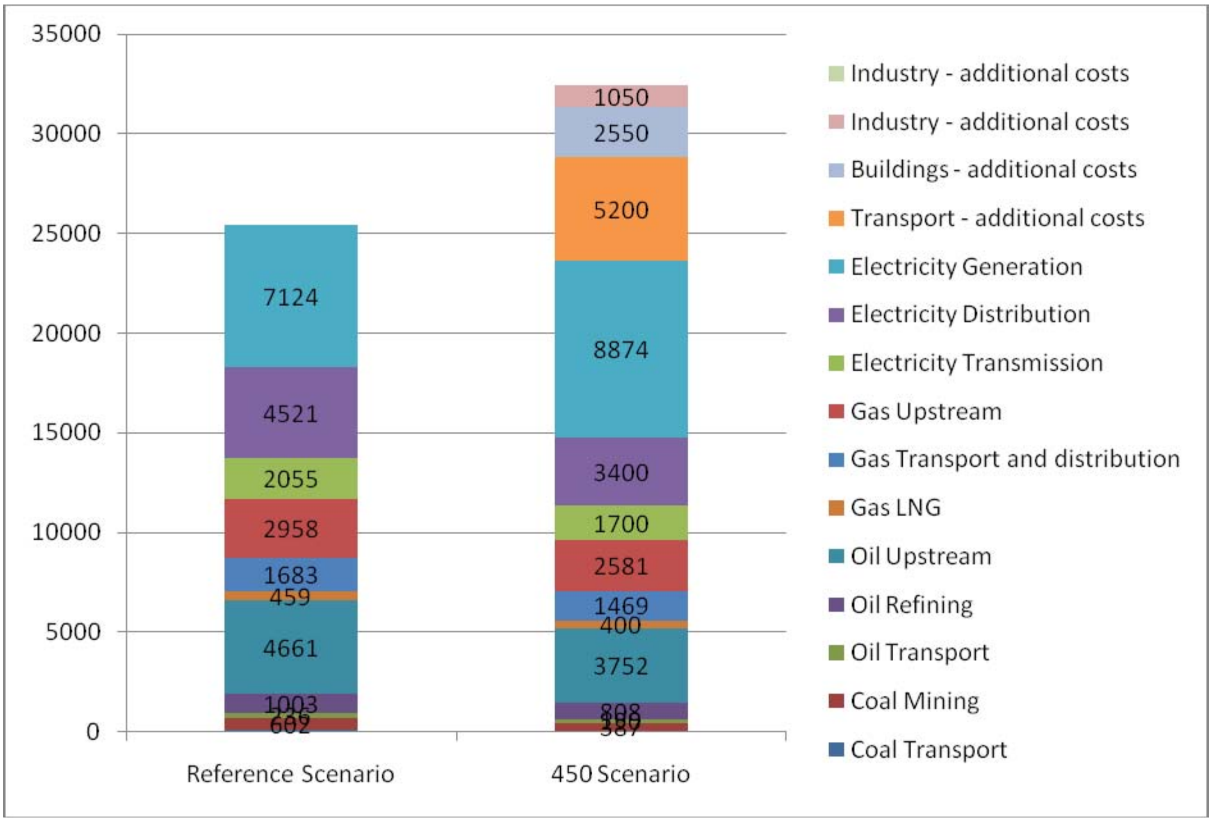
66 BWEA, *Wind Farm Planning Approvals by Local Councils Slump to Record New Low of 25%*, British Wind Energy Association (20 October 2009).
67 EWEA, *Wind Energy, The Facts: Volume 1, Technology*, European Wind Energy Association (2003).
68 Vestas (2009): "You can get a Vestas wind power plant up and running in a year – much faster than conventional energy plants – and this means a quick return on investment," http://www.vestas.com/en/modern-energy/understanding-modern-energy/fast.aspx

sector, according to the IEA, based on different scenarios. The IEA Reference Scenario assumes a total level of investment of $25.6 trillion by 2030; whereas under conditions that keep greenhouse gas emissions from raising global temperatures above 2 degree Celsius, the total investment would be increased by an additional $10.5 trillion. Most of this investment will be needed to improve end-use efficiency, such as in buildings or vehicles, but there is also an increased cost associated with fuel-switching and electricity generated by non-fossil fuels or carbon capture and storage (CCS). However, this additional investment would lead to a lower demand for fossil fuels, reduce the level of new investment required to extract and transport fossil fuels by around $2.1 trillion and reduce the amount spent on fuel. The IEA predicts that fuels savings until 2030 would be in the order of $8.6 trillion, and over the lifetime of the investment around $17 trillion.

Figure 17: Changing Investment in Low-Carbon Energy Sectors



Source: IEA, World Energy Assessment, 2009.

This example shows the degree to which policy targets should influence investment. Failure to recognize this will either lead to policy failure or stranded investments.

The same logic applies to investment choices for the power sector. Clearly, a much greater penetration of end-use energy efficiency will potentially reduce the need for further fossil fuel exploration and exploitation as well as transmission investment. However, the most direct impact will be between different electricity sources, as clearly an increase in investment in one reduces the need for another.

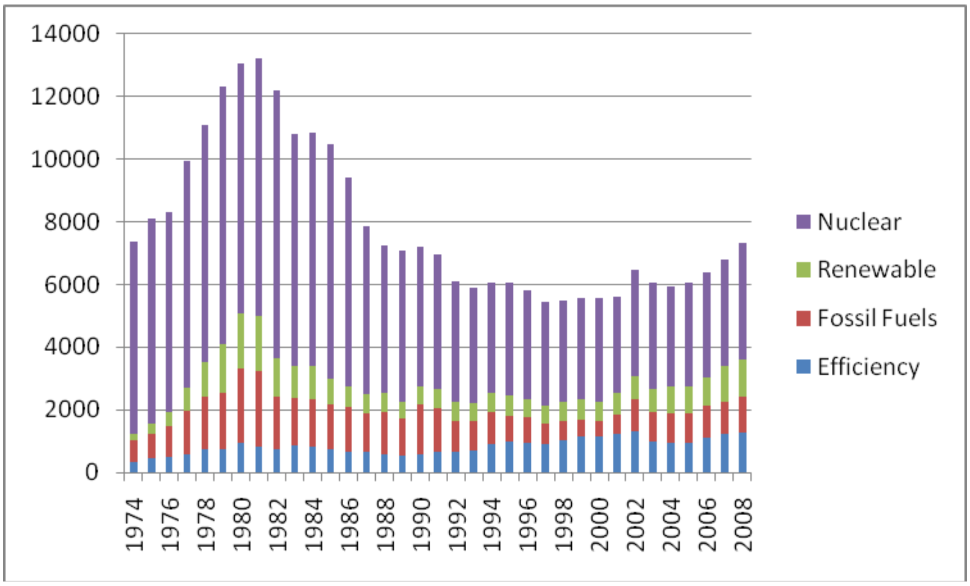
Under virtually all global scenarios that result in an energy sector with considerably lower emissions, nuclear's contribution compared to renewable energy (aside from conservation and efficiency) is relatively small. However, it is argued that nuclear power should nevertheless be included within a wider portfolio of "low-carbon energy options," in particular along with CCS from coal or gas-fired power plants.

Changing the energy sector to one which is genuinely low-carbon and sustainable will require transformative change not only in the sources of energy, but also in the way that energy is distributed and used. To enable this transition, changes in priorities and investments must be made across the entire technology deployment chain, from research and development through to widespread technological diffusion. The section below will look at each deployment stage and compare nuclear power and renewable energy.

Research and development

There are few areas in which there are such direct comparisons and competition between nuclear power and renewable energy as in the field of government research and development. Despite continued calls for increased R&D to address energy and climate security, in many countries the level of government research expenditure is nearly half of what it was in the 1980s. This has affected all energy sources and is an indication of both the desire for smaller government in general and the greater role of the private sector in the energy field over the last decades.

Figure 18: National Research and Development Budgets in OECD Countries (US$mil)



Source: IEA, 2010.[69]

This decline in budgets will decrease opportunities and limit the influence of governments in developing new energy technologies. Figure 19 shows the dominance of nuclear power within these R&D budgets, as it commands nearly two-thirds of total expenditures over the past couple of decades. This is a truly remarkable statistic and is a result of particular factors. Firstly, the nuclear sector includes fission- and fusion funding, of which fusion currently receives the largest share of R&D, as priority has been given to the development of the International Thermonuclear

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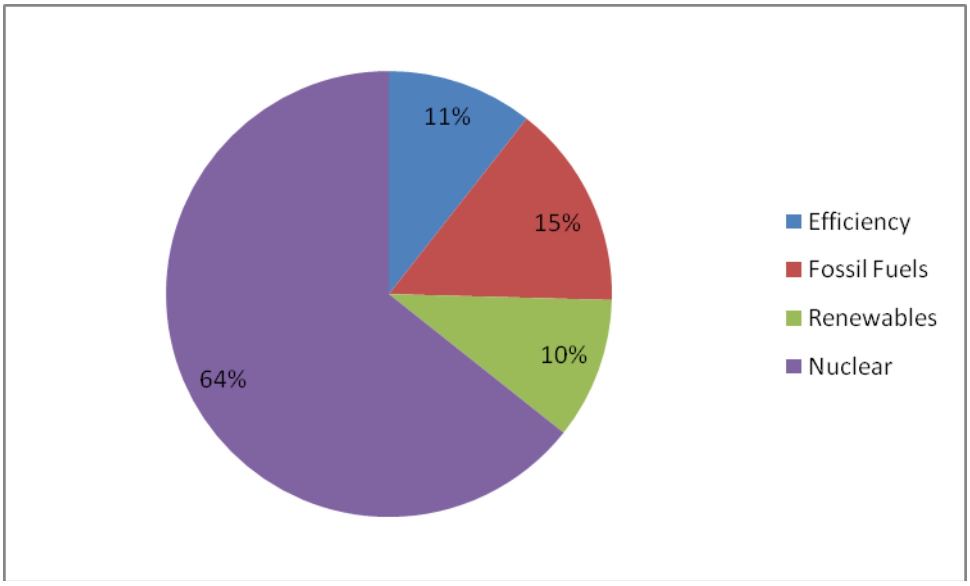
69 IEA, Research and Development Budget data-base (2010), http://www.iea.org/stats/rd.asp

Experimental Reactor (ITER) fusion project. Secondly, funding of nuclear power research – and in particular the financing of demonstration or pilot facilities – is expensive and requires a disproportionate level of funding, especially considering the lack of provided short-term energy service. The technical complexity and innovative nature of these demonstration facilities incur cost overruns, and delays have and continue to occur. In the case of the ITER project in 2006, it was expected to cost around €5 billion (US$7.4 billion) to construct and another €5 billion to operate over a 20-year period. But following an extensive design review, the construction costs are now expected to at least double.[70] Such cost overruns are likely to impact upon the availability of governments to fund other energy projects in the coming decades.

Figure 19: Technological Breakdown of OECD Energy Research and Development Budgets (1974-2008)



Source: IEA, 2010.[71]

Investment costs

In competitive markets there are a number of factors that will affect the decisions on the types of energy sources to be deployed. However, of particular importance is the cost of the energy produced, the price at which it can be sold and the financial cost and risks of its development and deployment.

Nuclear power is at a financial disadvantage when compared to most energy sources, as it has large upfront costs, long construction times and – given the technological complexity – difficulty in meeting anticipated budgets. The history of nuclear power is littered with examples of where the cost expectations of nuclear construction have not been met, as can be seen in the following box. Such cost overruns are important, not only because they significantly affect the cost of the particular project, but because this will affect the cost of capital for further nuclear projects and/or for the

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70 "Fusion Dreams Delayed International Partners are Likely to Scale Back the First Version of the ITER Reactor," *Nature* (27 May 2009): pp. 488-489.
71 IEA, Research and Development Budget data-base (2010).

utility in general. As the IEA notes, “construction costs uncertainty is a major risk factor for investors.”[72]

Box: Nuclear Cost Overruns

The construction costs of nuclear plants completed during the 1980s and early 1990s in the United States and in most of Europe were very high — and much higher than predicted today by the few utilities now building nuclear plants and by the nuclear industry generally.[73]
MIT 2003

[T]he evidence shows that, historically, cost estimates from the industry have been subject to massive underestimates – inaccuracy of an astonishing kind consistently over a 40, 50 year period.[74]
Jonathan Porritt
Chair of the UK government’s Sustainable Development Commission
2005

I do not have any reason to believe ČEZ [the Czech utility constructing the Temelin nuclear power plant]. I have been lied to nine times. I do not know why I should believe them in the 10th case.[75]
Vaclac Havel
then President of the Czech Republic
1999

Figure 14, taken from a report by the Vermont Law School, shows the extent of both the increased costs of reactor construction in the United States in the 1970s and 80s and the rapidly changing expectation of nuclear costs over the last few years. It is important to note that these cost increases were not as a result of actual experience in the United States, as no reactors are currently under construction, but presumably as a result of more in-depth economic analysis and the impact of experiences in other parts of the world.

Often these higher construction costs are not incorporated into the economic analysis that is used to assess the costs of energy production.

For example, in its latest economic analysis, the IEA states that the overnight construction costs for nuclear are in the range of $3,200 to $4,500 per kW.[76] This is well below the summary of analysis undertaken by academics from the Vermont Law School and others.[77] On this basis, the IEA assumes that production costs for electricity will be in the range of $55 to $80 per MWh.

Higher construction costs have a significant impact on the overall cost of nuclear electricity. The University of Vermont study quotes three sources for the impact of higher construction cost on electricity prices:

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[72] IEA, *World Energy Outlook* 2009, p. 268.
[73] Massachusetts Institute of Technology, *The Future of Nuclear Power* (MIT, 2003).
[74] Cited in House of Commons Trade and Industry Committee “New Nuclear? Examining the Issues,” Fourth Report of Session 2005–06, Vol. I.
[75] Office of the President, Press Department press release (12 May 1999).
[76] IEA, *World Energy Outlook* 2009, p. 266.
[77] See *New Nuclear – The Economics Say No,* Citi Investment Research & Analysis (November 2009).

- The MIT model suggests that for every $1,000 of increased overnight costs, the busbar costs[78] go up by $US 1.8 cents/kWh in the utility finance model and 2.4 cents in the merchant finance model;
- In the Harding study, busbar costs go up about 2.4 cents per kWh for every $1,000 increase in overnight costs;
- In the University of Chicago study, the increase in busbar costs per $1,000 in overnight costs was 3.0 cents per kWh.

Averaging these figures would give a $40/MWh increase if the electricity cost were a figure of $5,500 per kW installed used, which falls in line with the higher end of the current expected utility cost prediction and the lower forecast from Wall Street and independent analysts (see figure 14). This would make the IEA's average costs in the order of $95 to $120 per MWh.

Europe has also been experiencing higher than expected costs. The first order for a reactor at the Olkiluoto plant in Finland had a price tag in 2004 of around €3 billion. After five years of construction, although it should have been completed by last year, it is still about three years from completion and 90% over budget at around €5.7 billion.

Higher construction costs are likely to also reduce the ability of utilities or governments to invest in other power plants or alternative energy management strategies. Currently, the IEA assumes that the increased use of nuclear power will require 16% of the total investment. Assuming an investment cost more in line with current US or European expectations will either lead to a reduced investment of around 40% or a requirement of a similar increase in finances. Either option will create potential difficulties for the power sector.

The figure below, from the UK government review in 2002, shows the carbon abatement costs of different non-fossil supply options and energy efficiency. Nuclear power was expected to be vastly more expensive than all other energy efficiency measures and onshore and offshore wind; on a similar range as energy crops; but possibly cheaper than marine energies.

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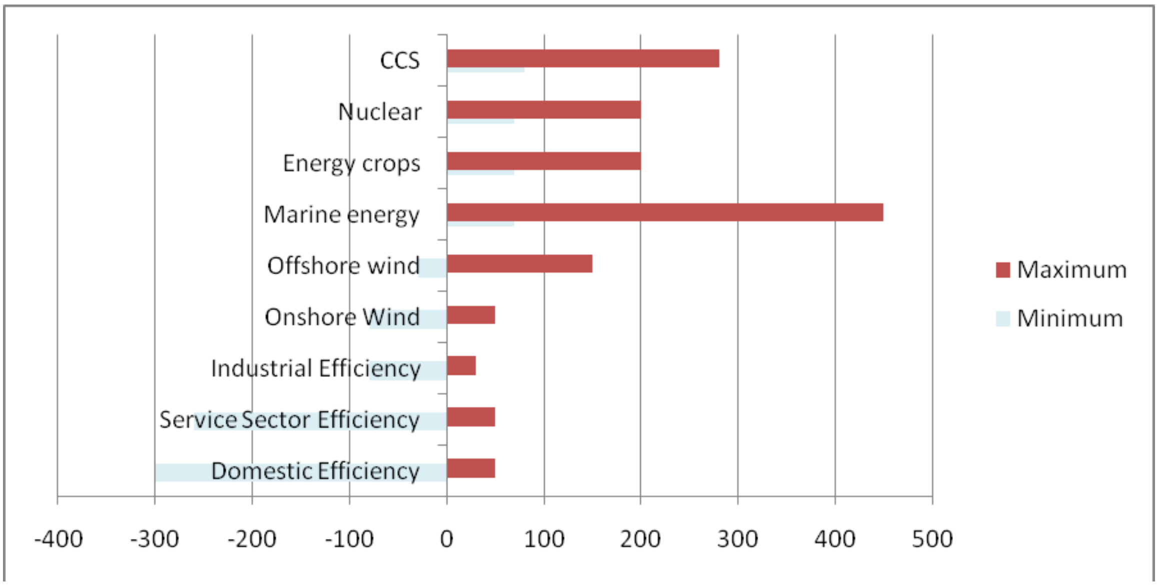
[78] The cost per kilowatt hour of producing electricity; it includes the cost of capital, debt service, operation and maintenance, and fuel. The power plant *bus*, or *busbar*, is that point beyond the generator but prior to the voltage transformation point in the plant switchyard.

Figure 20: Estimated Carbon Abatement Costs in the UK in 2020 (£/tC)



Source: PIU, 2002.

Other, more recent analysis suggests that the costs of nuclear power and renewable energy may be much closer to that suggested by the UK government. A 2009 assessment from the consultancy McKinsey[79] assesses the abatement costs of a range of demand and supply technologies and concludes that "several low-carbon technologies have a similar abatement cost by 2030, this reflects the high level of uncertainty about which technologies are likely to prove to be 'winners.'" The McKinsey analysis shows a range of new build nuclear and renewable technologies having a carbon abatement costs between €5 and 20/tCO_2equivalent; geothermal: 5 €/tCO_2 e; nuclear: 10 €/tCO_2 e; low-penetration wind: 12 €/tCO_2 e; concentrated solar power: 13 €/tCO_2 e; high-penetration wind: 20 €/tCO_2 e.[80] However, on nuclear power, the McKinsey analysis uses €3,000 per kW in 2005 for developed countries (€2,000 per kW is used for developing countries). This installed capacity cost-estimate falls below current actual construction costs and independent analysis.

The CEO of the largest US nuclear utility Exelon has stated recently that "economics of low-carbon options have changed dramatically" in just two years, with the company's new-nuclear cost estimates having more than doubled to about $100/t CO_2, (see following figure) ten times the cost estimated by McKinsey.[81]

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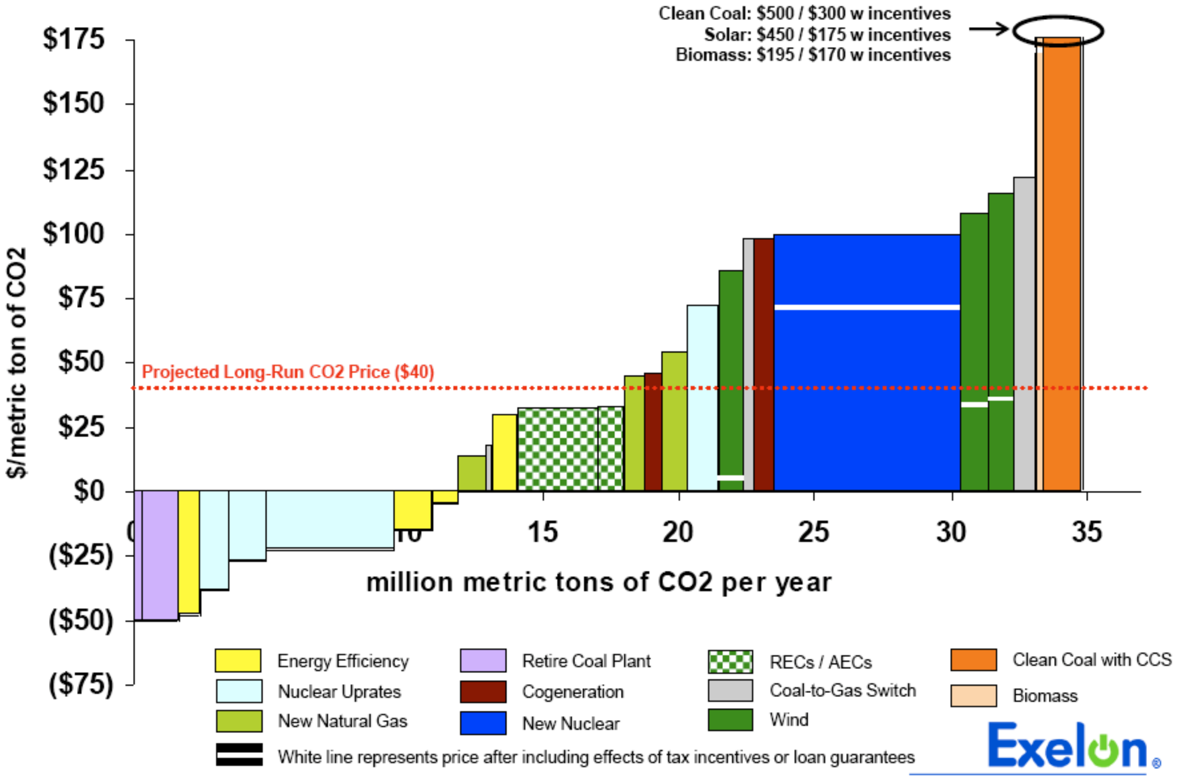
[79] Mckinsey, *Pathway to a Low Carbon Economy – Version 2 of the Global Greenhouse Gas Carbon Abatement Cost Curve* (Mckinsey and Company, 2009).

[80] Ibid., based on an estimation of exhibit 8.1.3 on page 63.

[81] John Rowe, "Fixing the Carbon Problem Without Breaking the Economy", Exelon, 12 May 2010

Figure 21: Exelon 2010 Carbon Abatement Cost Estimates (in US$/t of CO_2)



Source: Exelon, May 2010

Infrastructure and grids

Investment in electricity infrastructure will need to be accelerated in the coming decade, regardless of the energy used for generation. The latest assessment by the IEA, in its 2009 *World Energy Outlook*, concludes for its Reference Scenario that total investment needed by 2030 in the power sector is $13.7 trillion, of which 48% will be needed for transmission and distribution ($2 trillion transmission and $4.5 trillion for distribution). Investment costs for a system that produces less carbon emissions will likely be higher.

The existing grid is largely based on the operation of large centralized power producers that use high voltage cables to transport the power over long distances to urban or industrial areas, where lower voltage wires take the electricity to the end consumer. These grids were built largely at a time when the electricity sector was all under state ownership. Consequently, new power stations did not have to pay for the grid connections that enabled them to operate. This potentially creates an additional cost and economic disadvantage for new generating capacity entering the market at locations that are not on the existing grid system, if they are required to pay for either grid reinforcement or connections.

The current system is largely based on a “predict and supply” model, whereby the centralized utilities attempt to ensure that the demand-needs of the consumers are met at all times. However, as has been noted in the previous chapter, this system is inefficient and not fit for the creation of a low-carbon and sustainable energy sector. Furthermore, large-scale changes will be needed for the scope and functioning of the grid in order to accommodate renewable energy production from a geographically wide and varying size-set of generators. In some cases, for example offshore wind, there can be no ambiguity about the need for the grid investment. Without this investment in the grid, the development will not take place.

Such changes have been recognized both in policy statements and investment proposals, particularly in the economic stimulus packages. However, in many cases the details are lacking and there remains confusion over definitions and the extent to which a radical change is underway. In particular, the use of the term "smart" has now become synonymous with change, but yet there is no clear and universal understanding of what this means. One of the most striking examples of this was a press release by the UK Department of Energy and Climate Change, just prior to the Copenhagen conference. This statement, entitled "UK energy system gets smart," used the word "smart" 22 times in a 19-sentence statement.[82]

The UK national stimulus packages produced as a result of the economic crisis highlighted both "green" activities and the need for investment in "smart grids" in particular. According to analysis by the London-based bank HSBC, the total funding pledged for new grids globally was $92 billion, although the majority of this, around $70 billion, was in China (out of total finances for Green activities of $430 billion)[83]. However, it is clear that not all of the projects that are classified as "low-carbon" or "green" differ significantly from existing maintenance or expansion plans.

The EU's stimulus package for energy focuses on the European Energy Programme for Recovery, which created the basis for providing substantial co-financing from the Union budget to key energy projects, through a €4 billion scheme that was said to be aimed at "protecting jobs and purchasing power, boosting infrastructure and creating jobs in the low-carbon sectors of the future." Investment in gas and electricity infrastructure projects received the largest share, €2.365 billion (60% of budget), then CCS €1.05 billion (26% of budget) and finally offshore wind energy projects €0.565 billion (14% of budget). Details about the CCS and offshore wind projects funded have been made available, but not those of the gas and electricity infrastructure projects, which are still under consideration. However, the projects under consideration do not appear to be related to low-carbon, particularly renewable energy, but re-enforce the existing electricity market.[84]

Furthermore, only 10% of the criteria for judging the suitability of the projects relate to environmental issues, and even here, there is no reference to "impact of the action *inter alia* on nature, emissions, noise, land use and the measures to reduce or compensate any negative impacts."[85] Under the offshore wind subcategory, three major grid infrastructure projects are to be funded that will receive around €310 million for projects expected to cost in the order of €1.8 billion.

While the focus remains on heavy investment in high-tension power transport infrastructure, a thorough, systemic analysis about conflicting investment dynamics is overdue. The absolute priority given to the ever growing high-power – and high-loss – centralized transport and distribution

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[82] http://www.decc.gov.uk/en/content/cms/news/pn139/pn139.aspx (16 March 2010).

[83] HSBC, *A Climate for Recovery; The Colour of Stimulus Goes Green* (February 2009).

[84] OJ, Regulation (EC) No 663/2009 of The European Parliament and of The Council of 13 July 2009 establishing a program to aid economic recovery by granting Community financial assistance to projects in the field of energy L/200/31 (31 July 2009).

[85] European Commission, Information Day (2009), http://ec.europa.eu/energy/grants/docs/eepr/eepr_info_day_presentation_interconnections.pdf

systems constitute an effective barrier for the speedy introduction of highly efficient, decentralized smart grids that minimize transmission losses and constitute a key ingredient of future intelligent networks that profoundly redefine the roles of the electricity producer/user.

An electric car, for example, transforms electricity much more efficiently into mechanical power than the combustion engine. However, this physical reality remains pure theory unless the electricity is generated in a sustainable way. It is crucial to reorient the infrastructure investments toward an entirely different systemic approach rather than to continue to patch up the old, inefficient infrastructure with new devices that will not make the overall system performance any better.

In recent years, the capacity difficulties of integrating larger quantities of intermittent renewable energy into the grid has already been seen in a handful of cases. These problems were exacerbated by large and unwieldy nuclear power plants, which require *permanent* access to the grid. The growth of renewable energy in recent years has shown that projects are being constructed on time and within budget and connecting to the grid has not been a problem. Furthermore, it clearly makes sense to give priority access to renewable energy, as they use no fuel. Unless there is systematic change, then the inefficient use of renewables will increase. Therefore, there must be a fundamental reform of the management of grids with significant investment for new infrastructure and product development. This must be based on higher levels of supply efficiency that prioritizes the localized production and use of energy, supplies responsive consumption and storage, integrates regional electricity grids and creates clusters of micro-grids to reduce the need for backup generation and, where necessary, exploits larger renewable resources such as offshore wind.

Market mechanisms

Over the last decades, the global trend to greater market liberalization has resulted in less state intervention in the operation of the gas and electricity markets. However, this has not led to a total “hands off” approach to energy supply, but rather the introduction of more market-based mechanisms to support particular technologies.

These market mechanisms have been most recently and effectively used – in some, but not all cases – to help establish renewable energy. In particular, within the electricity market, mechanisms such as feed-in tariffs and guarantees on market share, have been introduced. By early 2009, policy targets for renewable energy existed in at least 73 countries. This includes state/provincial- level targets in the United States and Canada, which have no national targets.[86] These policy mechanisms are the foundation of the success of renewable energy.

Importantly, it has been stated and legally tested in Europe that these mechanisms do not constitute state aid. Specifically, in a test-case judgment delivered in 2001, the European Court of Justice stated clearly that well-structured feed-in tariffs did not represent state aid, but are justified as a means to balance out the external costs that are not factored into pricing. This ruling has been expanded upon by the European Commission, which states that from an economic-efficiency perspective, a number

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86 REN 21, *Renewables Global Status Report 2009 Update: Renewable Energy Policy Network for the 21st Century* (2009).

of market failures justify state intervention in renewable electricity markets.[87] The reasons given for this were as follows.

- "Since complete internalisation of […] externals does not appear politically feasible at present in most countries […] supporting renewables to take account of their lower emissions profile can be justified on efficiency grounds."
- "Although some renewables, such as wind in prime locations, exhibit cost structures close to those of conventional sources, renewables are generally considered to be not yet commercially competitive on an unprotected electricity market, especially as this market is still distorted by a large number of direct and indirect subsidies for the existing electricity system, and is based on infrastructure that was mainly built when the electricity sector was publicly owned […] Despite the long-term prospects of renewables, the market is still under-investing in research and development, which is why governments should provide incentives to innovate."
- "Regulatory systems nowadays favour conventional energies, which have additionally profited from massive government support for R&D in the past."

US Nuclear Subsidies Compared

In their first 15 years, nuclear and wind technology produced a comparable amount of energy (nuclear: 2.6 billion kWh; wind: 1.9 billion kWh), but the subsidy to nuclear outweighed that of wind by a factor of over 40 ($39.4 billion to $900 million).

Marshall Goldberg, "Federal Energy Subsidies: Not All Technologies Are Created Equal," *REPP* no. 11 (July 2000)

The lack of orders for new nuclear power in most liberalized markets has resulted in fewer technology support mechanisms actually being used, although there is increased financing being made available or earmarked. The clearest example is in the United States, in which the 2005 Energy Act made clear its financial support for nuclear power, including:

- production tax credits: 1.8 cent tax credit for each kWh from new reactors for eight years for six reactors – cost to US treasury: $5.7 billion;
- loan guarantees for first 6 to 8 reactors (worth up to $18.5 billion);
- a support framework against regulatory or judicial delays, worth up to $500 million for the first two reactors and $250 million for the next four;
- further research and development funding worth $850 million;
- assistance with historic decommissioning costs (up to $1.3 billion).

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[87] European Commission, Communication from the Commission: *The Support of Electricity from Renewable Energy Sources*, SEC(2005) 1571, Com(2005)627 final, (2005).

In December 2007, Christopher Crane, president of Exelon Generation, one of the utilities that has stated an intention to build new nuclear plants, said: "If the loan guarantee program is not in place by 2009, we will not go forward."[88] The importance of this particular market mechanism was made clear in January 2010, when President Obama trebled the potential financing available, ensuring that up to $54 billion would be made available under his proposed energy bill.

As noted, in other countries with liberalized electricity markets, there are currently fewer overt market mechanisms purely for nuclear power. However, broader support mechanisms are being developed that could enable the further financial support for nuclear power. At the informal Summit at Hampton Court in October 2005, during the term of British Prime Minister Tony Blair, Dieter Helm put forward an informal paper, "European Energy Policy, Securing Supplies and Meeting the Challenge of Climate Change."[89] This paper suggested that the need for investment – due to the retiring of much of the current generating capacity – was an ideal opportunity to invest in "non-carbon energy sources." Furthermore, the paper stated "the EU should consider widening the definition of renewables towards a definition that includes a number of emissions reductions technologies."

In some cases, more explicit attempts have been made to reclassify nuclear power as a renewable energy source. In the US state of Arizona, language in legislation on the renewable energy bill was defeated in February 2010 – it had proposed to include nuclear power within the definition of renewable energy. This would have enabled nuclear to be included in the target that required utilities source to acquire 15% of their electricity from renewable sources. Arizona Governor Jan Brewer issued a statement when the nuclear elements were withdrawn from the bill: "This sends a clear and united message to employers around the world — Arizona remains the premier destination for solar industries."[90]

The European Commission released on 8 March 2006 the Green Paper, "A European Strategy for Sustainable, Competitive and Safe Energy."[91] It included the following section on low-carbon technologies:

> Furthermore, it might be appropriate to agree an overall strategic objective, balancing the goals of sustainable energy use, competitiveness and security of supply. They would need to be developed on the basis of a thorough impact assessment and provide a benchmark on the basis of which the EU's developing energy mix could be judged and would help the EU to stem the increasing dependence on imports. For example, an objective might be to aim for a minimum level of the overall EU energy mix originating from secure and low-carbon energy sources. Such a benchmark would reflect the potential risks of import dependency, identify an overall aspiration for the long term development of low-carbon energy sources and permit the identification of the essentially internal measures necessary to achieve these goals.

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[88] "Loan Guarantees Tagged as Key for Nuclear Builds," *Power, Finance and Risk* (21 December 2007).
[89] http://www.fco.gov.uk/Files/kfile/PN%20papers_%20energy.pdf
[90] "Bill to Classify Nuclear as Renewable Energy Killed," *Phoenix Business Journal* (22 February 2010), http://phoenix.bizjournals.com/phoenix/stories/2010/02/22/daily51.html
[91] http://europa.eu.int/comm/energy/green-paper-energy/index_en.htm

Such measures are now being proposed in Europe and in February 2010, the UK energy regulator – OFGEM – announced that “there is an increasing consensus that leaving the present system of market arrangements and other incentives unchanged is not an option” for security of supply and environmental reasons.[92] One of the measures that OFGEM was considering was capacity tenders for all forms of generation, including renewables and nuclear power, to provide clearer long-term investment signals.

The use of market mechanisms for the wider deployment of renewable energy has been legally justified, in Europe, as they seek to balance the existing environmental and economic distortions that exist in the market. Furthermore, they facilitate the development of new technology that has not benefited either from the historically much larger research and development budgets or from the construction of infrastructure that occurred when the system was state owned. These same justifications cannot apply to nuclear power as the technology has, and continues to, receive the largest share of research and development; has been favoured by the implementation of infrastructure; and is not responsible for the full cost of its actual and potential environmental cost. However, as noted, measures are now being introduced in the United States to financially support the introduction of nuclear power once again, while in Europe attempts are being made to move away from specific targets for the introduction of renewable energy and to create a “low-carbon” target. These measures will potentially dilute the effectiveness of renewable policies and, more importantly, raise doubts in the minds of investors about the seriousness of the commitment by governments to renewable energy.

This section has looked at the opportunity costs of nuclear power and renewable energy. However, there are many other issues that a detailed comparison would address. One study by Mark Jacobson published in the journal *Energy and Environmental Science*[93] looked at a range of energy sources and their potential to address climate change, air pollution and energy security, while considering a range of other issues, such as water supply, land use, wildlife, resource availability, thermal pollution, water pollution, nuclear proliferation and malnutrition. The conclusions of Professor Jacobson’s research shows that nuclear power[94] is ranked below all renewable energy options that are used for generating electricity. The technologies considered were solar PV, concentrated solar power, wind, geothermal, hydroelectric, wave, tidal, nuclear and coal with CCS, along with biofuels, corn and cellulosic.

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92 OFGEM, “Action Needed to Ensure Britain’s Energy Supplies Remain Secure,” press release (4 February 2010).

93 Mark Z. Jacobson, “Review of Solutions to Global Warming, Air Pollution and Energy Security,” *Energy and Environmental Science* (1 December 2008).

[94] The impact of nuclear energy policy on climate change and the environment has been assessed in more depth in an article by Felix Matthes, see http://www.boell.de/downloads/ecology/NIP6_MatthesEndf.pdf

Conclusions

Nuclear power has already been and continues to be the recipient of large government interventions. As one example notes, in their first 15 years, nuclear and wind technologies produced comparable amount of energy in the United States (nuclear: 2.6 billion kWh; wind: 1.9 billion kWh), but the subsidy to nuclear outweighed that to wind by a factor of over 40 ($39.4 billion to $900 million). Even today, with the demise of new orders for nuclear power and the rise of other technologies, nuclear power continues to enjoy unparalleled access to government research and development funding.

Furthermore, it continues to receive large, indirect subsidies[95] through the lack of inclusion of environmental costs into the electricity prices, particularly through government guarantees for the final storage or disposal of radioactive waste. More direct financial assistance is made available through the limitations and government financial guarantees for third-party liability insurance, through export credit agency guarantees, production tax credits or loan guarantees.

Global experience of nuclear construction shows a tendency of cost overruns and delays. The history of the world's two largest construction programs, that of the United States and France, shows a five- and threefold increase in construction costs respectively. This cannot be put down to first of a kind costs or teething problems, but systemic problems associated with such large, political and complicated projects. Recent experience, in Olkiluoto in Finland and the Flamanville project in France, highlight the fact that this remains a problem. The increased costs and delays with nuclear construction not only absorb greater and greater amounts of investment, but the delays increase the emissions from the sector.

From a systemic point of view the nuclear and energy efficiency+renewable energy approaches clearly mutually exclude each other, not only in investment terms. This is becoming increasingly transparent in countries or regions where renewable energy is taking a large share of electricity generation, i.e., in Germany and Spain. The main reasons are as follows.

- **Competition for limited investment funds**. A euro, dollar or yuan can only be spent once and it should be spent for the options that provide the largest emission reductions the fastest. Nuclear power is not only one of the most expensive but also the slowest option.
- **Overcapacity kills efficiency incentives**. Centralized, large, power-generation units tend to lead to structural overcapacities. Overcapacities leave no room for efficiency.
- **Flexible complementary capacity needed.** Increasing levels of renewable electricity sources will need flexible, medium-load complementary facilities and not inflexible, large, baseload power plants.
- **Future grids go both ways.** Smart metering, smart appliances and smart grids are on their way. The logic is an entirely redesigned system where the user gets also a generation and storage function. This is radically different from the top-down centralized approach.

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[95] For a more in-depth discussion of historic government subsidies to nuclear energy in Germany, see Green Budget Germany (2009) "Staatliche Förderungen der Atomenergie im Zeitraum 1950 bis 2008."

For future planning purposes, in particular for developing countries, it is crucial that the contradictory systemic characteristics of the nuclear versus the energy efficiency+renewable energy strategies are clearly identified. There are numerous system effects that have so far been insufficiently documented or even understood. Future research and analysis in this area is urgently needed.

This is particularly important at the current time because the next decade will be vital in determining the sustainability, security and financial viability of the energy sector for at least a generation. Three key policy drivers and considerations have come together that must transform the way in which energy services are provided and energy carriers (electricity, hydrogen…) and fuels are generated, transported and used. These are:

- the growing awareness of the need for action to reduce the threats of dangerous climate change and the realization of the important contribution of the energy sector;
- increased and expected further increases in global competition for traditional energy resources, with this increased demand not being matched by new discoveries of larger resource reserves;
- and a need for accelerated investment in the energy sector, in OECD countries, as a result of the obsolescence of existing infrastructure, and in developing countries as a result of accelerated urbanization and demand for different and amplified energy services.

As has been noted by the OECD's International Energy Agency and others, business as usual is not an option. Renewable energy has been a, if not the, major industrial success story of the last decade. Globally in 2009 spending on new renewable energy capacity, excluding large hydro, was for the second year running bigger than investment in new fossil fuel capacity. In 2009 in Europe, €13 billion of wind investment was made, which led to wind power plants accounting for 39% of new power production installations – the second year running that more wind power was installed than any other generating technology. Furthermore, renewable power installations in general accounted for 61% of new EU grid connections in 2009. The EU power sector continues its move away from coal, fuel oil and nuclear, each technology continuing to decommission more than it installs. While it is clear that some countries are more successful in their renewable energy deployment, there is a global attempt to increase the use of the technology with policy targets for renewable energy existing in at least 73 countries. Importantly, many developing countries are at the forefront of the manufacturing and use of renewable energy. China already leads the world in the use of solar thermal, is expected to become the largest manufacturer of wind turbines shortly and, in 2009, was responsible for the largest increase in installed wind capacity. Furthermore, the use of renewable energy in Europe is expected to treble in the coming decade and significantly increase in most OECD countries.

The use of renewable energy has shown that it is a key set of technologies for reducing greenhouse gas emissions from the power sector. However, to date, its role for other sectors, in particular for transport and heat and cooling, has yet to be fully recognized. Consequently, its contribution to the energy mix is considerably less than for electricity in many countries, when not considering traditional and non-commercial energy sources.

It is crucial, however, to realize that renewable energy policies will not achieve the indispensable emission reduction results without a massive effort in energy efficiency throughout all energy systems. Germany’s power sector is a striking example, as consumption increased faster than the decarbonisation of the kWh, wiping out most of the beneficial environmental effects of the highly successful renewable energy program. This starts with the appropriate layout for long-term infrastructure investments, in particular in urban planning, building design and land use. We cannot afford to continue creating additional artificial transport needs because we build office buildings and shopping malls where there are no homes. We have neither the time nor the resources to waste by investing in inefficient buildings first and (maybe) retrofit after.

Confidence in the longevity and effectiveness of government policies are vital if private finance is to be attracted to the energy efficiency+renewable energy sector. “Investment grade”[96] renewable energy policies must remain in place and be extended into the long term. Ideally, these policies and targets should spell out the opportunities and objectives for each renewable energy sector, reflecting the status of the market and each technology, to ensure that adequate, but not excessive, support is made available. However, the relatively low contribution of non-hydro renewable energy to the global electricity supply demonstrates both the potential market that exists and the scale of investment that will be needed on the short- and long term. Therefore long-term, clear signals must be introduced that demonstrate the commitments by governments to this sector. Sending mixed signals with proposals to blend renewable energy targets with “low-carbon” objectives will create uncertainty and undoubtedly delay or halt investment.

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96 See Kirsty Hamilton, *Unlocking Finance for Clean Energy: The Need for “Investment Grade” Policy*; Hamilton is Research Fellow at the Chatham House, http://www.chathamhouse.org.uk/files/15510_bp1209cleanenergy.pdf (15 March 2010).

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