European Electricity Generation Post-2020: Renewable Energy Not To Be Underestimated

by Christian von Hirschhausen, Claudia Kemfert, Friedrich Kunz, and Roman Mendelevitch

In its Green Paper on a 2030 framework for climate and energy policies, the European Commission calls for a framework for the future development of environment and energy policy beyond 2020. However, much like the Energy Roadmap 2050 adopted by the Commission in December 2011, the Green Paper is based on scenario assumptions that are, to a great extent, not up-to-date. The European Commission would need to provide updated model calculations rapidly to enable energy policy decisions to be taken on the basis of transparent and comprehensible scenarios.

A comparison of recent estimates conducted by DIW Berlin indicates that the Commission systematically underestimates the cost of nuclear power and carbon capture, transport, and storage (CCTS), while the cost of renewables tends to be overestimated. In particular this applies to photovoltaics where current capital costs are, to a certain extent, already lower than the Commission's estimates for 2050. In contrast to renewables, neither nuclear energy nor carbon capture, transport, and storage are cost efficient enough to play a central role in the future European electricity mix. It is therefore vital for Europe to continue to focus on the further development of renewables. This requires the setting of ambitious renewables targets for 2030 as well as clear emissions reduction and energy efficiency targets.

In 2009, the European Commission agreed on a package of directives for energy and climate conservation[1] which contained specific targets for the year 2020 (known as 20-20-20 targets). The objectives were a 20 percent reduction in greenhouse gas (GHG) emissions by 2020 (compared to 1990 figures), a 20 percent improvement in energy efficiency over current forecasts and an increase in the proportion of renewables in overall energy consumption (gross final energy consumption for electricity, heat and transport) to 20 percent. To achieve these targets, the intention was to reform emissions trading as a key instrument for reducing greenhouse gases and to set national targets for increasing the share of renewable energies.[2] These energy efficiency targets were agreed in the Energy Efficiency Directive[3] and the Energy Efficiency Plan.[4]

Targets for 2020 have so far been achieved to varying degrees. The EU's emission reduction targets, for example, have already been almost fully achieved. In 2011, emissions were only about two percentage points above the reduction target.[5] The EU has certainly made progress on the renewables target and has increased the share of renewable energies in gross final consumption from 8.5 percent in 2005 to 13 percent in 2011.[6] However, there are still concerns about whether the overall target for 2020 will be achieved. To do this, renewables in Euro-

1 European Climate and Energy Package of 2009. This includes Directives 2009/28/EC on renewable energies, 2009/29/EC on emissions trading, 2009/31/EC on CO_2 storage and Decision 406/2009/EC on effort sharing.

2 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

3 Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency.

4 European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy Efficiency Plan, 2011(Brussels: March 8, 2011) COM (2011) 109 final.

5 European Environment Agency (EEA), Annual European Union greenhouse gas inventory 1990–2011 and inventory report 2013 (Technical report no. 8/2013). (Copenhagen: 2013).

6 Eurostat, Europe 2020 indicators (2013).

pe would have to grow by an average of more than six percent per annum.[7] In terms of the efficiency target, the consensus here is that increased efforts are necessary to achieve the 20 percent target.

Green Paper 2030: EU Launches Debate on Energy and Climate Strategy

The European Union and the 28 member states which are responsible for the national energy mix under Article 194 of the EU Treaty[8] will soon have to make strategic decisions about the future structure of power generation beyond the year 2020. With its Green Paper on "a 2030 Framework for Climate and Energy Policy",[9] the European Commission is launching a discussion on the direction of European energy and climate policy beyond the year 2020. In consultations on the Green Paper 2030, questions were asked about experience gained from the energy and climate policy framework up to 2020 and further developments in the coming decade. The reasons for compiling the roadmap up to 2030 at this early stage are the length of investment cycles and the need for fixed framework conditions. In addition, existing long-term targets must be substantiated by binding intermediate targets. Consequently, both the climate roadmap and the Energy Roadmap 2050 contain explicit reductions in GHG emissions by 2050 of 80 to 95 percent compared to 1990; these figures assume a far-reaching decarbonization of the power sector.[10]

The Green Paper builds on the long-term targets of the European energy and climate policy: the European Union has committed itself to reducing GHG emissions significantly and to increasing the share of renewables. At the same time, the competitiveness of the European economy should be improved, while increasing security of energy supply, and ensuring affordability of energy in the internal energy market. In particular, the EU plans to reduce GHG emissions by 80 to 95 percent. To achieve this, it will be necessary to establish binding GHG reduction targets for 2030. The European Commission has proposed introducing an interim reduction target of 40 percent by 2030.

Going beyond the issue of target setting, the Green Paper also highlights the problem that two important policy instruments currently show very little impact towards the creation of a sustainable energy mix. These instruments are the emissions trading scheme, and promoting schemes for the carbon capture, transport, and storage (CCTS) technology. Emissions trading leads to insufficient price signals because there are too many surplus certificates on the market and limits on the number of emissions were not consistently adjusted downward.[11] As a result, the very low CO2 price (currently at three to five euros per ton) fails to set the necessary signals required for long-term innovation in the field of low-CO2 power generation technologies.[12] Furthermore, the EU's efforts to develop the CCTS technology have come to nothing because neither the energy industry nor national governments have made corresponding efforts to implement the technology.[13]

Green Paper 2030 Based on Outdated Assumptions and Puts Renewables at a Disadvantage

When the Green Paper was compiled by the Commission, there were no updated model runs and scenarios available, so it had to rely on cost assumptions that were up to four years old. In particular, it failed to take into account the most recent development in costs of renewable energies.[14] As a result, neither the European Commission nor the member states, nor citizens who were also called on to participate were able to form their opinion based on current and transparent calculations.

In particular, the Green Paper neglected to factor in recent sharp reductions in the production costs of renewable energy. Moreover, the development of costs of

7 Germany has committed to a national target of 18 percent, in 2011, according to Eurostat, the share of renewables in final energy consumption was 12.3 percent.

8 According to Article 194 of the EU Treaty, energy policy is a shared competence of the European Union and the member states. In particular, member states still have sole decision-making authority over the energy mix. Nevertheless, specific EU measures and other stimuli are of great importance. As a result, the efficiency of almost all power generation technologies is directly influenced by European directives or regulations.

9 European Commission, Green Paper: A 2030 framework for climate and energy policies (Brussels: March 27, 2013), COM (2013) 169 final.

10 European Commission, Energy Roadmap 2050 (2011), COM (2011) 885 final, and European Commission, A Roadmap for moving to a competitive low carbon economy in 2050 (2011), COM (2011) 112 final.

11 K. Neuhoff and A. Schopp, "Europäischer Emissionshandel: Durch Backloading Zeit für Strukturreform gewinnen," Wochenbericht des DIW Berlin, no. 11 (2013).

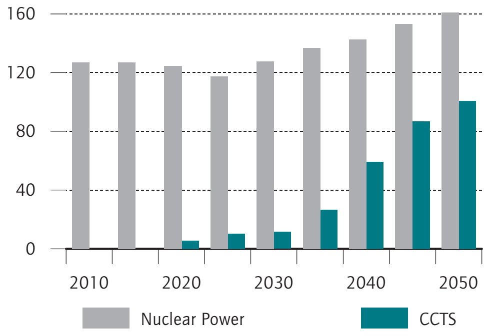
12 See open letter to Chancellor Angela Merkel on European emissions trading, dated 18 March 2013, and J. Diekmann, "EU-Emissionshandel: Anpassungsbedarf des Caps als Reaktion auf externe Schocks und unerwartete Entwicklungen?," report commissioned by the Federal Environment Ministry, Climate Change, no. 17 (Dessau/Berlin:2012).

13 In this regard, the Green Paper 2030 refers to two simultaneous consultations on i) international negotiations on a new legally binding agreement on climate protection and ii) a concept for demonstrating technologies for CO_2 capture, transport and storage.

14 In addition, the responsible Directorate-General for Energy still has not presented the "Reference and Policy Scenarios 2050" from that time which, in addition to European level model calculations, also contain results for each member country.

Figure 1

Installed Capacity of Nuclear Power and CCTS According to the Energy Roadmap[1]
In gigawatts

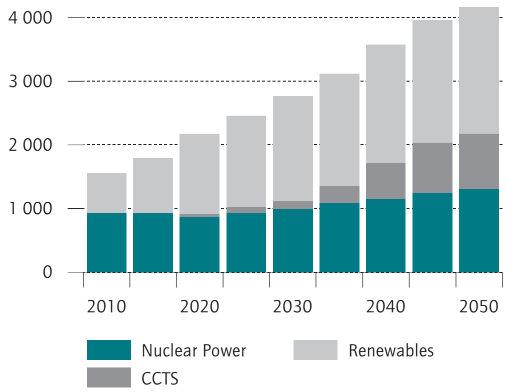


1 Based on the reference scenario.
Source: Prepared by DIW Berlin based on European Commission (2011).

The Energy Roadmap forecasts a sharp rise in the output of CCTS power plants by 2050.

Figure 2

Electricity Production from Nuclear Power, CCTS and Renewable Energy Sources According to the Energy Roadmap[1]
In terawatt-hours



1 Based on gross power generation in the reference scenario.
Source: Prepared by DIW Berlin based on European Commission (2011).

According to the Energy Roadmap, nuclear power and CCTS are the cornerstones of power supply.

thermal power generation after the nuclear accident in Fukushima and the persistent lack of operating CCTS demonstration projects must be taken into account. For technical and economic reasons, third-generation nuclear power plants and CCTS technology are unlikely to play a major role in the future energy mix of the EU. Although neither technology is available on an operational level yet, significant cost reductions have been predicted. As a result, some scenarios anticipate that, by 2050, both technologies become the cornerstones of European electricity supply (see Figures 1 and 2).

In the reference scenario capacity of nuclear power plants increases from the current 127 gigawatts to 161 gigawatts by 2050. Power plant capacity with CCTS technology, which is currently not available in demonstration plants in Europe or anywhere in the world, will jump from zero to over 100 gigawatts by 2050. In the following the plausibility of these results is scrutinized and the assumptions behind them are challenged.

Literature Study by DIW Berlin on Current Cost Trends

As a basis for the development of its electricity market model (ELMOD), DIW Berlin conducted a systematic survey of the costs of renewable and conventional power generation.[15] Here, investment costs for a wide range of production technologies were quantified and own analyses of operating costs were conducted, based on exogenous parameters such as fuel costs. The study also discusses the differences between various quantification approaches and developes plausible development paths from today's perspective. Selected results of this analysis are used as an aid in the following discussion of future scenarios for European energy supply, particularly in comparison with figures contained in the Energy Roadmap 2050.

The use of a comprehensive cost concept depends on the inclusion or non-inclusion of relevant cost factors. While a private investor is primarily focused on private production costs, the government's energy and environmental policies should take into account all costs, including social environmental and transaction costs (see box).

15 A. Schröder, F. Kunz, J. Meiss, R. Mendelevitch, and C. von Hirschhausen, "Current and Prospective Costs of Electricity Generation until 2050,"Data Documentation, no. 68, DIW Berlin (2013). In the following, all details relate to this data documentation unless otherwise stated. The authors would like to thank Mr. Schröder for his assistance with the literature and data research conducted in preparing this weekly report.

Box

Cost Components

The development of power generation costs is an important indicator for assessing future developments in the energy system. However, there are methodological and practical differences in quantifying power generation costs that can lead to varied and controversial assessments. Therefore it is necessary to take account of the assumptions made in determining current and future cost structures and to depict cost categories transparently.

In principle, a distinction should be made between *private* and *social* costs: private costs refer to costs incurred by the power producer, while social costs also take into account costs borne by society, such as the cost of environmental pollution.

Furthermore, a distinction should be made between production and *transaction* costs:

- Production costs are the costs of generating electricity directly incurred in the production process, which consist of investments, fixed operating and maintenance costs, and CO2 allowance costs;
- Transaction costs include the provision of the necessary framework, for example within the company, in terms of market infrastructure or in terms of the overall energy policy framework.

A largely neglected category of transaction costs is risk costs, which include the costs of unforeseeable events borne by the investor, society or other stakeholders. These events can be "normal" risks, such as market and regulatory risks, but also technological risks, such as a serious accident. Risk costs can accrue explicitly in the form of insurance costs but can also occur implicitly by increasing the capital costs of financing. In the case of major uninsured risks, society bears the risk costs, for example, of major nuclear power plant accidents. The risk costs incurred here can be considerable, but are often erroneously neglected in quantitative investment appraisals.

Furthermore, it is common to make a distinction between the timing of the costs: Variable costs are short-term costs dependent on production quantities (operating costs), whereas fixed costs are short-term but do not depend on production; in the long term all costs are variable and subsumed under the term "standardized average costs" (levelized cost of electricity, LCOE). Additional aggregates can be analyzed beyond the specific costs of individual technologies, for example, energy system costs or macroeconomic effects.[1]

1 M. Pahle, B Knopf, O. Tietjen, and E. Schmid, "Kosten des Ausbaus erneuerbarer Energien: Eine Metaanalyse von Szenarien," Climate Change, no. 23 (Dessau/Berlin: Federal Environment Agency, 2012).

Costs of Nuclear Energy Prohibitively High

Right from the beginning, the use of nuclear power for civilian purposes was never really exposed to market competition. After World War II, some countries developed nuclear power generation with military objectives in mind. Either government-owned enterprises were entrusted with the task (such as in the UK and France) or private businesses were given government grants or guarantees to encourage them to develop nuclear energy (for example, in Germany and the US).[16]

A detailed survey of the total cost of power generation from nuclear power plants is particularly difficult. Costs are incurred in research and development, the construction, operation and decommissioning of the power plant. Fuel costs and other variable costs as well as the costs of possible accidents (cost of risk) should also be taken into account.

Due to technical uncertainties and the increasing safety requirements of nuclear powerthe technology has not become cheaper over the decades—in contrast to all other power generation technologies— but rather its capital costs have increased many times over. For example, the output-specific investment per kilowatt in France in 1980 was approximately 1,000 euros, in 1990 it was between 1,300 and 1,600 euros, and in 2000 it was between 1,500 and 3,000 euros (see Figure 3).[17] In the US, too, output-specific investment rose significantly from 1973 (ca. 1,000 US dollars/kilowatt) to 1990

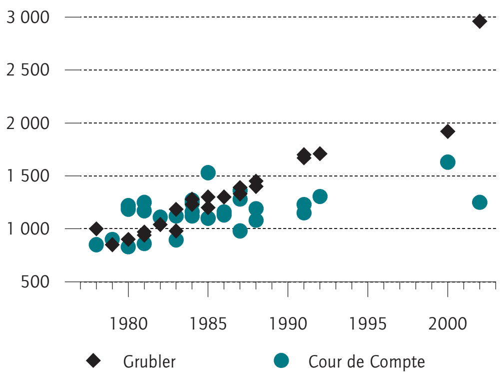
16 J. Radkau and L. Hahn, Aufstieg und Fall der deutschen Atomwirtschaft (Munich: 2013). In socialist countries like the Soviet Union, the GDR or China, or in emerging countries such as Iran, the development of nuclear power had already extended beyond any economic considerations.

17 Based on 2010 prices. See L. Rangel and F. Lévêque, "Revisiting the cost escalation curse of nuclear power. New lessons from the French experience," Working Paper 12-ME-08, Interdisciplinary Institute of Innovation, (Paris: 2012), and A. Grubler, "The cost of the French nuclear scale-up: A case of negative learning by doing," Energy Policy38 (2010): 5174-5188. Rangel and Lévêque refer to Grubler and to cost data from the French Court of Auditors (Cour de Compte).

Figure 3

Historic Specific Investment Costs[1] for French Nuclear Power Plants

In euros per kilowatt



1 Based on 2010 prices. Figures related to "second generation" nuclear power plants. Projections by Grubler and the French Court of Auditors (Cour de Compte).

Source: Prepared by DIW Berlin based on Rangel and Lévêque (2012).

New nuclear power plants are becoming increasingly expensive over time.

(ca. 5,000 US dollars/kilowatt).[18] The reasons for this are, in particular, more stringent safety regulations, changing standards, and a lack of continuity in the construction of nuclear power plants.

Past experience of rising capital costs appears to apply to the current stage of development for the "Third Generation" (European Pressurized Reactor, EPR) of nuclear power plants. The cost estimates for the two nuclear power plants currently under construction in Olkiluoto (Finland) and Flamanville (France) are continually increasing. In 2006, the original estimate was 1,500 euros per kilowatt. Since then it has risen to 4,500 euros per kilowatt (mid-2008)[19] and has recently climbed to 5,100 euros per kilowatt (December 2012).[20] Reasons for this include planning errors, problems with the automatic control systems, and also revised safety requirements.21

The planned construction of a new nuclear power plant in the UK also underlines the high costs of nuclear power. Negotiations are currently being held between the government and the French state company EdF on the level of financial security the latter should receive to build a new third-generation nuclear power plant. It is becoming apparent that the potential investor is not keen on making market-based investments, and is also calling for a very high price guarantee.[22] In the discussion, a "strike price" (equivalent to the German feed-in tariff) is somewhere in the region of 100 pounds sterling (about 116 euros) per megawatt-hour over 40 years plus government guarantees to secure against various risks. By way of comparison, this is roughly the same as the "strike price" for onshore wind turbines in the UK, but this is only granted for 15 years.

Costs for Disposal and Insurance Often Neglected

The cost of disposing of spent fuel elements is still largely unknown because even after six decades of nuclear energy use there are no permanent disposal sites anywhere in the world that guarantee the safe storage of nuclear fuel rods for tens of thousands of years. In Germany, too, it is likely to take at least another 15 years before a suitable site can be identified. The concern remains that the full costs of disposal will continue to be inadequately considered in energy system models.

Another important, but often neglected, cost factor is insurance against potential major accidents. The costs of such major accidents at nuclear power plants can be extremely high and are difficult to quantify.[23] Currently, these costs are borne primarily by society because nuclear power plant operators are only subject to very few insurance obligations.[24] As a result, the government and/or uninsured private citizens bear the risk costs. Irrespective of the most economically advantageous form of insurance (public, private, or a mix of the two),[25] such costs must be considered accordingly in the economic evaluation.

The economic viability of nuclear power is also diminished by a further tightening of safety regulations which are currently being developed at European level. As a result of the nuclear accident in Fukushima, EU Ener-

18 M. Cooper, "The Economics of Nuclear Reactors: Renaissance or Relapse?," Nuclear Monitor WISE (August 2009): 1-20.

19 S. Thomas, The EPR in Crisis (London: University of Greenwich, 2010).

20 EnergyMarketPrice, EDF Unveils a Sharp Rise in Costs for Flamanville Nuclear Reactor Construction (2012).

21 Reuters, Finland's Olkiluoto 3 reactor delayed again (2012).

22 D. Toke, "Nuclear Power: How Competitive is it Under Electricity Market Reform?" Presentation at the HEEDnet Seminar (London: July 17, 2012).

23 J. Diekmann, "Verstärkte Haftung und Deckungsvorsorge für Schäden nuklearer Unfälle – Notwendige Schritte zur Internalisierung externer Effekte," Journal of Environmental Policy and Law 2 (2011): 119-132.

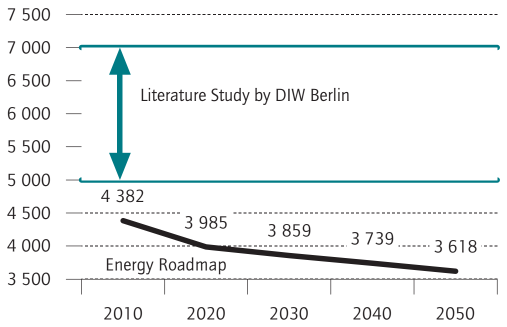
24 In Germany, for example, 2.5 billion euros, see Diekmann, "Verstärkte Haftung"(2011).

25 R. Schwarze and G.G. Wagner, "Wir brauchen eine echte Atomhaftung. Mit einer Versicherungspflicht gegen Elementarschäden könnte die Welt „sicherer" werden," Süddeutsche Zeitung, March 28, 2011.

Figure 4

Estimated Specific Investments Costs for Future Nuclear Power Plants[1]

In euros per kilowatt



1 Figures related to "third-generation" nuclear power plants. The cost range calculated by DIW Berlin includes construction, decommissioning, disposal, and completion risks.
Sources: European Commission (2011) and research by DIW Berlin.

Third-generation nuclear power plants are likely to be much more expensive than assumed by the Commission.

gy Commissioner, Günther Oettinger recommended the mandatory stress testing of European nuclear power plants which revealed the urgent need for some to be retrofitted. A draft regulation will form the basis for binding rules on liability and compulsory inspection routines to be introduced in all countries.[26]

Droping Costs of Nuclear Power in the Roadmap Implausible

The cost estimates of the Energy Roadmap 2050 as well as those of other scenarios that attribute considerable importance to nuclear power as a future energy supply assume comparatively low costs and high competitiveness for the techonology. Third-generation nuclear power plants currently under construction require an investment of approximately 6,000 euros per kilowatt which includes expenditure on construction, decommissioning, disposal, and completion risks. Based on past empirical evidence of increasing safety requirements, future cost reductions for this generation of power plants are not plausible; rather, constant capital costs can be assumed. In addition, there are variable operating and maintenance costs of about 20 to 25 euros per megawatt-hour. Even these figures, which correspond to an average cost of 109 euros per megawatt-hour (MWh), show that nuclear energy is comparatively expensive. Risk costs that are largely borne by the general public add on to that.[27]

In contrast, the Energy Roadmap 2050 is based on significantly lower values: firstly, the starting value for the year 2010 is only 4,382 euros per kilowatt, secondly, significant cost reductions are assumed for the coming decades (see Figure 4); both of which stand in contrast to the experiences described above. These circumstances explain the surprising and systematic extra in capacity of nuclear power in the energy scenarios of the Energy Roadmap in the reference scenario from currently 127 GW to 161 GW. Given the cost estimates outlined above, such a development is somewhat unlikely.

CO_2 Capture Between Hopes and Reality: No Prospects for Widespread Use in Europe

Carbon capture, transport and storage (CCTS) plays a very important role in the Energy Roadmap for the decarbonization of power generation: in the reference scenario, power plant capacity increases from zero GW to more than 100 GW by 2050; while in other scenarios the corresponding figure is up to 193 GW ("diversified supply technology scenario"); even in a scenario where the availability of the technology is delayed, the capacity of CCTS power plants is still expected to be 148 GW.[28]

No CCTS Demonstration Projects To Date

These optimistic development scenarios run contrary to current developments. On a demonstration scale, there are still no production chains anywhere in the world where carbon is captured in power plants, transported downstream and then stored permanently underground. Despite efforts in some countries to develop pilot projects in the last decade, there have been no significant successes to date. In continental Europe, all demonstration projects have so far been canceled or postponed indefinitely. In Germany, both industry and policy-makers have buried their plans for the large-scale industrial implementation of CCTS technology as part of the

26 European Commission, Draft proposal for a Directive amending Nuclear Safety Directive IP/13/532, June 13, 2013.

27 This value is calculated assuming a lifespan of 40 years, an interest rate of ten percent, and a capacity factor of 83.3 percent; if a capacity of 50 percent is assumed, which may be quite realistic in a future with increasing feed-ins from renewable energy sources, this figure increases to 165 euros per MWh.

28 European Commission, Energy Roadmap 2050 (Impact assessment Part 1) SEC Statistical annexes (Brussels: European Commission, 2011), 1565.

energy transition.[29] Only three countries in the North Sea region are still perusing to demonstrate the technology (the UK, the Netherlands, and Norway), but here too, the prospect of a transnational, mashed CO2 infrastructure is no longer being discussed.

The current failure of CCTS technology is outlined in the recent Commission Communication on the future of carbon capture and storage in Europe.[30] The Commission notes that all efforts to date, despite having been afforded lucrative financial support, have not led to the construction of a single demonstration plant. The blame for this has been attributed to both the energy industry itself and the restrained policies of member states. The Communication also illustrates that of all the planned demonstration projects not one has taken the planned development path and there is little chance of a demonstration power plant being built any time soon. Discussions that could lead to an investment decision for a demonstration project within the next two years are only ongoing at locations (Rotterdam in the Netherlands and the Don Valley in the UK).[31]

Large Cost Reductions Unlikely for CCTS

Given the fact that the CCTS technology has not been successfully demonstrated in any power plant with downstream carbon transport and storage, all cost estimates are speculative; in particular, long term cost forecasts be made with serious caution. The capital cost of a CCTS power plant is generally estimated at 3,000 to 4,000 euros per kilowatt. Irrespective of the selected carbon capture technology (post-combustion, pre-combustion, and oxyfuel), efficiency decreases by 21 to 33 percent compared to the reference power plant due to the additional energy demand. Overall, the carbon capture stage alone leads to an increase in power generation costs of 50 percent.[32] The cost reduction potential of this part of the technology chain is estimated to be very low.[33]

In addition to carbon capture costs, there are also costs of transport and storage. For a large-scale deployment of CCTS technology, as envisaged in the scenarios in the Energy Roadmap 2050, a CO2 transport network of many thousands of kilometers of pipeline would be required due to the distances between the emission sources and potential CO2 storage sites.[34]

Long-term CO2 storage could be done in depleted oil and gas fields or saline aquifers. The respective storage costs will vary significantly from case to case. In general, the first two options will require lower investment costs, since the subsurface will already have been extensively explored and old infrastructure could potentially be reused for constructing and operating the deep-injection facilities. Depending on the location (onshore/offshore) and geological characteristics, the average storage costs are between two and 12 euros per megawatt-hour. The technology is considered the least developed stage in the CCTS process and is associated with considerable uncertainty about effectively usable storage capacity and regulatory processes. This risk is reflected in addition burdens in financing for such projects.

In terms of future cost developments, it is unclear whether CCTS technology would have positive or negative learning rates. Analog developments in other technologies would suggest positive learning rates, that is, a gradual decrease in the average cost of power generation.[35]

The rather inflexible mode of operation of CCTS power plants is likely to drive costs upward. Given the increasing demand for flexibility of fossil fuel power plants in the context of the increasing share of supply from fluctuating renewable energies sources, such as solar and wind power, even adjusted cost estimates may be too low

29 C. von Hirschhausen, J. Herold, P.-Y. Oei, and C. Haftendorn, "CCTS-Technologie ein Fehlschlag – Umdenken in der Energiewende notwendig," Wochenbericht des DIW Berlin, no. 6 (2012).

30 European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the of Future of Carbon Capture and Storage in Europe COM (2013) 0180 final (Brussels: March 27, 2013).

31 Characteristic of the parlous state of carbon capture is the Commission's description of the status of the pilot project in Belchatow (Poland), the largest lignite power plant in Europe, „The project received no funding as part of the NER300 program and has a significant financing gap. In addition, Poland has yet to implement the CCS Directive and to adopt legislation for the planning and construction of the CO_2 transport corridor. Against this background, the project initiators decided to begin ceasing the project in March 2013.": p. 31.

32 European Academies Science Advisory Council (EASAC), "Carbon capture and storage in Europe,"EASAC policy report, no. 20 (Halle, Saale: 2013).

33 The Crown Estate, Carbon Capture & Storage Association, DECC, UK Carbon Capture and Storage Cost Reduction Task Force, Final Report (2013). UK. Expected technological developments could hypothetically reduce this share to 30-45 percent over the next 20 years, but given the current situation this is purely speculative.

34 The capital costs in this network-based, part of the CCTS technology chain represent 90 percent of the total costs. Depending on terrain, transport volumes, and distances, costs are in the range of four to 21 euros per megawatt-hour of electricity generated.

35 However, negative learning rates are also plausible, analogous to nuclear energy, which would lead to cost increases. Already In 2009, researchers at Stanford University highlighted the risk that the positive learning effects expected for CCTS could in fact fail to materialize. R. Varun, D.G. Victor, M.C. Thurber, "Carbon Capture and Storage at Scale: Lessons from the Growth of Analogous Energy Technologies," Energy Policy 38 (2009): 4089–4098.

because current calculations for the sensitive thermodynamic and chemical processes of carbon capture are designed for continuous base load operation. Increasing the flexibility of CCTS power plants can only be achieved with significant cost increases.[36]

Against this background, the optimistic cost estimates for CCTS in the Energy Roadmap 2050 are certainly surprising: Although the estimated capital costs of 3,481 euros per kilowatt for CCTS coal-fired power plants in 2010 are in the plausible range, no transport costs were factored in and storage costs were set very low, even though considerable cost increases are expected here. A very high figure of 5.4 GW of generating capacity for CCTS was assumed for 2020. This figure supposes the successful implementation of all current proposals of the European Economic Program for Recovery. Moreover, the Energy Roadmap assumes significant learning rates beyond the year 2020. Given the presumed high growth rates, specific investment costs are expected to fall to 2,064 euros per kilowatt by the year 2020, which will generate additional capacity at CCTS power stations; this additional capacity will further reduce investment costs, so at the end of the observation period in 2050, the price per kilowatt in 2050 levels at 1,899 euros and installed CCTS power plant capacity exceeds 100 gigawatts.

Costs of Power Generation from Renewables Systematically Overestimated

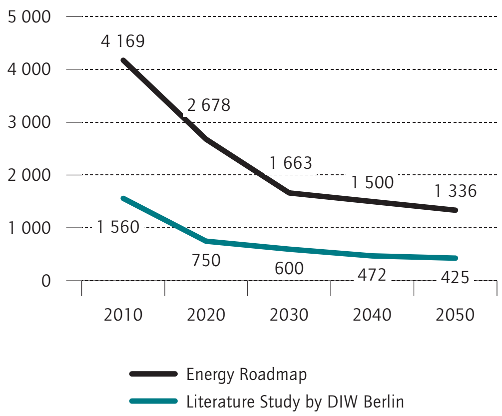
The production cost of power from renewable energy sources has plummeted in recent years. This development is not sufficiently taken into account in the model assumptions that underlie the EU Energy Roadmap. Unlike nuclear and coal power plants with CCTS, the cost of producing power from renewable energies has been systematically overestimated. Given the progressive global diffusion of renewable energy technologies, it is no surprise that there are economies of scale. Given ongoing technological innovation, especially in solar and wind power generation technologies, further decreases in specific production costs and significant learning potential can be expected for these technologies on the 2050 horizon.

36 E. Rubin and H. Zhai, "The cost of carbon capture and storage for natural gas combined cycle power plants,"Environmental Science & Technology 2013 47(6) (2012): 3006–3014.

Figure 5

Development of Specific Investment Costs for Photovoltaic Systems

In euros per kilowatt



Sources: European Commission (2011) and research by DIW Berlin.

The cost of photovoltaics has been grossly overestimated by the Commission.

Photovoltaics: Costs Continue to Fall

More recently, there have been significant cost reductions in the field of photovoltaics. There have been both increases in efficiency[37] and reductions in plant costs; this has led to significantly lower average costs for photovoltaic power. Given some excess capacity, particularly in the last two years, the price pressure on photovoltaic modules, which make up the largest proportion of total costs, has continued to rise. Due to the cost dynamics, it is particularly important to include the latest developments in scenario calculations.

Many studies point to annual cost reductions of 15 percent since 2008.[38] Unlike other technologies, learning rates in photovoltaics over the last few years have remained stable at 15 to 20 percent;[39] this means that the specific costs fall by 15 to 20 percent when installed capacity is doubled. It can be generally assumed that this

37 L. Kazmerski, Solar Energy Technologies Program - Multi-Year Technical Plan 2003-2007 and beyond (Hamburg: National Renewable Energy Laboratory (NREL), 2013). Original from 2007, updated 2013.

38 H. Wirth, Aktuelle Fakten zur Photovoltaik in Deutschland (Freiburg: Fraunhofer ISE,2013). See also T. Gray, M. Huo, and K. Neuhoff, "Survey of Photovoltaic Industry and Policy in Germany and China,"DIW Discussion Paper, no. 1132 (Berlin: 2011).

39 Pahle et al. "Kosten des Ausbaus erneuerbarer Energien,"(2012).

trend will continue for the foreseeable future.[40] It is anticipated that the installed capacity of solar photovoltaics all over the world will double again from the current 70 GW to about 150 GW by as early as 2015.[41]

The cost of photovoltaics is made up of module costs, inverter costs, installation, maintenance and area, also known as the "balance of system" (BOS). Module costs make up about 50 percent; but are following a downward trend given the rapidly falling specific module prices. While numerous studies in the mid-2000s still assumed specific investments at around 3,000 euros per kilowatt-peak, today less than 1,000 euros per kilowatt-peak for large-scale systems including installation costs is more realistic.

Figure 5 compares the estimate on specific investment costs contained in the Energy Roadmap with figures that appear to be more realistic today. There is a striking difference in both the initial level and the trend:

In 2020, a figure of 750 euro per kilowatt would be plausible,[42] whereas the Energy Roadmap assumes costs of 2,678 euro per kilowatt by 2020;

In terms of dynamics, the authors believe development with a slight decline in economies of scale is plausible. The assumption is that costs will fall by 20 percent between 2020 and 2030, by another 15 percent by 2030, and by ten percent between 2040 and 2050. Here, the Energy Roadmap appears very conservative in its estimate of the cost reductions in photovoltaics beyond the year 2030: although capital costs will decrease linearly from 2010 (about 4,000 euros per kilowatt) to 2030 (about 1,660 euros per kilowatt), they will only drop slightly by 2050.

Both the initial figures and the development of these cost estimates seem implausible from today's perspective. As a result, the costs of large photovoltaic systems today are already lower than the figures estimated in the Energy Roadmap for 2050.

40 W.Buchholz, J. Frank, H-D. Karl, J. Pfeiffer, K. Pittel, U. Triebswetter, J. Habermann, W. Mauch, and Thomas Staudacher, "Die Zukunft der Energiemärkte: Ökonomische Analyse und Bewertung von Potenzialen und Handlungsmöglichkeiten," ifo research reports 57, ifo Institute, 2012 This study also assumes a rapid cost reduction which will largely expire after 2030.

41 K. Bloche-Daub, J. Witt, M. Kaltschmitt and S. Jaczik, "Erneuerbare Energien. Stand 2012 weltweit," BWK Das Energie Fachmagazin 65, no. 6 (2013): 6–17.

42 J. Meiß, "Prospective Energy Generation Costs – Topic 1: Solar," Workshop on Prospective Generation Costs, (DIW Berlin, March 8, 2013).

Onshore Wind Turbines Have Considerable Cost Reduction Potential

Like with photovoltaics, field of onshore wind turbines has seen significant production increases and cost reductions in recent years. Most scenarios still assume possible cost reductions in the future. Different studies identify learning rates ranging from five to 15 percent;[43] however, these will decline over time.[44] The decline of onshore wind turbine capital costs was as rapid as that of photovoltaic systems. While investors had to raise more than 2,000 euros per kilowatt in the early 2000s, specific investments have since fallen to about half that.

A discrepancy between the estimates in the Energy Roadmap and those in other analyses is also prevalent in the investment costs for onshore wind: while most studies predict cost reductions, in the Energy Roadmap, the specific investment costs for onshore wind remain almost constant for the next four decades (1,106 euros per kilowatt in 2010 to 1,074 euros per kilowatt in 2050).

Furthermore, recent experience with different types of wind turbines has shown that it is possible to decrease the average production costs of wind power when using optimized turbine designs, even when specific investment costs remaining constant. By adapting the design of the generator, rotor length, and mast height to locally prevailing wind conditions, significant gains in yield can be achieved. A lower specific capacity installation can lead to lower specific power generation costs.[45] A smaller design also results in lower grid connection costs, since the required cable size decreases. Greater turbine utilization leads to a reduction in system costs.[46] However, the Renewable Energy Sources Act has not yet taken this advantage of wind power into consideration by reducing connection costs.

Conclusions and Recommendations for Energy Policy

The European Commission's Green Paper 2030 gives a valuable impetus to the discussion on the future structure of the power generation systemin Europe. However, there is currently no transparent, quantitative scenario analysis which allows a forward-looking assessment

43 Pahle et al. "Kosten des Ausbaus erneuerbarer Energien,"(2012).

44 Offshore wind farms will not be discussed here due to more uncertain cost estimates.

45 J.P. Molly, "Auslegung von Windturbinen und Speichern: Eine Frage der Systemoptimierung," DEWI Magazin, no. 40 (February 2012): 23-29.

46 Agora Energiewende, Optimierte Windenergieanlagen bieten Vorteile für das Stromsystem (2013).

of robust development paths. An analysis by DIW Berlin of the technological developments and cost structures shows that the European Commission's data basis does not take into account important recent developments and is to some extent, based on unrealistic assumptions. This data needs to be updated, made more transparent, and publically available. The costs of renewables are overestimated by the Commission; in contrast the costs and technical challenges, in particular, of nuclear power and the CCTS technology are systematically underestimated. This could lead to erroneous conclusions, as the future role of renewable energy sources is underestimated. The current cost estimates indicate that a stronger focus on renewable energy would be favorable.

Given the lower variable costs of production, renewable energy sources have a long-term strategic competitive advantage over conventional fossil power generation technologies which tend to have higher and rising fuel costs and are associated with CO_2 emissions. Although renewables still have higher investment costs than some conventional power generation technologies, in recent years, a significant decline in costs has been observed. Moreover, not only private electricity generation costs but the full costs, including social and environmental risk costs, should be taken into account when assessing thermal power generation. Given the high cost and high risk, the assumption that CCTS and nuclear power can play a leading role in the future energy mix of the European Union seems implausible.

It is a matter of urgency that the European Commission, in cooperation with the member countries, develops realistic scenarios based on updated cost assumptions, which can be used to derive energy policy targets and measures to be implemented at European and national level. Besides challenging emission reduction targets, Europe should set ambitious, binding targets on expanding the use of renewable energy sources and improving energy efficiency, for the period after 2020.

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