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Energy- and research-policy recommendations following the events in Fukushima

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Contents

1. PRELIMINARY REMARKS

This statement was produced in a relatively short space of time as a reaction to the events following the Fukushima disaster. Many of these declarations are based on estimates, not on precise calculations. Although estimates like the ones used here cannot replace detailed systems analyses, they do provide a clear framework for making decisions in the short-term. In the coming months, additional detailed analyses should be carried out, by energy suppliers and grid operators in particular. That said, the declarations in this statement can draw on a series of detailed energy-system studies which include scenarios for phasing out nuclear energy. This statement also follows on from the 2009 energy research concept produced by the German National Academy of Sciences Leopoldina, the German National Academy of Science and Engineering (acatech), and the Berlin-Brandenburg Academy of Academy of Sciences and Humanities.

2. KEY DECLARATIONS

1. From a technical and scientific perspective, it appears to be possible to phase out nuclear power within about a decade – providing the framework conditions set out in this text are met.

2. Even if from a technical and scientific perspective it seems possible to phase out nuclear power faster than originally planned in Germany's Nuclear Phase-Out Act *(Atomausstiegsgesetz)*, before any final decisions are made, we need a more detailed examination of the consequences of the various possible routes to phase-out with regard to security of supply, dependency on imports, costs and acceptance.

3. Because a task as major as restructuring an energy system involves so many uncertainties, the process will require continuous adaptation along the way. It is crucial that, as far as possible, these adaptations are made with society's consent. We therefore recommend establishing for the long-term a compact, independent body to oversee energy-system restructuring. Similarly, in parallel to this process, the development of research programmes should be adapted to reflect the key indications of the latest political decisions and to keep pace with new scientific findings.

4. An accelerated nuclear phase-out would not affect Germany's long-term energy-policy and energy-research goals, since the Federal Government's energy concept only accords nuclear power the role of a bridging technology. The key declarations of the Academies' 2009 energy research concept also continue to apply.

5. However, the prioritising and timeline of research efforts are liable to change. In particular, changes to the planned course of **energy-policy** will have to be made at short-notice.

6. In the **short-term**, an accelerated nuclear phase-out will primarily affect the electricity sector. Possible measures must therefore focus on this sector. However, there are links to other areas of the energy system. Replacing nuclear with conventional power plants will increase CO_2 emissions in the energy sector. Total emissions will increase for a limited period of time because, given the ambitious goals already set in other areas of the energy system, it will be impossible to fully balance the equation by reducing emissions in these areas.

7. Increasing efficiency in our consumption of electricity – and also in other sectors – is the most effective way of helping to accelerate the phase-out of nuclear power. Many technologies for this are already available and can reduce costs as well. The crucial factor here will be sidestepping any rebound effects and creating incentives for actually implementing the possible savings potential.

8. We can assume that an accelerated phase-out will increase the cost of the process. We must ensure that the short-term measures taken are compatible with long-term goals. This will avoid pursuing options that seem suitable now, but that in the long term will put a strain on the economy, environment and society and lead to financial losses, environmental damage or reduced acceptance of the measures.

9. Even if short-term measures are initially planned and implemented on a national level, we should not look at Germany from an isolated standpoint. The European market for electrical energy will continue to become increasingly integrated, and much planning will happen on a Europe-wide level. Therefore, to optimise energy supply in Germany, we need to maintain a primarily European perspective. Opening up to an integrated European electricity market could, however, result in Germany importing nuclear energy from other Member States.

10. Current events show how important it is for energy research to offer a wide range of options to ensure a secure energy supply even in the event of framework conditions changing.

11. In the short term, research efforts must concentrate primarily on quick-to-implement measures that will improve efficiency particularly in the energy sector. In doing so, it is key that they include the demand side in their work. Furthermore, work must continue developing ways of incorporating more renewable energies in grids.

12. In the long-term, energy research must address a broad spectrum of topics. It must present society with additional options by covering everything from basic research to highly application-oriented investigations. While it is important to establish priorities in research, we must also, to a certain extent, pursue directions that are not part of the mainstream. Energy research demands continuity. Reactivating suspended research fields requires a great deal of time and effort.

3. SITUATIONAL ANALYSIS

3.1 Challenges for our energy systems

A secure, climate-friendly, sustainable and low-cost energy supply is one of the greatest challenges facing the ever-growing population of the 21st-century world. Our future energy supply must negotiate a challenging environment that is influenced by a number of different factors. Fossil fuels currently secure the overwhelming majority of our transport requirements, but the supply is limited and we are probably not far off reaching the maximum global production levels. Most of our electrical energy is also generated using fossil fuels like lignite, bituminous coal and natural gas. The CO_2 emissions that this produces, combined with those from the transport sector and from supplying heat energy, are one of the major causes of climate change. Governments must therefore conclude international agreements to reduce greenhouse-gas emissions. Nuclear energy technologies have always been controversial, but the debate has intensified in the wake of the Fukushima disaster. Boosting the expansion of renewable energies will demand comprehensive restructuring of our electricity grids to ensure that they can handle the requirements brought about by highly fluctuating feed-in levels. It is also important not to consider electricity grids from a purely national perspective. Expanding grids requires concerted international action – something that will become even more crucial with the increased liberalisation of the European gas and electricity market, which is planned for 2014. Governments must therefore ensure that national energy policies are always linked to the international level. All decisions regarding a future energy system must take these framework conditions into account because they can considerably limit the scope for action. Furthermore, national and international observers are playing close, critical attention to the way Germany proceeds here. An expert hearing on this statement by the Energy Steering Panel of the European academic association EASAC[1] issued the following comment: "An important consideration in our review has been Germany's position as a major economy and hence energy user in Europe, and also the leadership it has demonstrated in addressing the challenge of climate change, an issue inextricably linked to decisions on energy supply and use. We sincerely hope that decisions made on the future course of the energy system in Germany are consistent with Germany continuing to show leadership on tackling climate change" (see Appendix).

3.2 The three sides of the energy system: Physics – Market – Acceptance

Any discussion of a future energy system should take into account the fact that energy supply and distribution are subject not only to physical laws, but also to the effects of market mechanisms. Each level interacts with the other, but they do not necessarily operate in the same direction. The discussion in the *DENA Grid Study*[2] on integrating a storage facility into an electricity grid provides a good example of this point: depending on the location of the best-value power plant relative to the storage facility and grid bottleneck, a storage facility can either relieve the grid or not. If Germany is to stop using nuclear power, in the short- and medium-term, power plants must instead be used that are lower down the electricity market merit order – gas power plants are one of the options that fit this bill. But market mech-

1 European Academies Science Advisory Council; see also: http://www.easac.eu/energy/steering-panel.html

2 Deutsche Energie-Agentur GmbH DENA (2010) DENA Grid Study II – *Integration of Renewable Energy Sources in the German Power Supply System from 2015-2020 with an Outlook to 2025*, Berlin: pp. 285-286 (of the German version).

anisms could create a situation where it is cheaper to import electrical energy from countries that might have generated it using nuclear power. If we are to avoid these kinds of effects, we need to develop new mechanisms that will achieve the right effects. Every measure must take into account this interplay between the physical grid and market-driven load flows. Despite wide-scale liberalisation, electricity remains one of the most heavily regulated markets. Technical measures must therefore always be assessed to establish whether, given such a vast array of regulations and market mechanisms, they can actually succeed in creating the effect they are designed to have.

A third important aspect of the energy system is the demand side. Energy services, including those designed to boost efficiency, must be in demand from consumers, who must also accept the plants and infrastructure services necessary to provide them. Even if technologies are fully developed and available at a reasonable cost, we cannot rule out the possibility that consumers will not demand them, or that they might even reject them. One example of this is the sluggish uptake of energy-efficient renovations of residential buildings – even though these often make very good economic sense. It is therefore of great importance that the process of reconstructing the energy system takes account of these social and psychological aspects, in addition to technological framework conditions and market mechanisms.

3.3 Point of departure for this analysis

The incidents at nuclear reactors in Japan – at the Fukushima I facility in particular – following the earthquake and tsunami in March 2011, have resulted in a shift in thinking in regard to short- to medium-term energy policy in Germany. The events in Japan have not changed the objective security situation in German nuclear power plants, but they have caused a reassessment of what constitutes acceptable risk and generated approval for an accelerated phase-out of nuclear power among large sections of society. In response to the dramatic drop in public acceptance of atomic energy, the Federal Government passed a decision to shut down 7+1 nuclear power plants, provisionally for a period of three months. Two of these plants (Brunsbüttel and Krümmel) were already offline due to retrofitting work even before the events in Japan, and reactor B of the plant in Biblis had not been in operation since the end of February 2011, anyway, for inspection purposes. Beyond this immediate step, the decision passed in October 2010 to extend the lifetime of the country's nuclear power stations was suspended. At the moment it is still unclear whether, after the end of the moratorium, the government will adhere to the lifetime extension, will revert to the originally agreed lifetimes, or whether a third, possibly accelerated nuclear phase-out scenario will be realised. It would certainly be sensible to wait until some time has passed after the events in Fukushima and to analyse the situation thoroughly before making any decisions with long-term effects.

But whatever the specifics of the decision to phase out nuclear energy turn out to be, the main implications for energy policy and priorities in energy research are already clear. The following statement provides an assessment of the situation and possible consequences from a scientific perspective. It offers recommendations for energy research policy and specific opinions on aspects of energy policy.

In any case, current events have shown how important it is for energy research to offer a wide range of options to ensure a secure energy supply even in the case that framework conditions change. Over the long term, our society will have to come up with flexible strategies that can be adapted to sudden shifts in global economic, social, climate, and technological conditions. Thus we will have to learn to respond to transformation processes more rapidly and be prepared to develop bridging technologies and crisis management strategies, even if not all of them are ultimately needed (see the academies' energy concept[3]). The term used internationally to refer to a research and development concept designed for maximum flexibility is "resilience". A resilient society is able to cope better with external influences and internal change. The following recommendations are also targeted towards this goal of resilience. In light of the current debate, it must be taken into consideration that research efforts can only bear fruit in the medium term. In the short term, we can only make use of technologies that are based on previous research and are ready to be applied immediately. Nevertheless, it is vital that we pursue a wide variety of different approaches in both basic and applied research to give us a range of options and enable us to adapt energy strategies to changing conditions in the future – as the current situation has made patently clear.

During the moratorium on lifetime extension, the safety of nuclear power plants in Germany will be reassessed. However, a detailed overall evaluation is not feasible within the space of three months; the only thing that can be achieved in such a short period is a basic analysis. Great care should be taken to perform this analysis based on criteria that are transparent; otherwise the results are unlikely to gain acceptance from the population, no matter what they are. In the short term, the older nuclear power plants have been shut down. While age is certainly an indicator of the operational safety of nuclear plants, it is by no means the only one. Here again, a differentiated and transparent evaluation is of the utmost importance to ensure acceptance of a political decision made on this basis.

The events in Fukushima have triggered widescale public debate in a number of countries, particularly in Germany, on which risks presented by using different energy technologies are socially acceptable and which are not. The government should make the most of this discussion to reach a widely accepted, ideally non-partisan consensus on our future energy policy. The time scale involved in changing energy systems is so long that changing course in time with Germany's four-year electoral term is counter-productive. This does not mean, however, that once we choose a path we must see it through to the end without ever deviating. Unforeseeable events or breakthroughs in science and technology might make it necessary to adapt our energy strategy, or make it seem sensible to do so. A complex society should not rely on a single scenario. Rather, it must have at its disposal second-, third- and fourth-best alternatives to allow it to react to external events and internal changes. However it is necessary, perhaps even crucial, that these adaptations are implemented in a way that will have broad social support. Otherwise, society might block urgent measures. Germany should use this opportunity to establish participative procedures and changes in current planning law that will facilitate efficient, timely and effective planning on the one hand, and will take better account of the concerns and wishes of the affected population on the other. The overall aim must be to establish a widely supported energy consensus that is geared towards the long term. To do so, it might be helpful to set up for the long term a compact, independent body to monitor the

3 Leopoldina, acatech & BBAW (2009): *Concept for an integrated energy research programme for Germany*. Halle.

restructuring of the energy system. A similar body could oversee the development of research programmes and the adaptation of these programmes to changing circumstances.

3.4 Security of energy supply if Germany accelerates its phase-out of nuclear power

Shutting down nuclear power stations faster than set out in the original Nuclear Phase-Out Act could lead directly to critical situations in three areas: in the total amount of electrical energy that Germany can produce; in the output that must be continually supplied to meet the demand for electrical energy; and in the stability of the transmission grids. We must address these three areas if we want to phase out nuclear energy faster than originally planned in the Nuclear Phase-Out Act.

3.4.1 Amount of electricity required

At the level of a national economy, energy amounts are usually given in terawatt hours (TWh, 1 TWh = 10^{12} Wh) or in petajoules (PJ, 1 PJ = 10^{15} J). One TWh equates to 3.6 PJ. In recent years, Germany consumed around 600 TWh of electrical energy annually (gross electricity consumption). In addition to that, the country exported some 20 TWh (net) of electrical energy.[4] Nuclear energy generated some 140 TWh of electrical energy. This suggests that if Germany shut down a significant number of its nuclear power plants, it would create a gap in the energy supply. However, one must take into account that the supply capacity is not fully utilised because the merit order dictates which power plants are used to meet demand. Legislation means that renewable energies and nuclear energy take precedence in the order and are the first to be fed into the grid. In each of the years 2008 and 2009, renewable sources supplied some 94 TWh of energy, meaning that conventional power plants had to provide a little more than 500 TWh to meet the demand for non-nuclear energy. According to the power-plant database of the German Federal Environment Agency, the gross installed capacity of conventional power plants is around 72.5 GW.[5] However, the database only includes power plants that have outputs of over 100 MW. Smaller power plants can supply approximately 7 GW[6] more. This means that, at full availability, conventional power plants in Germany could supply 79.5 GW x 8760 h = 696.4 TWh. Therefore, even if the average power-plant availability was just 72% – in reality it is much higher – the current supply capacity means that we could completely cut out nuclear power and still provide the **amount of electrical energy the country requires**.

This conclusion also holds if one takes into account the Federal Government's plans to have 1 million electric cars on the road by 2020. In 2007, some 47 million cars were registered in Germany and have clocked up a total of 588 billion vehicle kilometres.[7] Assuming that electric cars would be used as much as the rest of the country's fleet, 1 million electric cars would equate to 12.5 billion vehicle kilometres. We can assume that an electric car will consume an average of 0.15 kWh/km. Thus, 1 million electric cars would consume around 1.9 TWh each year. Because this equates to less than 0.3% of annual electricity consumption, we can ignore the effects of electromobility until at least 2020.

4 *Energiedaten — Nationale und Internationale Entwicklung*, Federal Ministry of Economics and Technology (ed.), updated on 13 Jan. 2011 http://www. bmwi.de/BMWi/Navigation/Energie/Statistik-und-Prognosen/energiedaten.html

5 German Federal Environment Agency (2011) database *Kraftwerke in Deutschland*. Dessau.

6 Data on power plants with outputs below 100 MW come from the report *Platts World Electric Power Plants Database* (version of 2010).

7 *Shell Deutschland Oil GmbH* (2009) Shell Passenger Car Scenarios up to 2030. Hamburg.

3.4.2 Required output

When considering the previous point, it should be noted that the amount of energy required for our economy is averaged out over the whole year. However, to a first approximation, the amount of electrical energy supplied must always correspond exactly to the amount being consumed. The relevant measured quantity is the output, in physical terms energy/time, which is usually measured in gigawatts (GW 1 GW = 10^9 W) at the level of a national economy. To ensure security of supply, the available output must exceed demand at times of peak load, plus a contingency reserve, plus a margin for system services. Peak load in Germany normally occurs in winter. In 2009 it occurred on 2 December at 6 p.m. when demand hit 73 GW. In 2008 it was 76.8 GW,[8] and if we take a contingency reserve into account, we can assume a maximum load of 80 GW in the medium term. This maximum load must be matched by a reliable supply capacity, which the German Federal Network Agency's *Monitoring Report 2010*[9] gives as 92.8 GW of guaranteed net output. For the maximum load expected in the medium-term, this data shows that there is an output reserve of nearly 13 GW. The nuclear moratorium has caused an 8.5 GW drop in output – but over 2 GW of that was already factored in (for the nuclear plants Krümmel and Brunsbüttel). Therefore, this analysis shows that even if the nuclear power plants shut down in the moratorium never go online again, Germany has a sufficient output reserve to meet demand in the medium-term. On the basis of an analysis by grid operator Amprion, the German Federal Network Agency[10] comes to a similar conclusion. For a reference scenario which takes into account contingency reserves and the output necessary for system services, that leaves capacity just in the black, at 0.4 GW for the 2011/12 winter half-year. The updated version of the *Monitoring Report* from 26 May 2011 also confirmed this.[11]

The Network Agency also comes to the conclusion that we can definitely assume full load coverage from the point in time that the shutdowns come back into line with the timetable set out in the original Nuclear Phase-Out Act, because all participants had originally geared themselves towards this schedule. This will be the case in 2013. Of the nuclear plants that have been shut down, Krümmel is the only one with a lifetime planned to run until 2021. Due to technical retrofitting, however, Krümmel has been offline since 2009.

To establish whether nuclear power plants can be shut down faster than set out in the original Nuclear Phase-Out Act, a detailed assessment must be carried out using the current expansion plans. A net increase in availability-independent[12] plant output of around 6.6 GW is planned for 2011/12. This will more than compensate for the output lost as a result of shutdowns set out in the original Nuclear Phase-Out Act. According to a summary compiled by the German Association of Energy and Water Industries (BDEW),[13] plans exist to increase the availability-independent output capacity of power plants by approximately 32 GW by 2019. This is in addition to increasing the capacities of availability-dependent renewable energies. An accelerated nuclear phase-out depends on which of these plans can be put into practice

8 German Federal Network Agency (2011) *Monitoring Report 2010*. Bonn, p. 30.

9 Ibid.

10 *Impact of the nuclear power moratorium on the transmission networks and security of supply*. Report submitted by the German Federal Network Agency to the German Federal Ministry of Economics and Technology, Bonn, 11 April 2011, p. 54.

11 German Federal Network Agency, 26 May 2011, p. 6.

12 Availability = the amount of e.g. wind available to a power plant

13 Annex to the press release *Strom- und Gasverbrauch um vier Prozent gestiegen*. BDEW, 4 April 2011.

and on what time scale. Therefore, as far as the necessary installed output in Germany is concerned, it would appear that there is additional scope for accelerating nuclear phase-out. The reactivation of power plants currently on stand-by ("in cold-reserve"), which are estimated to have an output of around 2.5 GW,[14] will not be further considered here. Many of these power plants have been on stand-by for so long that it is unclear how much it would actually cost to reactivate them. Furthermore, these plants are generally old and inefficient, which means they would emit more CO_2 than new plants.

3.4.3 Stability of transmission grids

The public debate on nuclear power plants often overlooks the role they play in stabilising our transmission grids. In addition to the balance of active power, which is maintained by frequency regulation, the reactive power must also be balanced at all times. This means that power plants must be available to provide varying reactive power supplies. Currently, reactive power regulation is mostly managed by the synchronous generators in large-scale power plants and by specially equipped pumped storage power plants. For physical reasons, this reactive power should not be transported over long distances within the grid. The power should therefore be available in geographically distributed locations to fulfil consumer demands and ensure that the transmission network remains stable. The fact that most of the nuclear power plants that have been shut down are located in the south of Germany makes the task of providing reactive power considerably more complex.[15]

The updated version of the Federal Network Agency's report identifies challenging situations that may arise in the 2011/12 winter half-year.[16] Furthermore, shutting down the nuclear power plants has changed the load-flow situation in the transmission grids. This has already affected planned maintenance work and grid-expansion measures. This creates a difficult situation: accelerating nuclear phase-out has made it more pressing to upgrade grids to prepare them for incorporating renewable energies, but increased strain on the grids can severely hamper the task. This will require detailed analysis in the coming months.

In addition to incorporating power plants, grids can be stabilised using other measures known as FACTS – Flexible Alternating Current Transmission Systems. However, these systems must first be installed, and the process can take anything from 14 months to three years.[17] However, the original Nuclear Phase-Out Act means that these measures have already been prepared and the grid should comply with all stability requirements when Germany gets back on track with the original schedule – so by 2013 at the latest. But this can only happen if the necessary grid measures are implemented within this period. If, over and above the power plants that have already been shut down, additional plants are to be taken off the grid earlier than planned, then the necessary changes to the transmission grids must happen sooner. To draw up realistic timelines for this, grid operators, suppliers and the German Federal Network Agency must carry out a detailed analysis of the situation.

14 *Quick phase-out of nuclear power in Germany. Short-term options, electricity and price effects.* Öko-Institut, Berlin, March 2010.

15 *Impact of the nuclear power moratorium on the transmission networks and security of supply.* Report submitted by the German Federal Network Agency to the German Federal Ministry of Economics and Technology, Bonn, 11 April 2011, p. 9.

16 German Federal Network Agency, 26 May 2011, p. 9.

17 *Impact of the nuclear power moratorium on the transmission networks and security of supply.* Report submitted by the German Federal Network Agency to the German Federal Ministry of Economics and Technology, Bonn, 11 April 2011, p. 31.

The list of planned new power plants[18] contains a series of entries that are located close to nuclear power plants. When these power plants are connected to the grid, they could take over some of the grid-stabilising functions of the nuclear power plants. In the north of Germany, the new plants in question are Hamburg-Moorburg (1,640 MW, 2012) and Stade (1,000 MW, 2014). There are also projects in Brunsbüttel (1,820 MW) and Stade (1,100 MW) that do not yet have a finalised completion date. Two power plants are planned for the area around Grafenrheinfeld: Großkrotzenburg (1,100 MW, 2013) and Ludwigsau (1,100 MW, 2014). And in the region of Philippsburg/Neckarwestheim, two plants are under construction – one in Karlsruhe (912 MW, 2013) and one in Mannheim (911 MW, 2013). The function of the Isar 1 and Isar 2 nuclear power plants could presumably partly be taken over by the power plants Irsching 4 (530 MW, 2011) and Burghausen (850 MW, 2014). There are no major plans to construct power plants close to the nuclear power plants Gundremmingen I and II in the near term – apart from the plans of Stadtwerke Ulm, which are not yet finalised, even in terms of their capacity. This list suggests that by around 2015 many of the nuclear power plants still in operation will no longer be needed for their grid-stabilising capabilities. But here, once again, we must ensure that a careful analysis is performed in collaboration with network operators.

3.5 International embeddedness

We cannot assess energy systems solely within the bounds of individual national economies. Electrical energy is exchanged across national borders, even though a country will supply most of its electricity needs itself. There are generally no objections to this, because energy is a traded commodity, just like most other goods. Electrical energy does not, therefore, occupy a unique position in the overall energy industry, because Germany also imports other energy sources like gas and crude oil. As our main source of energy, however, electrical energy is unique in that we can only store it indirectly and in limited amounts. This means that the kind of heavy import dependencies we have for oil and gas, where short- and medium-term supply shortages can be bridged by storage, should be avoided in the case of electricity.

Germany can obtain nearly 17 GW of output from neighbouring countries via cross-border switching stations. This means that if Germany is unable to cover load peaks with its own electrical energy, it can fill the gap with imports – providing there is enough energy available in the other countries. According to the present figures,[19] Germany can import several gigawatts in both winter (7.7 GW) and summer (8.1 GW). Improving electricity grids at a European level[20] will help in the medium term to increase capacity for responding to peaks in load.

However, we must ask ourselves whether changing our risk assessment of using nuclear energy should lead to a situation where, to guarantee security of supply, Germany simply exports the risk to other countries – since many of our neighbours generate electrical energy using nuclear power. We can assume, however, that at times when Germany is experiencing peaks in load, it is also likely that its neighbours are in the same situation. This means that the nuclear power plants operating at base load will already be working at full

18 Annex to the press release *Strom- und Gasverbrauch um vier Prozent gestiegen*. BDEW, 4 April 2011.

19 *Impact of the nuclear power moratorium on the transmission networks and security of supply*. Report submitted by the German Federal Network Agency to the German Federal Ministry of Economics and Technology, Bonn, 11 April 2011, p.57-58.

20 European Academies Science Advisory Council EASAC (2009) *Transforming Europe's Electricity Supply*. London.

capacity, and that additional capacities will be supplied from power plants lower down the merit order – i.e. from non-nuclear power plants. Although Germany, as shown above, has sufficient electricity supplies and sufficient output, we cannot rule out the fact that if the country needs additional energy after shutting down its nuclear plants, this demand would be met – at least for a transition period – by imported nuclear electrical energy if this can be supplied at significantly less cost than non-nuclear electrical energy produced in Germany.

3.6 Impact of accelerated nuclear phase-out on CO_2 emissions

With the agreed cap on CO_2 emissions, carbon-trading mechanisms should ensure that increased emissions in the energy sector that result from shutting down nuclear power plants are balanced out by lower emissions in those areas where the marginal costs of reducing CO_2 emissions are the lowest. However, complying with the climate change goals by trading carbon certificates is tied to a number of conditions. On the one hand the agreed cap on emissions must be retained in its current form, and given the international signalling effect of Germany's actions this is something that should definitely be adhered to. On the other hand this is – at least at the beginning of emissions trading – "a shortage-free market", since some countries have more emissions rights than actual emissions. We must therefore assume that, at least in the early phases of emissions trading, additional CO_2 emissions caused by shutting down nuclear power plants will only be partially compensated by other industrial sectors or other countries.

The lack of generation capacity from nuclear power plants must be replaced by corresponding output from other available power plants. There are a number of ways to achieve this. Economically speaking, the necessary output would be supplied by available power plants in line with their merit-order ranking. According to BDEW[21] data, coal-fired power plants are run for an average of 3,550 hours per year, while gas power plants are run for 3,170 hours. It is therefore possible and imperative that we increase the use of these power plants to compensate for the loss of nuclear capacities. Generating energy from coal produces emissions of around 900 g CO_2/KWh; using gas as fuel produces around 450 g CO_2/KWh.[22] Shutting down the power plants affected by the moratorium has resulted in a shortfall of around 40 TWh/a, calculated using the production data of these power plants published in 2008 and 2009.[23] If coal-fired power plants alone were used to bridge this gap, CO_2 emissions would increase by some 36 million t/a. Using gas-fired power plants would halve this figure. Given energy-related CO_2 emissions of around 700 million t/a,[24] this equates to between 2.5 and 5% of all such emissions.

If Germany were to replace its **entire** supply of nuclear-generated electrical energy (some 140 TW/h, averaged over the last four years) with fossil technologies such as gas- or coal-fired power plants, this would theoretically increase CO_2 emissions by between 63 million and 126 million t/a. This means that the emissions produced by supplying electrical energy would climb by as much as 20% (if coal-fired power plants alone were used to replace total nuclear

21 http://bdew.de/internet.nsf/id/DE_Energiedaten

22 H.-J. Wagner, M.K. Koch, J. Burkhardt, T. Große Böckmann, N. Feck, P. Kruse (2007) *CO_2-Emissionen der Stromerzeugung- ein ganzheitlicher Vergleich verschiedener Techniken.* BWK, Vol. 59, Nr. 10, pp. 44-52, Springer-VDI-Verlag. Düsseldorf.

23 atw — International Journal for Nuclear Power (2010) *Operating Data 2009.*

24 *Energiedaten — Nationale und Internationale Entwicklung,* Federal Ministry of Economics and Technology (ed.), updated on 13 Jan. 2011 http://www. bmwi.de/BMWi/Navigation/Energie/Statistik-und-Prognosen/energiedaten.html

capacity). Increasing the use of renewable energies would make it possible to gradually reduce these additional emissions in the energy sector. Detailed analyses are needed to show exactly what this roadmap could look like.

Any evaluation of the abovementioned figures should take into account that they refer to increases in absolute emissions. The phase-out of nuclear-energy use stipulated in the Nuclear Phase-Out Act was already taken into account when the CO_2 reduction targets were formulated. The **additional** CO_2 emissions that would result from accelerated phase-out are therefore lower than the abovementioned amounts, although the precise figures depend on the phase-out roadmap.

3.7 Impact of accelerated phase-out on energy prices

With regard to the cost of an accelerated phase-out of nuclear energy, different studies vary enormously in their estimates. This is the result of differing basic assumptions concerning the costs of supply technologies. Furthermore, there is no consensus on which methodology to use and on what effects should be included in phase-out costs. This statement does not intend to add any further detailed analyses to the many, often contradictory studies that are already available. Rather, the idea is to use a simple model calculation to estimate the scale of the expected costs. However, the result depends heavily on the basic assumptions made at the outset. These are set out in detail here.

To analyse how an accelerated nuclear phase-out will affect energy costs, we must first define the base-case scenario. The Federal Government's Energy Concept outlines the restructuring of Germany's energy system and the costs that this will incur. The *DENA Grid Study II*[25] contains estimates of the grid costs, broken down according the different technical options, associated with a phase-out under the original Nuclear Phase-Out Act. It puts the annual costs until 2020 for the different scenarios at between a little less than €1 billion (380 kV overhead lines) and almost €5 billion (gas-insulated lines). The *DENA Grid Study II* says that, irrespective of additional measures, expanding the grid would increase grid fees for household customers by between 0.2 cents/kWh and 0.5 cents/kWh.[26]

Phasing out nuclear power faster than as set out in the original Nuclear Phase-Out Act will require additional adaptation work on the grids to ensure that they can, already in the short term, meet the changed demands placed on them. At this stage, it is not possible to provide a reliable estimate of what this work will cost. We can, however, compare the magnitude of the necessary grid changes investigated in the *DENA Grid Study* with the measures that an accelerated nuclear phase-out would require. It is very likely that the latter are significantly smaller. It therefore seems realistic that the additional grid costs would be far below those that have been estimated to date for expanding the grid, i.e. a good deal below 0.2 cents/kWh.

In addition to grid costs, replacing relatively low-cost nuclear energy with power plants that have higher marginal costs will push up the price of electrical energy. Economists also predict that significantly increasing power-plant capacities in a short space of time will lead to a situation where full costs will at times determine prices. With regard to the costs of producing electricity using different technologies, a great deal of (in some cases clearly divergent) information is available. Here, one should start with a conservative estimate that

25 Deutsche Energie-Agentur GmbH DENA (2010) *DENA Grid Study II – Integration of Renewable Energy Sources in the German Power Supply System from 2015-2020 with an Outlook to 2025*, Berlin.

26 Ibid., p. 16.

puts the costs of nuclear energy at a relatively low level (these should be roughly doubled for new-build nuclear power plants) and the costs for coal- and gas-fired power plants at a relatively high level – i.e. the estimate is located at the upper end of the expected cost increase. If we put the average production costs for nuclear energy at between 2 and 2.5 cents/kWh, which rises to around 3.5 cents/kWh with nuclear fuel-rod tax and payments for renewable energy funds (Ökoenergie-fonds), and the costs for replacement energy (coal and gas new-build mix 2020, CO_2 price: €50/t) at 6.7 cents/kWh,[27] then with a 23% shortfall from nuclear energy, average costs would rise by just under 1 cent/kWh, including the abovementioned grid expansion costs. This estimate is not too far off the 2012 development of the *Phelix Base Future*, which represents the expectations of market participants and which rose by some 0.6 cents/kWh after the government announced the moratorium.[28]

That said, this approach only provides a simplified model calculation. Energy prices are influenced by numerous other factors that are difficult to model. More fossil-fuelled power plants would make carbon certificates more expensive, which would push up electricity prices. However, the estimate set out above already assumes a relatively high carbon price, and as mentioned in the previous section, the market for carbon certificates is likely to be, at least in the initial phase, a "shortage-free market". In contrast, the Renewable Energies Act (EEG) levy brings prices down, because the levy is reduced as the stock-market price for electrical energy increases. Finally, increasing supply capacity could bring new suppliers to the market. This would boost competition, which normally brings down prices. Also, we must assume that nuclear energy will probably become more expensive because additional security requirements are likely to come into force.

Ultimately, we can assume that market mechanisms will probably result in Germany importing cheaper electrical energy from abroad rather than increasing its use of power plants lower down the merit order. This will prevent costs rising too sharply.

Overall, if nuclear electrical energy is to be replaced by energy from conventional power plants, the abovementioned estimate of around 1 cent/kWh is probably not far off the mark. For energy-intensive industries, this represents a considerable increase in costs and could have a major impact on their ability to compete at an international level. By contrast, the impact on private electricity customers remains within bounds that seem to be broadly tolerable.

Here, as with the CO_2 levels, the additional costs are not estimated in comparison to the original or amended nuclear phase-out – they are estimated as absolute costs. Relative cost increases compared to the original roadmap are lower and depend on the exact phase-out roadmap.

It is difficult to predict the extent of additional, indirect effects on the national economy that an accelerated nuclear phase-out might create, because contradictory effects arise here, too. On the one hand, higher electricity costs will make energy-intensive sectors less able to compete internationally. On the other hand, increased momentum in restructuring Germany's energy system will strengthen businesses working in these areas, and Germany's lead-market function will boost its export capabilities. Due to factors such as differing expectations of the rel-

27 C. Kemfert & T. Traber, Wochenbericht DIW23/2010, *Nachhaltige Energieversorgung: Beim Brückenschlag das Ziel nicht aus dem Auge verlieren*. Berlin. http://www.diw.de/documents/publikationen/73/ diw_01.c357248.de/10-23.pdf

28 *Impact of the nuclear power moratorium on the transmission networks and security of supply*. Report submitted by the German Federal Network Agency to the German Federal Ministry of Economics and Technology, Bonn, 11 April 2011, p. 62.

ative significance of the effects, one can make either positive or negative predictions regarding the implications for the national economy. In addition, the time scales in which these effects will become visible are not identical.

3.8 Socio-cultural framework conditions

Increasing efficiency is the measure that can be put into action fastest to provide climate-neutral and cost-effective compensation for reduced output brought about by accelerated nuclear phase-out. Many efficient technologies are already available and would even reduce energy costs. But they are often not applied. The effectiveness of improved efficiency in transforming primary energy into secondary energy and from there into the desired energy services depends on the efficiency of the technology used on the one hand and on organisational, social and psychological factors on the other.

Many of the energy scenarios under discussion today assume an improvement in efficiency of almost 50% by 2050. According to these scenarios, this improvement should reduce our use of primary energies by the same amount. But looking at the past we see, for example, that although the efficiency of household devices increased by some 32% between 1990 and 2008, electricity consumption in households increased by around 21% in the same period. This rebound effect outbalances the savings. It is therefore crucial to create incentives in future that ensure that increases in efficiency do not encourage consumers to use more energy.

Equally important are the flexibility and speed of the desired changes in the area of energy infrastructure (in particular grids and storage facilities). If we consider that setting up an overhead power line today takes at least ten years from conception to implementation, then it becomes clear that the adaptations necessary for an accelerated nuclear phase-out will not keep pace with the demands. However, speeding up planning processes by reducing the population's right of participation is the wrong route to take. Rather, we need to develop, test and introduce more effective and efficient public-participation procedures that will allow us to make the infrastructure changes necessary for restructuring the energy system in time on the one hand, and to constructively integrate the justified wishes and concerns of the population on the other There is a great need for research and action in this area in particular.

3.9 Conclusion

On the basis of this initial analysis, we can conclude that from a technical and scientific perspective it appears to be possible to phase out nuclear energy within about a decade. However, this only holds if all the necessary measures are implemented rapidly and in a coordinated manner. In addition, an accelerated phase-out of nuclear energy should be regarded as just one aspect of the overall process of restructuring Germany's energy system. This is an exceptionally demanding challenge, and one that we must tackle over a much longer period of time. Drawing up a roadmap for this challenge could help us take a targeted, coordinated approach. Given the scale of this task, it seems necessary to support the restructuring process with intensive research and to gain broad social consensus on the goal and how to achieve it. This means that, in addition to technological innovations, we will also need social innovations to help us navigate this path with all its uncertainties and manage the many readjustments that are sure to be necessary along the way. Furthermore, we must ensure constant monitoring to regularly take stock of developments and to suggest measures if the desired target functions are not being met.

4. RECOMMENDATIONS FOR ACTION

From the analysis in the previous section, we have identified the following guidelines for action in a variety of fields with a focus on the associated research priorities. First, we provide the recommendations for action and research that concern an accelerated phase-out of nuclear energy (time scale: < 10 years). This will be followed by a summary of the research priorities that will only take significant effect in the medium- to long-term (time scale: 10-50 years). Although such research approaches are of great importance, they cannot help us to deal successfully with the current situation. For more information on these approaches, please refer to the academies' energy research concept, which sets them out in detail.[29] Time constants of between 10 and 50 years are not unusual in energy systems. On the one hand, the high costs and high levels of risk associated with failure demand technologies that are highly sophisticated and therefore robust enough for use in the energy sector. On the other, investments cycles in the sector are very long, meaning that it will take even a superior technology a while to penetrate the market. This should not, however, lead us to conclude that we can wait until later to begin tackling the medium- and long-term research priorities. It is important to lay the foundations now so that the options are available when they are needed in future.

4.1 Short-term recommendations

4.1.1 Energy supply

- The power-plant projects currently under construction or in the planning phase should ideally be completed without further delay. If necessary, a reassessment should be carried out of the fuel designated for the power plants currently in the planning phase.
- Efficient combined-cycle gas power plants should be given priority in providing the additional capacity required for an accelerated nuclear phase-out – for bridging potential gaps in output in the short-term and for additional operating reserve in the longer term. These power plants are compatible with a future energy system that relies more heavily on renewable energies, and they produce less CO_2 emissions than coal-fired power plants. That said, it is important to ensure that there is sufficient diversification in the fuels used.
- In the medium-term, wind farms will remain the best-value source of renewable energy. However, it is important to remember that this technology is not universally accepted.
- The costs of photovoltaic technology in Germany are relatively high compared to other regenerative technologies. Photovoltaics can make a significant contribution to supplying our energy needs, but given the costs involved, pursuing this route should not be given the highest priority in the short-term. Achieving grid parity, however, could provide new momentum for the photovoltaic market.
- Because expanding natural-gas-fired power plants increases our dependency on imported energy sources, we must investigate the socio-cultural framework for a secure energy supply and begin research into how Germany can tap unconventional sources of natural gas, such as coal-seam gas and shale gas.
- For all renewable energies, particular attention should be paid to research that could help reduce costs quickly. This is because the high cost of renewable energies compared to fossil fuels is one of the biggest hurdles facing these technologies.

29 Leopoldina, acatech & BBAW (2009): *Concept for an integrated energy research programme for Germany*. Halle.

- Research projects focusing on developing wind-energy plants that can also take on system services for the grid could help provide a more system-compatible solution to integrating fluctuating electrical energy into our supply.
- The systemic efficiency of the role of cogeneration must be analysed based on the assumption of a declining heating market.
- The systemic efficiency of the role of virtual power plants must be analysed within the context of new structures on the electricity market.
- We must develop and test innovative forms of participation in decentralised solutions through municipalities or cooperatives, new forms of public participation and new ways of integrating the concerns and preferences of residents.

4.1.2 Grid infrastructure

Adapting grid infrastructure is crucial to an accelerated nuclear phase-out. Many of the questions associated with this have been investigated in a series of studies – the *DENA Grid Study II*[30] focuses on Germany, while studies such as *Transforming Europe's Electricity Supply* by the European Academies Science Advisory Council (EASAC)[31] address the European grids. We, the authors of this statement, subscribe in principle to the declarations made in these studies, and provide the key recommendations for action below:

- Expanding transmission systems is vital to incorporating more wind-generated electricity. The transmission structure must become more flexible to manage higher proportions of renewable energies. The *DENA Grid Study*[32] analyses the ways of achieving this.
- Because shutting down nuclear power plants greatly reduces the reactive power available locally to transmission grids, alternative facilities for system stabilisation must be installed as soon as possible. New power plants should be built in locations where they can take over the stabilising function of nuclear power plants.
- Linking grids on a European level will become increasingly important. Germany must therefore ensure that its grid expansion is compatible with European planning.
- Europe must increase the transmission capacity of its grid by integrating Europe-wide controls and monitoring stations. The EASAC report contains additional detailed recommendations on this point.
- Measures for stimulating transmission capacity (operation at physical limits, high-temperature overhead conductors, overhead-line monitoring) must be developed and implemented.
- Different approaches to demand-side management must be investigated, along with the inclusion of consumers into these concepts.
- New market instruments that make it possible to integrate fluctuating output into the grids must be researched and implemented.
- Innovative planning and participation procedures for expanding grids and their routes must be investigated and tested.
- The significance of the new supply networks must be better communicated.

30 Deutsche Energie-Agentur GmbH DENA (2010) *DENA Grid Study II – Integration of Renewable Energy Sources in the German Power Supply System from 2015-2020 with an Outlook to 2025*, Berlin.

31 European Academies Science Advisory Council EASAC (2009) *Transforming Europe's Electricity Supply*. London.

32 Deutsche Energie-Agentur GmbH DENA (2010) *DENA Grid Study II – Integration of Renewable Energy Sources in the German Power Supply System from 2015-2020 with an Outlook to 2025*, Berlin.

4.1.3 Energy storage

- Storage capacity should be planned in line with the expected grid expansion.
- Higher-capacity transmission lines should be constructed throughout the EU to better connect the German grid to Scandinavia and the Alpine region. We must begin discussing and evaluating our links to Southern Europe and North Africa now, so that in the medium and long-term we can gain access to cheap solar energy.
- Cost-effective, efficient systems that can store electricity for at least up to a day (large static batteries, adiabatic compressed air energy storage, new storage concepts) must be developed.
- Investigations need to be carried out on the best way to integrate storage systems into the grid.
- Alternatives to energy storage – for example by building more wind turbines, photovoltaic plants or gas turbines that are not operated at maximum capacity, or by expanding the grid further – should be analysed with regard to their feasibility and costs.
- The efficiency of water electrolysis must be increased and investment costs decreased.

4.1.4 Efficiency technologies

- If we accelerate nuclear phase-out, gaps are most likely to occur in the electrical energy supply rather than in any other area. Therefore, short-term measures to increase efficiency should target consumers of electrical energy in particular.
- Measures to increase efficiency in other areas of the energy system (transport, heating) should be prioritised according to their effect on CO_2 emissions.
- Incentive systems and interventions to avoid rebound effects and to motivate private consumers to use energy more efficiently must be developed, researched and tested.
- In the short-term, an analysis should be carried out to identify the sectors of electrical energy consumption which have the greatest potential with regard to research efforts. There are many opportunities for savings here, and realising them often makes very good sense from an economic and business perspective.
- Particularly important research topics in industry are electrical crossover technologies (electric motors and their applications), new materials, tribology, materials efficiency and lightweight design.
- Research on using biogenic resources to produce materials in the chemical industry should be promoted because this area has greater potential for reducing CO_2 emissions than directly burning or producing biofuels.
- In the manufacturing, trade and service sectors, key research topics also include crossover technologies – especially for lighting, warm-water supply, cooling, ventilation, air conditioning and the IT sector.
- Important topics in household electricity use are measures to increase efficiency in lighting, heating and cooling supplies, warm-water supply, large household electric devices, TVs and the IT sector.

4.1.5 Overarching recommendations for action and research

- The public's perception of the risks associated with different energy technologies only partially reflects the scientific and technical values calculated for these risks. On the one hand it is important that the advantages and disadvantages expected for each energy source and system are communicated in a way that is clear and easy to understand.

On the other, it is necessary to identify the public's underlying concerns and values, and to incorporate these into the plans as far as possible. Both of these goals require the necessary dialogue procedures and communication platforms to be set up and operated.

- A comprehensive and transparent risk analysis of various supply technologies that includes different risk dimensions is essential for making objective, transparent decisions on future energy technologies and systems with the support of the majority of the population.
- The changeover to other forms of energy must be accompanied by a permanent process of cost analysis. This requires businesses and the energy industry to work together to produce a reliable database.
- Changing consumer behaviour offers immense scope for saving electrical energy without having to draw on technological innovations. It is important to research demand and to investigate the effects of incentive systems and regulatory and informational measures because the results of these approaches promise to reduce consumption with relatively little effort. To date, research has invested too little in work exploring the demand side. This gap must be closed as soon as possible.
- Given the international impact of possible nuclear accidents, we must investigate and set up global governance structures that could serve to establish universally accepted standards.
- The current situation shows that we need second- and third-best strategies which take effect when circumstances change, for example if a major nuclear accident occurs or we fail to reach a global agreement on climate policy.
- Nuclear research must also ensure that science can monitor international developments and that we can handle new developments like decommissioning and dismantling. Current experiences in Japan should be carefully analysed and used to increase the security of power plants and peripheral plants (e.g. spent fuel pools).
- We must find a technologically sound and socially acceptable solution as soon as possible for the final disposal of nuclear waste.
- The effects of disasters at foreign nuclear power plants could also reach German soil. As a precautionary measure, we must conduct research into security, into accident management and into handling the effects of a disaster.

4.1.6 Structural recommendations

- Because energy technologies are normally operated for a long time once they have been installed, a high level of continuity is required in energy policy to provide a reliable framework for businesses and consumers. We should therefore use the intense public debate on Fukushima to reach, to the extent possible, a non-partisan and widely approved consensus on future energy policy. This also requires encouraging intense public debate on future models of energy supply and their implications for the national economy, for our individual quality of life, and for the environment (including the climate).
- This broadly accepted guiding principle in energy policy must be regularly checked with regard to potentially changing constraints and adapted as necessary – also in a non-partisan process. If the government pursues multiple energy-policy strategies, these adaptations could happen without causing major disruptions.

- While the government should take action to establish suitable framework conditions, implementation is mainly the task of business and industry. Instruments should be developed that make it possible to set social priorities while also offering sufficient reliability to give businesses long-term planning security.
- We must use the current discussions on energy supply and the willingness for change that can be felt across many social groups to quickly establish a set of political instruments and create lasting structures that will assist with the necessary transformation of our energy system.
- The government should continue to drive forward its efforts to improve coordination and pooling of responsibilities in the field of energy to ensure that sufficient structures exist for decision-making and implementation.

4.2 Research priorities with medium- to long-term effects

The events in Japan and the subsequent reactions that could go as far as accelerating nuclear phase-out in Germany have shown how quickly the framework conditions of the energy system can change. This fact emphasises the academies' call, made in their energy research concept, for research to address a broad range of topics so that it can provide options for energy-policy decisions. Rather than having a knee-jerk reaction to Fukushima and limiting itself to the technologies that are the current focus of interest, research should continue to develop new possibilities and keep our options open for future developments. Although limited financial resources clearly mean that we must prioritise research efforts, we must retain a sense of proportion when doing so. On the one hand, available resources should be adapted to the size of the task, which would reduce the need for sharpening the focus. On the other, some of the available financial and personal resources should be used exclusively for research fields that are not currently part of the mainstream and that are likely to yield results only in the long-term. This is also compatible with the long time scales that are involved in significantly changing an energy system. As with the development of the energy system itself, research must also be integrated into European efforts. The European Strategic Energy Technology Plan (SET Plan)[33] picks up on many topics formulated in the energy research concept of the Leopoldina, acatech and the Berlin-Brandenburg Academy of Sciences and Humanities[34] – although some areas are significantly different due to variations in national strategies.

The academies' energy research concept from 2009 set out a series of long-term research needs. Below, we reiterate the main aspects of these needs. For more details, please refer to the energy research concept.

- All recommendations are based on the concept of a systemic approach. The technical and organisational solutions for making the necessary change to a sustainable energy supply can only be evaluated and effectively implemented in the complex environment of technical, social, political, cultural and economic relationships.
- Research must be geared towards continually identifying and exploiting potentials for increasing efficiency. To ensure quick market penetration and to avoid rebound effects, it is particularly important to incorporate research approaches from social studies and the humanities.

33 European Commission (2007) *A European strategic energy technology plan (SET Plan) – Towards a low-carbon future*. Brussels.

34 Leopoldina, acatech & BBAW (2009): *Concept for an integrated energy research programme for Germany*. Halle.

- Because fossil fuels will retain their importance at least on a global level, we need comparative studies of all options for reducing CO_2 emissions from these fuels (including carbon capture and sequestration (CCS) and carbon capture and utilisation (CCU)), as well as assessments of how they will affect the economy, environment and society.
- Research on innovative supply technologies is crucial if we are to attain the Federal Government's Energy Concept goal of using renewable energies to supply 80% of gross electricity consumption and 60% of gross final energy consumption by 2050. Wind, photovoltaics, concentrated solar thermal power (in Southern Europe and North Africa, with electricity transported to Central Europe) and geothermal energy offer great potential for Germany's energy supply. Alongside improving efficiency, lowering costs must also be one of the main goals. Fusion research is a shared international task with the potential to make a huge contribution to our energy supply, and as such we should continue to pursue work in this area.
- Different kinds of biomass should be reassessed for their suitability as sources of energy, and research into these should continue, taking account of economies of scale and adopting systemic perspectives. However, it seems that biomass as a sustainable source of energy only has limited potential in Germany, unless it imports more from abroad. The material use of biomass offers more potential for reducing CO_2 emissions and energy use, so research into this area should be systematically continued.
- Just like in the short term, we need to keep researching low-loss, flexible transnational grids in the long term. This must pay particular attention to how grid concepts interact with the market, contractual and legal systems of the participating countries. One research field of particular importance involves combining AC grids and DC grids at all voltage levels.
- Storage facilities could be key components of future energy grids. Research into storage technologies for electrical, thermal, mechanical and chemical energy must work on developing low-cost facilities with high energy and power densities. In the long term, seasonal energy storage facilities will become important. From today's perspective, the best option for these will be materials-based facilities that use small molecules such as hydrogen or methane. Technologies for using these kinds of materials-based storage facilities must be developed.
- For sustainable transport concepts, we need to develop electromobility further and investigate battery concepts that go beyond lithium-ion technology. It is also important for the transport sector that we explore conditions for an increased integration of technological and social transport concepts.
- More efficient supply technologies require high-performance materials that can be used, for example, in high-temperature power plants, wind turbines and heat-transfer media in solar-thermal power plants. Germany should use its strengths in materials research to supply innovative materials for use in energy systems.
- Irrespective of the industrial implementation of technologies, we also need to improve our basic understanding of energy-transfer processes on a molecular level, since they provide the foundation for almost every energy technology. Basic research on these topics forms the basis for optimising existing processes and for discovering and developing entirely new technologies.

- Energy policy needs integrated models and scenarios that can be adapted to developments as and when they arise. Research activities should focus particularly on the interactions between technology development, the dissemination of innovations, legal and ethical assessments, government regulation, and socio-political incentives and barriers.
- Research into demand is a key component of establishing a sustainable energy system. Research must explore what economic, legal and political steering instruments can help to achieve energy- and climate-political goals effectively, efficiently and in a legally and socially acceptable way, and how these instruments can be effectively integrated into global legal and governance structures.

5. METHODOLOGY

5.1 Reason, commissioning and production of this statement

The damage caused to Japan's Fukushima nuclear power plant by an earthquake and tsunami on 11 March 2011 re-launched a debate in German society on the risks of using nuclear energy. On 14 March 2011 the German Federal Government passed a decision to take all nuclear power plants that went into operation before the end of 1980 offline for an initial three-month period.

On 21 March 2011 the German Federal Minister of Education and Research, Prof. Annette Schavan, asked the German National Academy of Sciences Leopoldina to submit a statement on energy policy and energy research. The work was to focus primarily on the implications of the government's decision to abandon lifetime extensions for nuclear power plants in the wake of the reactor disaster in Japan for the energy system and energy research in Germany.

Headed by Prof. Ferdi Schüth (Max-Planck-Institut für Kohlenforschung, Mühlheim), a working group of 28 scientists spent the next eight weeks compiling this statement, using the 2009 *Concept for an integrated energy research programme for Germany* as the basis for their work.

The English-language preliminary version of this statement was submitted to the Energy Steering Panel of the European Academies Science Advisory Council (EASAC) for discussion on 3 May 2011. The ad-hoc statement of the extended Energy Steering Panel and the list of those who participated in the meeting are included at the end of this document.

A largely finalised working version of the statement *Energy- and research-policy recommendations following the events in Fukushima* was made available to the Ethics Commission for a Safe Energy Supply, which Federal Chancellor Angela Merkel appointed on 22 March 2011. The results of this statement were incorporated into the report *Deutschlands Energiewende – Ein Gemeinschaftswerk für die Zukunft* (Germany's energy transition: a collective project for the future).

Three experts evaluated the statement, and their comments were taken into account in the final version.

Comments from the Presidium of the Leopoldina were also taken into account.

5.2 Members of the Academy Group

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The following people were involved in the final version of this paper and uphold the content:

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The following people were involved in the production of this paper by commenting on different working versions, by participating in discussions or by contributing in other ways, but did not necessarily read or authorise the entire document:

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The Presidium of the German National Academy of Sciences Leopoldina has acknowledged and approved this statement.

The Leopoldina wishes to thank the authors and reviewers for their valuable contributions.

6. APPENDIX

Appendix 1

Ad-hoc statement by the Energy Steering Panel (ESP) of the European Academies Science Advisory Council (EASAC), May 2011

This statement is based on an earlier working version of the final paper. Some of the ESP's comments were addressed in later stages of editing the statement, meaning that they no longer apply, or no longer fully apply, in the final version.

EASAC *Energy Steering Panel* review of the Leopoldina reports on German energy policy and energy research policy

This report responds to a request from the Leopoldina to comment on the following two reports concerned with energy policy, and energy research policy, in Germany:

- The 2009 report 'Concept for an integrated energy research programme for Germany'.
- The draft report 'Outline of energy and research policy recommendations following the accident at Fukushima'.

Our review has been informed by a meeting held at Frankfurt Airport on 3rd May 2011, which involved invited experts and representatives of the Leopoldina, as well as members of the EASAC *Energy Steering Panel*. Attendees at this meeting and the members of the EASAC *Energy Steering Panel* are listed in the Annex. The invaluable contribution of the invited experts is gratefully acknowledged. Our task has been to provide an international perspective on the issues raised in the two reports, reflecting on the identified priorities for German energy research, and on the implications for other European countries, and for the EU as a whole, of German decisions on nuclear power. Time scales for our review have, of necessity been short given the pace of the current public debate in Germany. We are pleased to have had the opportunity to contribute.

An important consideration in our review has been Germany's position as a major economy and hence energy user in Europe, and also the leadership it has demonstrated in addressing the challenge of climate change, an issue inextricably linked to decisions on energy supply and use. We sincerely hope that decisions made on the future course of the energy system in Germany are consistent with Germany continuing to show leadership on tackling climate change. And we have suggested that rather more is said about the broader context - climate change, fossil fuel depletion, energy security etc. – in finalising the second Leopoldina report.

We are similarly concerned that decisions on the German energy system, and on energy research, be positioned firmly within EU policies and initiatives. The EU is committed to integrated gas and electricity markets by 2014, and the development of the necessary European transmission infrastructures. These physical and market integrations could be of great help to Germany in meeting its future energy needs and in ensuring a stable electricity grid. But their realisation will require Germany's full support, and we felt that they should have had a rather higher profile in the draft report that we reviewed.

Similarly, the EU has recognised that the magnitude of the energy challenge requires a concerted effort on research and development at a European level. The SET plan has therefore been put in place, which relies to a large extent on activities initiated at a national level. Given the importance of German R&D activities within the SET Plan, its continuing support is essential to a successful outcome. We felt that rather more emphasis could be put on EU-level R&D initiatives in planning Germany's future research programme.

Decisions on energy systems need to be informed by a systematic and quantitative evaluation of the options. Such analysis is essential to ensure that decisions are firmly grounded in practical realities, and to evaluate how reduction of risks in one area, e.g. phase-out of nuclear, can lead to increased risks in another, e.g. insecurity of gas supplies, increased climate change risks etc. Without it, unrealistic choices may be made. While such quantitative analyses may have been beyond the scope of the current exercise due to its short time scales, we hope they will be available to inform public debate before decisions on Germany's energy system, and in particular on the phase-out of nuclear power, are finalised.
Turning to the recommendations presented for energy research we were impressed by the breadth of the proposals, and the depth of analysis and consultation that underpinned them. However, notwithstanding the difficulties, some clearer sense of priorities will be needed given the large resources and long time scales needed to bring new energy technologies to commercial application. And the Leopoldina should not shy away from stating that research budgets must match the task, otherwise society's expectations will not be met.

Our own sense of priorities point to more emphasis being given to the following areas:

- The design and operation of a future integrated European electricity grid, dominated by non-synchronous generators and employing a mix of AC and DC technologies. This will be a very different system to those currently operating and will require many fundamental questions to be answered.
- On increasing the efficiency of energy use, in service and industrial sectors as well as households. Closer integration of social and technical aspects is needed to avoid rebound effects.
- Concentrating solar power (CSP) given the potential resources available in Southern Europe and North Africa, and the capability of CSP with thermal storage to supply most of the grid operational services of mid-range fossil plants.
- Carbon capture and storage which will become more important if Germany places increased emphasis on fossil fuels due to an early nuclear phase-out.
- Reducing the cost of renewable technologies.
- Basic research in areas such as nano-science, materials and biosciences that may be the source of future breakthroughs in energy technologies.
- Conversely, we felt that research on electricity storage technologies had been rather overemphasised as other approaches to matching electrical supply and demand, such as integrated, intelligent grids, demand management and peaking turbines, may be preferred. And research on fusion and hydrogen technologies will, at best, only bring returns in the long-term. We have been impressed by the quality of the analysis and thought presented in the two Leopoldina reports, and by the desire of the German Government to ensure that there is a strong voice for science in the current debate. We hope that our contribution will prove to be useful in providing a broader scientific perspective on the issues 'on the table' in Germany at the present time. These issues, and German decisions on them, resonate across Europe, particularly in light of events at the Fukushima power plant in Japan. There are no easy choices if a future reliable supply of energy in Europe is to be consistent with meeting the pressing need to substantially reduce greenhouse gas emissions.

Appendix 2

Participants at the hearing of the Energy Steering Panel (ESP) of the European Academies Science Advisory Council (EASAC) on 3rd May 2011 in Frankfurt:

Prof. Dr. Sven Kullander	*Royal Swedish Academy of Science (ESP Chair)*
Prof. Dr. Sébastien Candel	*Ecole Centrale Paris; Institut Universitaire de France*
Prof. Dr. Ronald Griessen	*Vrije Universiteit in Amsterdam*
Prof. Dr. Peter Lund	*Delegation of the Finnish Academies (Member of the ESP)*
Prof. Dr. David MacKay	*Chief Scientific Advisor, Ministry for Energy and Climate Change; University of Cambridge*
Dr. Giovanni de Santi	*European Commission, Institute for Energy, DG Joint Research Centre*
Prof. Dr. Ferdi Schüth	*Max-Planck-Institut für Kohlenforschung, Mülheim (Member of the ESP)*
Prof. Dr. Jan Vaagen	*Academia Europaea (Member of the ESP)*
Prof. Dr. Hermann-Josef Wagner	*Ruhr-Universität Bochum*
Dr. Vladimir Wagner	*Academy of Sciences of the Czech Republic — Nuclear Physics Institute*
Prof. Dr. Sir Brian Heap	*EASAC President*
Prof. Dr. Jörg Hacker	*President of the Leopoldina*
Prof. Dr. Volker ter Meulen	*Immediate Past President of EASAC and the Leopoldina*
Dr. John Holmes	*EASAC, Energy Programme Secretary (ESP Secretary)*
Dr. Christian Anton	*Leopoldina, Department Science – Policy – Society*
Dr. Christiane Diehl	*Executive Director of EASAC*

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