Jaap C. Jansen

In the Wake of Fukushima, Should our Electricity become Almost Completely Renewable and Completely Non-Nuclear?

In the last few years before the Fukushima nuclear disaster, which started to unfold on 11 March 2011, support for the nuclear power option was picking up in several EU member states. New nuclear power plants are currently being built in Finland, France, Bulgaria and other countries; the UK, Sweden, Italy, Czech Republic, Romania and the Netherlands were seriously considering new nuclear reactors, while in Germany, Spain and Belgium a relaxation of the existing moratorium was under political discussion. The commission chaired by former Spanish Prime Minister Felipe Gonzales advising the European Council on the future of Europe stated:

"The search for a more viable energy mix must also involve recourse to nuclear energy. Europe cannot afford to relinquish this important source of power, but unlocking investments in nuclear energy requires a greater level of regulatory certainty, as well as the further development of safety standards."[1]

Yet all over the world, not least in Europe, the Fukushima nuclear accident has given politicians and energy policy analysts food for thought in reassessing the role of nuclear energy and renewables in their long-term energy policies. The first government to radically revise its energy policy regarding the deployment of nuclear power reactors was the German coalition government of Christian Democrats and Liberals, led by Angela Merkel. Mrs. Merkel had already made up her mind on 12 March 2011: she ordered the 7 oldest of Germany's 17 nuclear energy plants to be switched off "for the time being" for three months.[2] At the same time, she revoked the decision approved by the German Parliament on 28 September 2010 to extend the operational lifetime of nuclear plants by an average of 12 years relative to the moratorium plan promulgated in 2002 by the Social Democrat/Green Party coalition government. To that effect, she installed an ethics commission that has to submit a report with a proposed date for the complete demise of German nuclear power generation. According to leaked information, this will be no later than ten years from now, i.e. by 2021. At the time of writing this article, the governments of the other 14 EU mem-

1 F. Gonzáles Márques et al.: Project Europe 2030. Challenges and Opportunities, Report to the European Council by the reflection group on the future of Europe 2030, May 2010.

2 Der Spiegel: Das war's!, No. 14, 2011, pp. 62-72.

ber states with operating nuclear energy plants did not go further than to announce ad hoc audits that should integrate the lessons learnt from Fukushima. Yet among the remaining member states without operating nuclear reactors, Italy has put the intended reintroduction of nuclear power generation capacity on hold.

This article presents a preliminary qualitative assessment of a fast phase-out of nuclear electricity capacity and a transition towards a largely (80%+) renewable electricity supply sector in Germany and the greater EU. The focus is on the associated costs and the feasibility of the envisioned transition towards a completely renewables-based electricity supply sector. Special attention is paid to Germany as this country is pioneering an *Energiewende* (a fast transition towards a renewables-based energy economy). Moreover, it has a large power sector accounting for about 30% of EU power demand. The article is structured as follows. First, three politically important scenario studies are briefly introduced which have developed (among others) scenarios for an 80%+ renewable power sector in Germany and the EU by 2050. Next, the most important conditions for making such scenarios come true are reviewed. Finally, the major consequences of a political decision to introduce or speed up a nuclear moratorium in EU member states will be addressed. The article closes with conclusions.

Making Power More Renewable: Some Scenarios

To date, the most relevant scenarios for energy policy formulation in Germany are the scenario study[3] underlying the Energy Concept policy document[4] of the German government and a study commissioned by the Federal Ministry of the Enviroment in 2010 (Pilot Study 2010).[5]

The scenario study for the Energy Concept develops target scenarios for reducing GHG emissions in Germany by 85% by 2050 relative to 1990. Moreover, in the target scenarios, primary energy demand and electricity demand in 2050 relative to the base year 2008 are to be reduced by more than 50% and by 20-25% respectively. In the target scenarios, renewable-based electricity, including substantial renewable electricity imports, are to account for around 80% of gross electricity demand by 2050. By then, an important non-renewable power component would be coal-based power in CHP (combined heat and power) mode with CCS (carbon capture and storage). Some of the major points envisaged by the aforementioned target scenarios include the following:

- Wholesale electricity prices in 2050 will be in the order of €20-30/MWh[6] as opposed to spot prices which currently oscillate within the €55-65/MWh range. Saharan solar power will exert a substantial downward effect on wholesale power prices, especially during the mid-day peak hours.
- In 2050 the unit cost of electricity (generation cost only) will be about €15/MWh higher than in 2008. The major reason for the increase is the expansion of renewable electricity generation.
- Offshore wind will be the renewable option providing the largest contribution to the increase in renewable electricity generation, with other – e.g. biomass-based – options being constrained by factors such as biomass or land availability.
- In Germany photovoltaics (PV) will not become economically feasible by 2050 in spite of learning curve effects. Feeding in at lower network voltage levels hardly saves network costs, as these are more than 90% determined by fixed costs.
- The *EEG Umlage* (surcharge on the household electricity bill to pay for the extra costs of renewable electricity stimulation by the German feed-in tariff system) will be approximately €0.04/kWh in 2050.
- The household electricity price in 2050 will be approximately €0.22/kWh, i.e. broadly the same level as at present.

The Pilot Study 2010 analyses renewables-dominated energy futures for Germany through 2050. One of the scenarios presented in this study projects a 100% renewable-based power supply sector. Its baseline demographic, structural and economic assumptions correspond largely to the ones used in the Energy Concept scenario study. As a result of assumed increasing primary energy productivity, electricity is to gradually diminish through 2030 and level off thereafter through 2050. Hence the reduction in power demand from 2008 to 2050 in the Pilot Study 2010 scenarios is much less than in the Energy Concept target scenarios. According to the Pilot Study, power demand by "new uses" such as electric vehicles, heat pumps and air conditioning are bound to largely offset electric energy efficiency improvements. In the 100% renewable electricity scenario, hydrogen production for electricity storage purposes would even push total electricity demand in an upward direction. Balancing options to be implemented for stabilising the electricity system include: (1) grid extensions, (2) the provision of new storage capacities, and (3) generation and load management. Controllable renewable power such as biomass, including biomass for flexible CHP (with heat or gas storage opportunities), pumped-storage and H_2-powered plants as well as inter-

3 Prognos/EWI/GWS: Studie Energieszenarien für ein Energiekonzept der Bundesregierung, Basel/Köln/Osnabrück, August 2010.

4 Bundesrepublik Deutschland: Energiekonzept, BMWI/BMU, Berlin, 28 September 2010.

5 DLR/Fraunhofer IWES/IfrE: Leitstudie 2010, Study commissioned by BMU, December 2010.

6 Unless otherwise stated, monetary values mentioned in this article are "real", i.e. not including future price inflation.

national electricity exchanges, are primarily to be used for load management. Because of the high share of intermittent renewable generation with priority grid access, the need for base-load power plants is set to diminish. Generation costs of renewables-based electricity in Germany would come down from €0.14/kWh in 2011 to €0.06/kWh in 2050. Note that transmission and distribution costs are not included in these amounts. Given projected trends, within the period 2025-2032, all-renewables power generation would become cheaper than power generation according to the baseline scenario, i.e. a scenario in which conventional power still makes up an appreciable share.

At the time of writing, the European Commission has not yet presented scenarios with a time horizon as far off as 2050.[7] Therefore we now briefly discuss Roadmap 2050 scenarios with a largely renewable-based European power supply sector based on a study prepared by a well-regarded source, the European Climate Foundation (ECF).[8] The study concerned uses as its point of departure an 80% CO_2 reduction in the EU[9] by 2050 relative to 1990. This equates to a 95-100% non-CO_2 electricity generation mix. The "pathways" (backcasting target scenarios) considered include ones with a 40%, 60% and 80% renewable electricity share (RES). The non-renewable shares are assumed to be equally divided between fossil fuels with CCS and nuclear power. At the EU level, power demand is set to grow by about 40% from 2005 to 2050 under low carbon pathway conditions. This is similar to the Roadmap 2050 baseline scenario without intensified climate change policy: extra energy efficiency improvements would be offset by extra demand for electricity due to "new uses" such as electric vehicles and space heating by electric heat pumps. The ECF study concludes that if the presumed framework conditions were met, the cost of electricity for the three low-carbon pathways could be 10-15% higher than the baseline excluding carbon pricing. At a carbon price of €20-30/tCO_2eq, the cost of electricity of the three low carbon pathways and under the baseline scenario would be roughly the same. However, the overall cost of energy would decline by 20-30% relative to the baseline, due primarily to greater energy efficiency and a shift from oil and gas to decarbonised electricity in transport and buildings. If a low carbon pathway of 100% electricity from renewable sources in the electricity mix were to be pursued, this would be feasible technically and at a cost of probably only 5-10% more than the 60% RES pathway.

7 The European Commission communication: Energy 2020, a strategy for competitive, sustainable and secure energy, COM(2010)639 final. Brussels, 10 November 2010, falls short of presenting detailed scenario results.

8 EFC: ROADMAP 2050, practical guide to a prosperous, low-carbon Europe, Berlin, Brussels, The Hague, April 2010.

9 Apart from the EU27, Norway and Switzerland are also included.

General Framework for High Renewable Power Scenarios

The three studies reviewed all come with an invariably happy message: end-user electricity prices will hardly rise or (e.g. according to the Pilot Study 2010) may even fall if a high energy efficiency (EE) cum renewable (RES) power scenario is adopted to support long-term energy policy. A moratorium on nuclear energy would not materially affect this forecasted upshot. This "happy news" is compounded by some of the major benefits an EE/RES scenario has relative to a business-as-usual scenario:

- carbon emissions will decrease by substantially higher amounts;
- supply security will be much greater as dependency on imported fossil fuels from politically less stable countries will decrease markedly;
- electricity prices will become more stable;
- innovation will lead to job creation.

Some qualifying remarks can be made concerning the presumed general framework. First, let's examine some of the major conditions. Future prices of coal and natural gas will have a major impact on the future fuel mix in the electricity sector. Rising fuel prices improve the competitiveness of both nuclear and renewable energy. Future fuel prices are surrounded by great uncertainty, yet it would seem likely that strong long-term upward trends for fossil fuel prices are in the offing. For supply to meet fast increasing non-OECD demand, marginal supply has to come from increasingly expensive sources. Regarding the market for internationally traded coal, it is often overlooked that supply concentration is quite high. Countries with major coal resources, such as the USA, China and India, need virtually all their production to meet their domestic demand. As for gas, non-conventional gas is often touted as a "game changer". Indeed, current gas prices are somewhat depressed, though it is a distinct possibility that this situation could last for only a few years. A major reason for this is that gas is the fossil fuel of choice due to its fairly moderate environmental impact – including its carbon emissions impact – compared to coal. Moreover, the investment costs of gas-based power plants are low, while their construction period is short.

Therefore, it would seem prudent for scenario developers to assume quickly rising fuel prices as well as a high correlation among oil, gas and coal prices, i.e. the rise in coal prices will not be substantially less steep than the others. Table 1 shows the assumptions made for the scenarios introduced above. The price paths A of the Pilot Study 2010 would seem most appropriate. The Roadmap 2050's reliance on IEA figures for coal seems rather off the mark, as the coal market in coal-importing Europe is quite different from non-Europe OECD.

Table 1

Assumed Price of Coal and Natural Gas in the Scenarios Considered

(€/MWh)

		2008	2030	2050
Coal	Scenarios for Energy Concept	17.3	10.8	14.0
	Pilot Study 2010: path A	13.7	23.4	33.1
	Roadmap 2050[a]	6.1[b]	7.9	9.4
Gas	Scenarios for Energy Concept	25.2	25.9	31.7
	Pilot Study 2010: path A	26.3	49.7	69.1
	Roadmap 2050[a]	21.4[b]	25.2	35.6

[a] US $1 = €0.704. Figures are based on the IEA World Energy Outlook 2009; [b] Figures for year 2009.

Sources: Prognos/EWI/GWS: Studie Energieszenarien für ein Energiekonzept der Bundesregierung, Basel/Köln/Osnabrück, August 2010; DLR/Fraunhofer IWES/IfrE: Leitstudie 2010, Study commissioned by BMU, December 2010; EFC: ROADMAP 2050, practical guide to a prosperous, low-carbon Europe, Berlin, Brussels, The Hague, April 2010.

Table 2

Assumed Parameter Values for Cost of Electricity from Offshore Wind

		2010	2030	2050
Investment cost (€/kW)	Scenarios for Energy Concept	2400[a]	1670	1350
	Pilot Study 2010	3300	1800	1300
	Roadmap 2050	3000 -3600	2000 -2400	1900 - 2300
Running cost (€/kW-year)	Scenarios for Energy Concept	132[a]	92	74
	Pilot Study 2010	182	99	72
	Roadmap 2050	80-100	80-100	80-100

[a] Figures for 2020.

Sources: Prognos/EWI/GWS: Studie Energieszenarien für ein Energiekonzept der Bundesregierung, Basel/Köln/Osnabrück, August 2010; DLR/Fraunhofer IWES/IfrE: Leitstudie 2010, Study commissioned by BMU, December 2010; EFC: ROADMAP 2050, practical guide to a prosperous, low-carbon Europe, Berlin, Brussels, The Hague, April 2010.

Second, apart from large hydro and a few biomass power generation technologies in limited biomass-rich regions, renewable power technologies cannot yet compete on a commercial basis with conventional sources for grid electricity. This may well change for a variety of renewable generation technologies as a result of technological learning. In all high-RES scenarios for the future power supply in Germany and Europe, the key technology that is forecasted as the largest domestic contributor to incremental renewable power generation is offshore wind. Should the forecasted growth of power generation from offshore wind not materialise, then the goal of an electricity mix including 80%+ renewable electricity by 2050 will be very hard to achieve.

Table 2 shows key assumptions regarding the future cost evolution of electricity from offshore wind. The offshore wind running cost assumptions made by the two German studies seem reasonable, as experts point to a large scope for economies of scale and technological learning in the operation of offshore wind parks. In contrast, the assumed investment costs of €1300-1350/kW in 2050 would seem rather (overly) optimistic, even with the sharing of seaborne connecting cables, as opposed to the more realistic €1900-2300/kW assumed by Roadmap 2050. Material inputs such as steel, copper and rare earths such as neodymium provide a solid lower limit to the level of cost reductions that can be achieved. Moreover, with the number of offshore wind parks increasing, locations for new parks will be further from shore and in deeper waters, which escalates total investment cost. We note that optimistic "learning" assumptions like the ones described have a large impact on the results of "happy news" scenarios on long-term energy futures.

Third, all three studies assume an EU-wide stringent climate policy resulting in clearly rising carbon prices. High carbon prices favourably affect the competitiveness of both nuclear and renewable power. Indeed, the EU emissions trading system is a precious instrument to be retained and further strengthened in order to cost-effectively render the European economy less carbon-intensive. Yet the political feasibility of a stringent European climate policy strongly depends on whether or not credible climate policies are introduced elsewhere in the world as well.

Fourth, another common assumption is that massive investment in expansion (by roughly a factor of three by 2050 compared to what is currently in place) and closer integration of the transmission networks in the EU and the Maghreb occurs.[10] This is a difficult condition, both in terms of the financial requirements and implementation efforts. As the Roadmap 2050 study rightly points out, in order to achieve energy transitions to low-carbon power systems, such as 80% renewable power systems, there is no time to lose in quickly reinforcing European electricity networks. However, the EU-wide BANANA[11] syndrome is exerting a strongly negative impact on transmission network expan-

10 This is absolutely necessary to address the system stability issue, given a fast increase of intermittent renewable electricity such as wind power in particular but also PV and wave power. Moreover, it enables cost-reducing competition between a multitude of European suppliers and generation technologies as well as the location of renewable power at sites with the lowest-cost resources in Europe (e.g. wind power in Western Europe, solar power in Southern Europe and the Maghreb, and bio power especially in Central and Eastern Europe).

11 Build Absolutely Nothing Anywhere Near Anyone.

sion. For example, the current expansion of the German transmission network falls seriously short of what the German Energy Agency (DENA) has identified as necessary to accommodate the expansion of wind power capacity. This will increase not only the volume of forced curtailment because of network constraints but also the risks of lesser network security in Germany and neighbouring countries. On the other hand, allowable returns on network investments in Germany in the order of 7% per annum do not encourage private-sector investors such as pension funds to allot equity capital to new network expansion projects. To solve the implementation problems in a timely manner, if at all possible, large budget overruns are likely. Furthermore, massive investments are needed to reinforce electricity distribution networks, enabling bi-directional power flows.

Fifth, it is assumed that the use of intelligent networks will become a common operational practice. These are badly needed to cope with network stability issues in the face of the high penetration of intermittent renewable power. Again massive financial investment is required for ICT hardware and software, the upgrading of networks as well as human capital. Additionally, wide-ranging European harmonisation in network regulation and regulatory reforms have to be put in place, enabling e.g. time-dependent end-user tariffs, also for households, and time- and location-dependent market stimulation of renewable power. For example, regulators might consider stimulating renewable power only during hours in which non-negative electricity wholesale prices occur and at locations where no network congestion takes place. Furthermore, in countries where renewable power commands a non-negligible share of the electricity mix, priority rules for renewable power can negatively affect market efficiency. For example, in these respects the German feed-in tariff system is strongly at odds with the introduction of "smart grids".

Finally, the emergence of a truly EU-wide electricity market is assumed. Similar to and contingent upon robust and strongly interconnected transmission networks, this is to enable price-reducing competition throughout the EU. Additionally, it helps to facilitate exports during times of peak production by intermittent renewable power plants and, conversely, cross-border imports at times of low domestic production by such plants. It is indispensible that, as assumed in the German study on scenarios for the Energy Concept, a transition will occur towards a technology-neutral renewable electricity support system that is harmonised throughout the EU. The assumed continuation of the German feed-in tariff system in the Pilot Study 2010 will hinder cost-reducing competition between renewable technologies and the EU-wide location of renewable power plants at the sites with the lowest-cost renewable resources. The consequence of the latter assumption becoming a reality would be a dramatic rise in the costs necessary to achieve an 80%+ renewable electricity supply system.

What Will Be the Consequences of a Nuclear Moratorium?

As already noted, the German government was remarkably fast in concluding that the Fukushima incident presented sufficient critical evidence to repeal a recent decision to extend the lifetime of the 17 existing German nuclear reactors and to consider an accelerated moratorium. The website of the BMU, the German ministry responsible for nuclear reactor safety, explains that the Fukushima accident denotes a game-changing event for Japan and the whole world. The BMU concludes that it has changed the security situation for German nuclear reactors, as the unfolding Fukushima accidents have shown that (catastrophic) events can occur beyond what is foreseen in the currently considered scenarios.[12] Many researchers corroborate this BMU reasoning, arguing that Fukushima demonstrates that the residual risk of a nuclear catastrophe leading to radioactive contamination of the environment as a result of a nuclear reactor meltdown is much higher than was generally assumed beforehand.[13] We shall avoid the question of whether this reasoning is true or not. We consider instead the consequences of introducing a(n accelerated) nuclear moratorium in EU member states or at the EU level.

In the medium and long term, the world is poised to face severe constraints throughout the entire energy supply sector. This will not only affect the supply of fossil fuels with concomitant rising fossil fuel prices. Renewable electricity and other renewable energy carriers will also face stringent supply limitations.[14] If this scenario holds true, as I believe it will, what would be the consequences of a European moratorium on nuclear power and a strong push towards achieving an 80%+ renewable power supply sector by 2050?

---

12 See http://www.bmu.de/moratorium/doc/47140.php: Fragen und Antworten zur Sicherheitsüberprüfung aller Deutschen Kernkraftwerke, download 22 May 2011.

13 Marcel Viëtor explains the German acronyms "GAU" and "super-GAU" for such incidents in his article dated 17 March 2011 on the website of the European Energy Review, http://www.europeanenergyreview.eu: Assumptions and accidents. He concludes that a super-GAU remains thinkable and questions whether governments and societies in the EU are willing to accept this risk. In answering this question, the European public has a right to unbiased information on whether the events in Chernobyl and Fukushima have had a material impact on expert opinions on the residential risk of nuclear reactors in the EU. As for Fukushima, there are still a lot of questions e.g. about nuclear safety supervision and implementation performance regarding severe accident precautionary measures that remain to be answered.

14 P. Mortiary, D. Honnery: Is there an optimum level for renewable energy?, in: Energy Policy, Vol. 39, 2011, pp. 2748-2753.

A moratorium on nuclear power would reduce and eventually remove the residual risk factor of exposing the European peoples to nuclear contamination as a result of accidents with nuclear reactor meltdowns within EU territory. It is a political choice whether this benefit should be pursued or not. Yet it should be realised that a nuclear moratorium comes at an economic price. A nuclear moratorium would further tighten the supply constraints of the European electricity supply sector. This is even more the case if the pursuit of ambitious European GHG reduction policy targets such as an 80% GHG reduction by 2050 are continued. Many authoritative publications by organisations such as the IEA and its NEA subsidiary indicate that the full costs of nuclear electricity are relatively low, even when factoring in investment cost escalation, reasonable costs for decommissioning, disposal of spent fuel and a fair premium for residual risk. Hence discarding the nuclear energy option has a non-negligible upward impact on the cost of electricity, which is already likely to rise anyway.

Furthermore, a moratorium acceleration which entails the premature decommission of some reactors before they have served out their economic lifetimes would typically result in a multi-billion euro amount of capital destruction. Consequently, nuclear operators would be negatively affected. As an alternative, governments could appropriate a substantive portion of the capital saved by avoiding the acceleration of a moratorium via case-specific taxation. This money could help to foot the staggering bill of energy transition implementation.

Concluding Remarks

An 80%+ carbon reduction in the power sector by 2050 will require a combination of:

- fossil fuels-based power generation with CCS;
- a shift from coal to gas;
- a significant reduction in the demand for electricity, coupled with an even stronger reduction in the demand for non-electric energy;
- the fast penetration of renewable power;
- a significant contribution from nuclear power.

None of these options can be dismissed if stringent carbon reduction targets are to be achieved. Apart from CCS, which has its own implementation problems and still needs to prove its viability, a shift from coal to gas in the power sector can offer only moderate carbon reduction. Furthermore, a more prominent role for gas in the electricity mix will increase Europe's dependence on gas imports. Yet even with a renewable share in the electricity mix, a role for gas in balancing the electricity system remains likely.

Further electrification of the European energy economy can have important benefits in terms of making our society more energy-efficient and consequently carbon-efficient. The penetration of electric vehicles, including plug-in hybrids, and efficient heat pumps for space heating will impact negatively on primary energy demand. Moreover, the production of hydrogen through electrolysis may eventually help to address the problem of managing electricity system stability. Nonetheless, the severe energy constraints looming at the world level and the climate change problem render technical fixes in the way of energy efficiency-boosting measures very necessary but still insufficient. Hence, an absolute reduction in total electricity demand and more importantly in total energy demand at large would seem a quite appropriate top energy policy target for affluent OECD societies. Therefore, as such, the German energy policy targets as outlined in the Energy Concept are laudable.

However, the scenario analyses underlying this policy document suggest that the reduction targets for electricity can be achieved without any increase in end-user electricity prices. This is a less credible outcome. To bring about the drastic lifestyle changes that will be necessary to achieve the Energy Concept targets for electricity and energy reduction, end-user electricity and non-electric energy prices will have to go up substantially. Politicians and energy policy researchers in Europe had better begin informing the general public that the days of cheap energy are most probably gone.

The goal of achieving the fast penetration of renewable electricity in the electricity mix deserves a high energy policy priority. Renewable energy, including renewable electricity, has some innate advantages apart from carbon reduction that are worthy of dedicated energy policy attention. Yet achieving 80%+ renewable electricity by the 2050 target date will add much more to the electricity bill than the results of the energy scenario analyses considered in this article would lead us to believe. Moreover, real world inertia renders this target hardly implementable at all. An EU-wide renewable electricity target in the order of 40-50% by 2050 would seem more realistic and affordable while still quite ambitious.

If nuclear energy were to be removed as a politically non-feasible option, this would make the achievement of ambitious European climate change targets all the more expensive. Moreover, it would boost imports of natural gas and coal, which is at odds with the political goal of improving the security of supply. It is up to the political domain in the EU and its member states to weigh these economic aspects against the intrinsic disadvantages of nuclear power, including the residual risk issue. The availability of impartial, non-politicised information on the pros and cons regarding the nuclear power option should assist a fair debate, ultimately leading to well-reasoned outcomes of the political decision process.