Dialogue on a RES policy framework for 2030

towards2030

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The role of nuclear power in the European Union

- Status quo, outlook and a critical review of planned support schemes

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About the project

The aim of **towards2030-*dialogue*** is to facilitate and guide the RES policy dialogue for the period towards 2030. This strategic initiative aims for an intense stakeholder dialogue that establishes a European vision of a joint future RES policy framework.

The dialogue process will be coupled with in-depth and continuous analysis of relevant topics that include RES in all energy sectors but with more detailed analyses for renewable electricity. The work will be based on results from the IEE project beyond 2020 (www.res-policy-beyond2020.eu), where policy pathways with different degrees of harmonisation have been analysed for the post 2020 period. **towards2030-*dialogue*** will directly build on these outcomes: complement, adapt and extend the assessment to the evolving policy process in Europe. The added value of **towards2030-*dialogue*** includes the analysis of alternative policy pathways for 2030, such as the (partial) opening of national support schemes, the clustering of regional support schemes as well as options to coordinate and align national schemes. Additionally, this project offers also an impact assessment of different target setting options for 2030, discussing advanced concepts for related effort sharing.

Who we are?

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This report

takes a closer look at the role of nuclear power in the European Union, summarising briefly the current status of deployment and future prospects. Moreover, costs and financial policy support for this low carbon generation option are compared and contrasted with renewable energies.

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1 Introduction

While there is a wide consensus about the needed reduction of greenhouse gas emissions, which once again was reconfirmed by the adoption of the '2030 Climate and Energy Policy Framework' in October 2014, the European Union is still divided on the appropriate technologies to reach that target. The 2030 target demands a 40% domestic reduction of greenhouse gas emissions until 2030 compared to 1990, which calls for a transformation of the existing energy sector in Europe.

Renewable energies (RE) and nuclear power are both classified as low carbon energy technologies, characterised by zero to low carbon emissions within their use. The question of whether to use renewables or nuclear power to achieve climate goals is highly controversial. When nuclear power was first used for electricity production it was accompanied by high expectations: there was a hope for a cheap, clean and safe technology which would produce enough energy for economic growth and avoid the need for smog-producing coal plants. Since that time major accidents such as Three Mile Island (USA) in 1978, Chernobyl (Ukraine) in 1986 and particularly Fukushima (Japan) in 2011, raised concerns regarding the safety of nuclear power and the still unsolved question of what to do with radioactive waste challenges the believe in its cleanness.

Recent experiences with the construction of new nuclear power plants (NPPs) in the EU (Flamanville 3 in France, and Olkiluoto 3 in Finland) and the controversy related to the planned financial support of nuclear power in the UK challenge the dogma of cheap energy. Both power plants, Flamanville and Olkiluoto, are suffering from delays of several years each, and a massive rise of construction costs (Schneider et al., 2014).

The aim of this brief report is:

1) To shed light on the status quo, the current role and the possible future development of nuclear power in Europe
2) To take a closer look at the cost of nuclear power. First, we will identify the different parts of the cost of nuclear power plants and give estimations for their current level. Afterwards we will compare these costs with the cost of renewable energies based on the levelized cost of electricity approach. Additionally, we take a closer look at policy costs and discuss implications – i.e. at the example of Hinkley Point C in the UK we compare and contrast the required financial support with renewables.
3) This paper ends with conclusions based on the findings of the previous chapters, discussing economic aspects of nuclear power in Europe.

2 Status quo and current developments in the nucle-ar power sector

2.1 European Union (EU28)

Despite all efforts of the European Member States in the field of renewable energies the majority of the European electricity still stems from conventional fossil fuels. As can be seen in Figure 1~~Figure 1~~ on the left side, nearly half of the total power supply in 2014 was produced in gas-, oil and coal- fired power plants. The second largest contributor to electricity supply was nuclear power (27.6%), and around one quarter of the EU's electricity was produced in wind parks, hydro power and photovoltaic plants. A closer look at total energy supply, specifically a balance of primary energy use as shown in the right side of Figure 1~~Figure 1~~, indicates that nuclear power accounts for a share of approximately 14% of gross inland energy consumption.

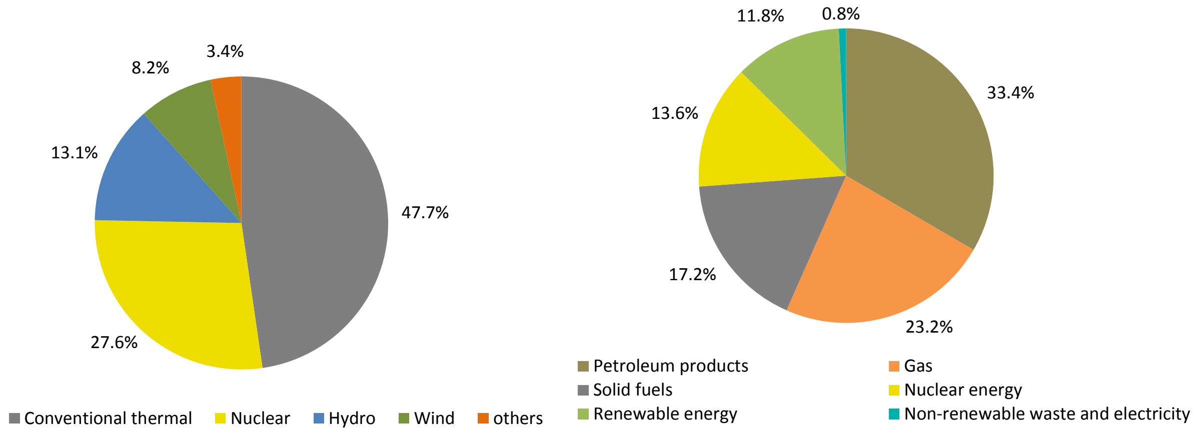


Figure 1: Breakdown of total electricity generation in 2014 (left) and gross inland consumption in 2013 (right) at EU28 level (Eurostat, 2015)

The above mentioned 28% share of nuclear power at EU level is produced by 130 operational power plants which are spread across Europe. According to Table 1~~Table 1~~ half of the EU Member States – i.e. 14 out of 28 – have nuclear power plants in operation. Among these countries significant differences are however applicable: the nuclear share in the domestic power production varies between 15.8% in Germany and 76.9% in France. Almost 50% of the total European nuclear power supply is produced in one country, namely France.

Table 1: Overview of existing and planned nuclear power plants, installed capacity and electricity production in European Union Member States (Source: WNA, 2015a)

Country	2014 nuclear generation		Reactors operable at June 2015		Reactors under construction at June 2015		Reactors planned at June 2015	
	TWh	% e	No.	MWe net	No.	MWe gross	No.	MWe gross
Belgium	32.1	47.5	7	5,943	0	0	0	0
Bulgaria	15	31.8	2	1,906	0	0	1	950
Czech Rep.	29	35.8	6	3,904	0	0	2	2,400
Finland	22.6	34.6	4	2,741	1	1,700	1	1,200
France	418	76.9	58	63,130	1	1,750	0	0
Germany	91.8	15.8	8	10,728	0	0	0	0
Hungary	14.8	53.6	4	1,889	0	0	2	2,400
Lithuania	0	0	0	0	0	0	1	1,350
Netherlands	3.9	4	1	485	0	0	0	0
Poland	0	0	0	0	0	0	6	6,000
Romania	10.8	18.5	2	1,310	0	0	2	1,440
Slovakia	14.4	56.8	4	1,816	2	942	0	0
Slovenia	6.1	37.2	1	696	0	0	0	0
Spain	54.9	20.4	7	7,002	0	0	0	0
Sweden	62.3	41.5	10	9,487	0	0	0	0
UK	57.9	17.2	16	9,373	0	0	4	6,680
EU	**833.6**	**~28%**	**130**	**120,410**	**4**	**4,392**	**19**	**22,420**

The outlook for the future development of nuclear power in the EU is quite diverse. The vast majority of the European nuclear reactors have been built before 1990 and the average reactor age is already 30 years (Schneider et al. 2014). Most existing reactors are licensed for a lifetime of 30 to 40 years, to reflect material ageing caused by the impact of neutron irradiation, high temperatures and pressure to the components. Thus, Figure 2 shows that without replacements or lifetime extension the number of nuclear power capacity will continuously decline. While today (2015) about 120 GW nuclear power plants are operable, a drop below 20 GW can be expected by 2043 if the technical lifetime is considered.

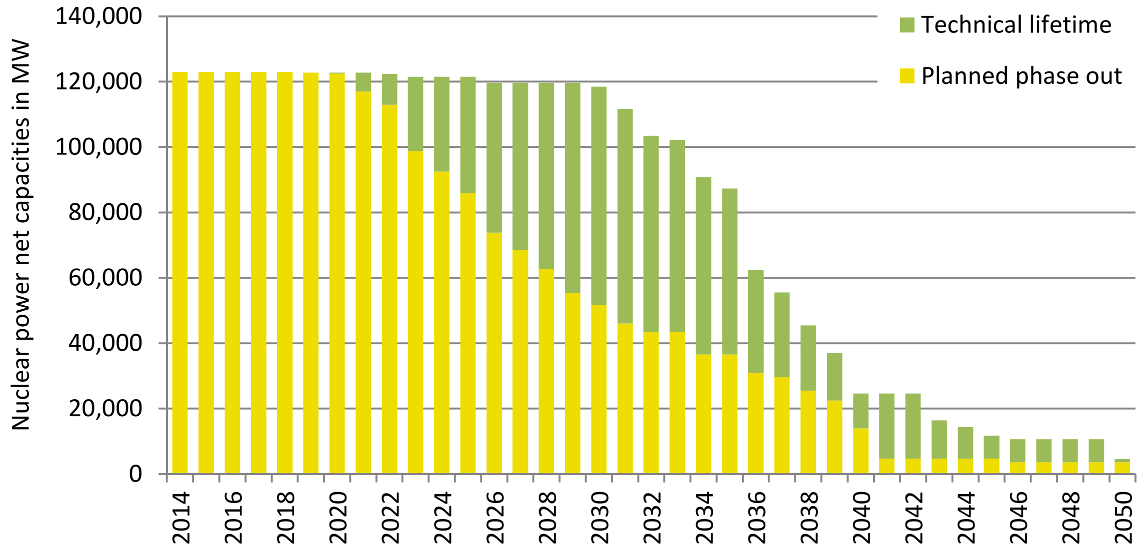


Figure 2: Development of the installed nuclear power capacity in EU 28 (Source: own depiction)

Figure 2 also shows, that, irrespective of their technical lifetime, some reactors are planned to be shut down earlier. This is especially the case in Germany. In Germany a political agreement on a nuclear phase-out was already taken in the year 2000 with a change of the Atomic Law. The so-called “nuclear consensus” included the prohibition of nuclear new-build, the limitation of the lifetime of operating NPPs and the amount of electric energy they were allowed to produce. In this period, three units were shutdown permanently until 2005. In 2010, after political changes, lifetime extensions of several years for the German NPPs were decided upon. Shortly after that, in 2011, the severe accident in Fukushima happened and forced the German Government to recall (and strengthen) their original plans of phasing out nuclear power. Of the remaining 17 reactors, the oldest and most unsafe eight reactor units were shut-down immediately. Also the Atomic Law was changed again: For the remaining nine reactors, shutdown dates until 2022 were fixed.

On the other hand, there are ten countries within the EU that are currently constructing or planning new nuclear power reactors. Two of those countries, Lithuania and Poland, do not have any nuclear reactors installed until now. Since most of these plans are kind of vague, these numbers are not yet included in Figure 2. In the following paragraphs four selected countries and their current constructions or plans for new reactors will be examined in further detail.

2.2 France

Nuclear power plays a central role in the French energy and economic system. After the first oil shock in the beginning of the 1970s the French government decided to rapidly expand and invest in nuclear power capacity. By today, France owns 58 operating nuclear reactors with a total installed capacity of 63.2 GW and has the highest share of nuclear power, approximately three quarters, in its electricity mix within the European Union. The last reactors that went into operation were Civaux 1 and2 in the years 1999 and 2000. France also owns the majority of the world’s largest nuclear company Areva, which developed an advanced 3rd generation pressurized water nuclear reactor (EPR).

In 2014 the French government passed the “Energy Transition for Green Growth” bill, which set a target of 50% for nuclear electricity production by 2025 and a target of 32% renewable share in the final energy consumption by 2030. The 50% nuclear share target for 2025 sets a capacity cap for installed nuclear power at the present level of 63.2 GWe. This also means that some existing capacities have to be shut down before new reactors can start their operation. (WNA, 2015d)

Already in 2006, the board of the French national nuclear company EDF approved the construction of a new European Pressurized Water Reactor (EPR) with a capacity of 1,650 MW at Flamanville. The initial cost estimation for the overnight construction costs was € 3.3 billion and the scheduled start of operation was in May 2012, which equalled a construction time of 54 months (Schneider et al., 2010). After the construction start in December 2007, the initial cost estimation had to be revised several times and was changed to € 4 billion in 2008, to €5 billion in July 2010, to € 6 billion in 2011, to € 8.5 billion in December 2012 and, finally, to € 10.5 billion in September 2015. The expected date for the start of operation was postponed synchronously with the increasing cost estimations and in September 2015, it was moved to the end of 2018 (WNA, 2015d).

2.3 Finland

Finland built four nuclear power reactors between 1977 and 1980 with a total installed capacity of over 2.7 GW and they are providing about one third of the final electricity consumption. The Finish reactors were upgraded several times and their lifetime has been extended to 50 and 60 years, respectively, even though their originally planned lifetime was only 30 years. Finland has a very high per capita electricity consumption and comparatively limited electricity generation capacities which leads to a high dependency on electricity imports. In 2012 Finland imported almost 20% of its electricity consumption, mainly from Sweden and Russia (WNA, 2015e).

In 2002 the Finish parliament approved to construction of a fifth nuclear reactor and in October 2003 it was decided that this reactor should be built at the Olkiluoto site, at which two reactors were already in operation. Due to this fact, the new reactor was given the name “Olkiluoto 3”. The Finish nuclear power company TVO, who already owned and operated the first two nuclear reactors at the Olkiluoto site, signed a contract with the French company Areva for the construction of an EPR with a capacity of 1600 MW in December 2003. It was the first nuclear reactor which has been ordered by a European country since 15 years and it was first EPR, which was ever constructed. The contract was a turnkey contract and the prize was € 3.2 billion. The construction started in 2005 and the commercial operation was expected to start in 2009, but, similar to the construction of the Flamanville EPR, severe delays led to a deferral of the start. The latest announcement regarding the start of the commercial operation was 2018, which would be 9 years after the originally planned date. The total costs are now estimated to be about € 8.5 billion, which would be approximately three times the originally contracted turnkey prize.

In July 2010 the Finish parliament agreed on the permit for construction of another reactor at the Olkiluoto site, “Olkiluoto 4”, but in 2014, this permit expired and was not renewed by the parliament. In January 2015, Jarmo Tanhua, CEO of TVO announced that *“The competitiveness of the electricity produced in Olkiluoto has declined during the recent years and the outlook of the future is uncertain. Electricity market price has dropped and there are no signs of improvement in the foreseeable future. In addition, costs related to nuclear power production have increased and the delay of Olkiluoto 3 project has caused remarkable additional costs. In order to improve the competitiveness of Olkiluoto electricity production we need to start these regrettable measures”.*

2.4 United Kingdom

The first NPP in the UK went into operation in 1956, two years after the first NPP worldwide in the former Soviet Union. As of today, the UK operates 16 units located at nine sites. The oldest of the operating reactors was put into operation in 1971 (with a planned shutdown at the end of 2015). The other fifteen NPP units were originally planned for shutdown in the next ten years, but lifetime extension will possibly keep most of them in operation for 5-10 more years. For the newest reactor of the UK fleet, Sizewell B (1995), a lifetime extension of even 20 years is planned (WNA, 2015b).

For replacement of the old NPP-fleet, four new-builds are planned. For two of the planned reactors (Hinkley Point C 1&2), the Environmental Impact Assessment procedure is already completed and state aids have been concluded by the European Commission. The NNB Generation Company Limited (NNBG), part of EDF Energy, plans to construct and operate a new nuclear power plant (NPP) at the Hinkley Point NPP site (Hinkley Point C 1&2). The NPP would comprise two European Pressurized Water Reactors (EPR) with an electrical capacity of around 1,630 MWe per unit, producing a total of 26 TWh per year during its 60 years of operational lifetime. If constructed, Hinkley Point C would be the UK’s first new reactor since 1989.

The construction costs of Hinkley Point C were first estimated to be close to € 19 billion (EDF, 2013), but were corrected by the EC to € 31.2 billion, and overall capital costs are assumed to be € 43 billion (EC, 2014). To cover such enormous investments, EDF has undergone time-consuming negotiations with the UK government and they reached an agreement for a contract for difference. European regulations allow member States to determine their energy mix within their national competence. However, when public money is spent to support companies, the European Commission must verify that this is done in accordance EU rules on state aid. Therefore the UK’s support scheme was investigated in 2013. During this investigation, the UK was required to modify the terms of the project financing. In October 2014, the European Commission concluded that “the modified UK measures for Hinkley Point nuclear power plant are compatible with EU rules” (EC, 2014).

The state aid, which is granted by the UK government, is essentially a contract for difference, which is analogous to the feed-in tariffs commonly used in Europe to support renewable energies. The duration of this contract is 35 years and the strike price for the first unit (reactor) will be € 108 per MWh, which will be index adjusted over time. Additionally, the operator NNBG will be granted a state loan guarantee for loans the company needs for the construction of the nuclear power plant.

In October 2015, EDF said, that *"it had turned down the offer of up to £16bn of UK government loan guarantees and had decided to fund its £12bn share of the project by borrowing in the market because it was likely to be cheaper".* At the same time EDF also announced, that they have sold a 33.5% stake of the Hinkley Point project to the Chinese state-owned company China General Nuclear Power (The Guardian, 2015).

2.5 Hungary

The history of nuclear power in Hungary is much younger than in the UK. In 1982 Hungary put its first commercial reactor into operation at the Paks site and three other reactors followed at the same site until 1987. As of today, those 4 reactors, all of the Russian VVEER-440/V-213 type, do have a total installed capacity of close to 1,900 MW and produced approximately half of the domestic electricity production in 2014. The four reactors had a designed technical lifetime of 30 years, which means they would have reached the end of their lifetime between 2012 und 2017, but in November 2005 the Hungarian Parliament supported a 20-year lifetime extension for all reactors at the Paks site.

The National Energy Strategy, published in 2011, envisioned a diversified electricity mix consisting of coal, gas, nuclear and renewable power generation as well, foreseeing about 2,000 MW new nuclear capacity by 2030. In March 2009 the Hungarian Parliament gave the preliminary approval for two new 1,000 MW nuclear units at the Paks site. Contrary to the original plan of tendering the construction of those reactors, in 2014 the government signed an agreement with the Russian company Rosatom to build two AES2006/VVER-1200 reactors. Each reactor is planned with a capacity of 1,200 MW each at cost of € 12 billion. Part of the deal was that Russian would finance around 80% of the total investment costs. The repayment period is planned to be 21 years and the interest is below 4% for 11 years and below 5% afterwards. The expected construction start is in 2018 and the first reactor is expected to start its operation in 2023 (WNA, 2015c).

3 Comparison of cost and support schemes of renewable and nuclear power generation

In chapter 2 various plans on new nuclear power plants of European Member States are explained. It can be seen that there is a wide range of different specific cost estimations as well as a significant discrepancy between the originally planned / expected cost and the actual cost. In order to shed more light on these differences and discrepancies the following chapter will elaborate on selected cost elements of a nuclear power plant.

Discussing the cost of nuclear power is a difficult and controversial task, as it depends on several factors and assumptions like the location of the plant, the used discount rate, the future utilisation rate (full load hours) of a plant and the internalization of external costs. This chapter will focus on the different components of the total costs and corresponding assumptions, the evolution of these components and the comparison with alternative low-carbon generation technologies – i.e. renewable energy technologies. The cost comparison will be based on an intensive literature review and will be performed following the concept of "levelized costs of electricity (LCOE)".

3.1 Cost elements of a nuclear power plant

Overnight costs

Nuclear power plants are characterized by relatively high capital cost and long construction times. Different power plant types and even nuclear power plants of a similar concept but at different sites are subject to strong differences concerning their construction time. These differences in construction time affect the capital cost. In order to make the pure construction cost, which is the main driver for the specific nuclear generation cost, comparable we will use the concept of overnight cost. The overnight cost assumes that a project will be completed in an instant and spending on material, labour and machines will be calculated based on the price in force when construction start.

The overnight construction is depending on the country and on the generation type of a nuclear power plant, thus overnight construction cost can only be estimated in ranges. Looking at chapter 2.2 and 2.3 we see that the original estimation for the overnight construction of a nuclear power plant of the EPR type in Finland and in France were at approximately at 1,500 €/kW. These estimations (in 2003 and 2006, respectively) were too optimistic and had to be revised several times. Since both plants are still not put into commercial operations we will use the latest estimations, which would translate into specific overnight cost of 6,360 €/kW for Flamanville 3 and 5,310 €/kW for Olkiluoto 3. These costs may not be representative since these two power plants are the first EPR constructions worldwide, and the latest number may already include cost of capital caused by the extended construction time. Thus, consequently we have also screened through relevant literature to verify these numbers.

The *German Institute for Economic Research (DIW)* performed an extensive literature review and suggested that a range of 4,000-5,000 €/kW is plausible for the overnight construction cost of a third generation nuclear power plant (like the EPR type in Flamanville and Olkiluoto) in Europe (Schröder et al., 2013). The *International Energy Agency* published a comprehensive report about electricity generation costs based on real life projects and states a range of 4,896-6,215 $/kW for nuclear power plant projects in Europe (IEA, 2015).

As initially mentioned, the overnight costs vary geographically, due to differences in the cost of labour, working rules and materials but also due to differences in regulatory frameworks. The IEA demonstrates this fact as it also shows numbers for Korea, China and the United States. According to these numbers, the overnight cost are between 1,807 and 2,615 $/kW in China and Korea, which means less than half of the European range.

For the United States, the IEA report indicates overnight cost of 4,100 $/kW. This indication is slightly lower than numbers recently published by the *U.S. Energy Information Administration (EIA).* The EIA reported an estimated range for an advanced nuclear reactor from 4,646 $/kW to 5,366 $/kW. The higher value already includes a contingency factor for specific provisions related to unforeseeable elements of costs within a defined project scope. Additionally, a technological optimism factor is considered, which is applied to the first four units of a new, unproven design, reflecting the demonstrated tendency to underestimate actual costs for a first-of-a-kind unit (EIA, 2015).

Additionally, we have found one reference from the private sector, which comes from the US based financial advisory and asset management firm *Lazard. Lazard* published a range of 5,385 to 7,591 $/kW for a current U.S. new nuclear construction (Lazard, 2014).

Financing cost

The financing cost depends on how long it takes to build a plant, but also on the the rate of interest on debt and the debt-equity ratio. In contrast to (most) renewables nuclear power plants do have significantly longer construction times. The construction of modern reactors is planned to last for five to ten years, and, thus, the overnight construction cost is spread over several years and must be discounted. The rate of interest on debt and the debt-equity ratio results in the choice of the discount rate and a company from the private sector may choose a discount rate between 5% and 10%. This would imply, that with construction lasting six years and using a 5% discount rate, the overnight construction cost must be multiplied by 1.16 and, using a 10% discount rate, by 1.31 (Lévêque, 2015).

Construction times vary geographically, similarly like overnight costs. In Japan in the 1990s and in South Korea reactors were built and put into operation in a little over 4 years (WNA, 2015f), but looking at the case studies of Flamanville 3 and Olkiluoto 3 these numbers seem too optimistic for Europe. According to the currently planned starts of operation, the actual construction time for Flamanville 3 would be 10 years and 12 years for Olkiluoto 3.

Operating costs

Operating costs can be divided into front-end and back-end fuel cycle costs. Front-end fuel cycle costs describe the all costs that occur until the fuel is used in the power plant and include uranium mining and milling, conversion, enrichment and fuel fabrication. Back-end fuel cycle costs, which are counted from the point after the spent fuel is unloaded from the reactor, may refer to one of two options: direct disposal/storage recycling. The International Energy Agency estimates front-end fuel costs to be at 7 €/MWh and the back-end fuel costs to bet at 2.33€/MWh (IEA, 2015).

Decommissioning costs

All sources of literature do agree that, even though cost for decommissioning is relatively high in nominal terms compared to other conventional power plants (15% vs 5% of the initial capital cost), it only plays a minor role in the total electricity generating cost. This is due to the long lifetime of nuclear power plants, which would be up to 60 years for third generation reactors, and the impact of discounting. The cost for decommissioning will occur at the end of the of operation of a reactor and even under the assumption of a low discount rate of 3% the net present value of the decommissioning cost is close to zero (WNA, 2015f; Lévêque, 2015; IEA, 2015).

3.2 Comparison of LCOEs for nuclear power and renewable energies

In chapter 3.1 different cost components of a nuclear power plant have been explained and valued. Comparing the total electricity generation cost of different technologies is at first sight a complex task due to differences in the technical life time, the full hours and the proportion between investment and operating costs. The assumption regarding the technical lifetime of a new nuclear power plant is 60 years, whereas a modern PV-plant or wind park is expected to operate for 25 years.

We use the common concept of “levelized cost of electricity (LCOE)”, which presents a method to put electricity generation from different sources on a comparable basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total power output of the asset over that lifetime.

The comparison of the LCOEs for nuclear and renewable power plants is to a large extent based on a recent report published by the International Energy Agency called “Projected cost of generating electricity” (IEA, 2015). As mentioned earlier, this report builds on actual real world power plant projects and the respective expected cost of commissioning these plants in 2020.

In chapter 3.1 we have discussed the relatively wide range of overnight cost and capital cost, as well as the influence of the chosen discount rate for nuclear power plant projects. Furthermore, for calculating the LCOEs one has to make assumptions regarding the utilisation of a power plant, which would be expressed in the full load hours. Those differences can lead to a wide range of LCOE, which make a comparison very vague. Lévêque (2015) demonstrates this problem with the example of 29 $/MWh for South Korea using a 5% discount rate, and 136.5 $/MWh for Switzerland using a 10% discount rate. The IEA (2015) report also shows a wide variety of different scenarios, using discount rates of 3%, 7% and 10% and load factors of 50% and 85%. To reduce the complexity we will focus on the LCOE scenario with a capacity factor of 85% and a discount rate of 7%.

Figure 3 below shows the ranges and the mean LCOEs of currently developed power plant projects across Europe, differentiated by generation technology. It is important to note, that the range of PV is relatively wide, as it contains several types of power plant like residential rooftop, commercial rooftop and large, ground mounted plants. The range of LCOEs for wind onshore and offshore is largely reflecting the different quality of deployment sites. It is interesting to see, that, at the best sites, onshore wind and PV can compete with nuclear power plants, whereas the LCOEs of wind offshore and PV are still significantly above the LCOEs of nuclear power.

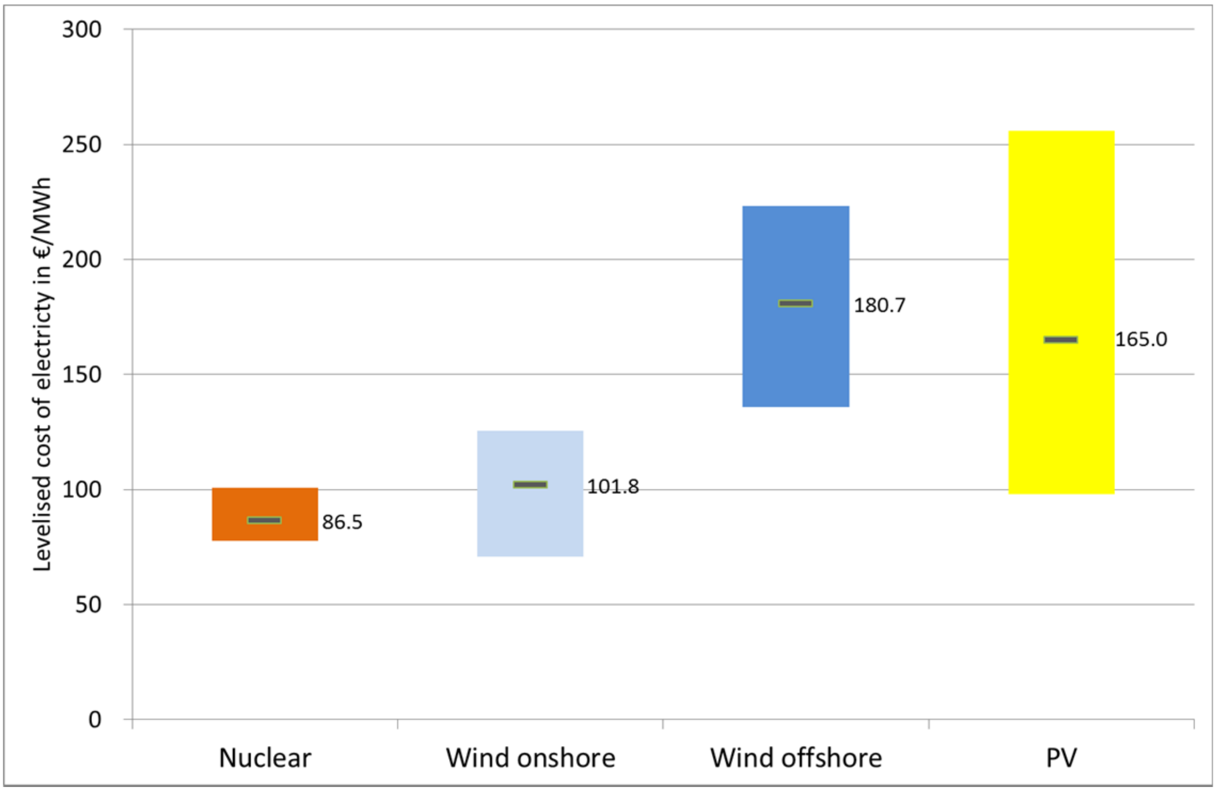


Figure 3: Range and mean LCOEs of current European power plant projects (IEA, 2015)

Historic development and expected trends of nuclear power and renewable cost

The concept of technological learning, which implies that an increase in production leads to a decrease in production costs, is common and widely used. In theory two causes are identified for this trend: the scale effect and the learning effect. The scale effect implies that the bigger a factory and the higher the production of a certain good, the less is the cost of each unit produced. The learning effect is based on the idea that with increasing production of a certain good the knowhow about the production increases and again, the cost per unit decreases. These effects have been analysed and empirically tested for renewable energies. Lindman et al. (2012) have shown that the cost of electricity produced by wind turbines drops by about 10% each time the installed capacity doubles. A similar trend could be observed for photovoltaics where learning rates of about 20% are reported in various studies, see e.g. Schaeffer et al., 2004. In Germany, the cost of PV modules dropped by about 80% between 2006 and 2013 (EuPD Research, 2013).

Nuclear power technology shows the opposite trend. This surprising trend has been studied in details for the US market. Lévêque (2015) mentions that the specific overnight cost in France rose from € 860 per kW for the first four reactors in Fessenheim and Bugey in the 1970s to approximately € 1,440 per kW for the last four reactors in Chooz and Civaux, that went into operation in the early 2000s (in Euros 2010). As we have explained in chapter 2.2 this trend has continued with the exploding cost of the reactor Flamanville 3.

Lévêque (2015) also tries to analyse the reasons for this trend. The first reason he identified is the missing economies of scale. The reason behind this is that nuclear reactors are hardly standardized and get often adapted to different regions and their regulatory framework. Another reason is that the increasing size of reactors leads to increasing construction times. So, even though the specific cost for a bigger reactor might decrease this decrease might be evened out due to the increase in cost of capital.

Lévêque (2015) also challenges the existence of significant learning effects. The major reason behind this was the change of regulations, especially safety regulations. In the US, the Nuclear Regulatory Commission (NRC) is responsible for the regulation of nuclear power plants and they published new standards, rules and measures each and every year. US economists estimate that this frequent changes in regulations led to a 10% to 25% annual increase in construction costs. Additionally, he also identified a failure of the US nuclear industry in industrial organization. The sector was divided into a large number of utilities, which built only small numbers of reactors and missed out on necessary standardization processes. Research has shown that similar reasons could be identified for the French nuclear industry. Large scale of construction projects, the relatively small numbers of projects, the adaptation to different sites and missing standardization led to a steep escalation in cost (Grubler, 2010).

Until further evidence for a different development it can be assumed, that the cost for renewable energies will continue to drop, while the nuclear energy industry still has to prove that cost reduction can be achieved.

3.3 Comparison of support schemes for nuclear power and renewable energies

Mraz et al. (2014) compare the financial support for nuclear power and renewables in several European countries. The basic idea of that report is to compare existing support schemes for renewables with the recent state aid case for the construction of the nuclear power plant Hinkley Point (see chapter 2.4) in the UK.

Two different approaches are taken in the comparative exercise. The first approach, called the static approach compares the current (as of 2013) level of incentives for renewables with the planned support mechanism for Hinkley Point. The focus lies on the amounts of electricity that can be produced with the same amount of public support. The second approach, called the dynamic approach, also considers additional factors including the cost of renewables today and in future, considering expected cost reductions due to technological learning as well as (the lower) market values of variable renewables like solar and wind power. The dynamic approach builds on modelling works, using scenarios that look up to 2050. Both comparative exercises are performed for five European Member States and the EU 28 at large.

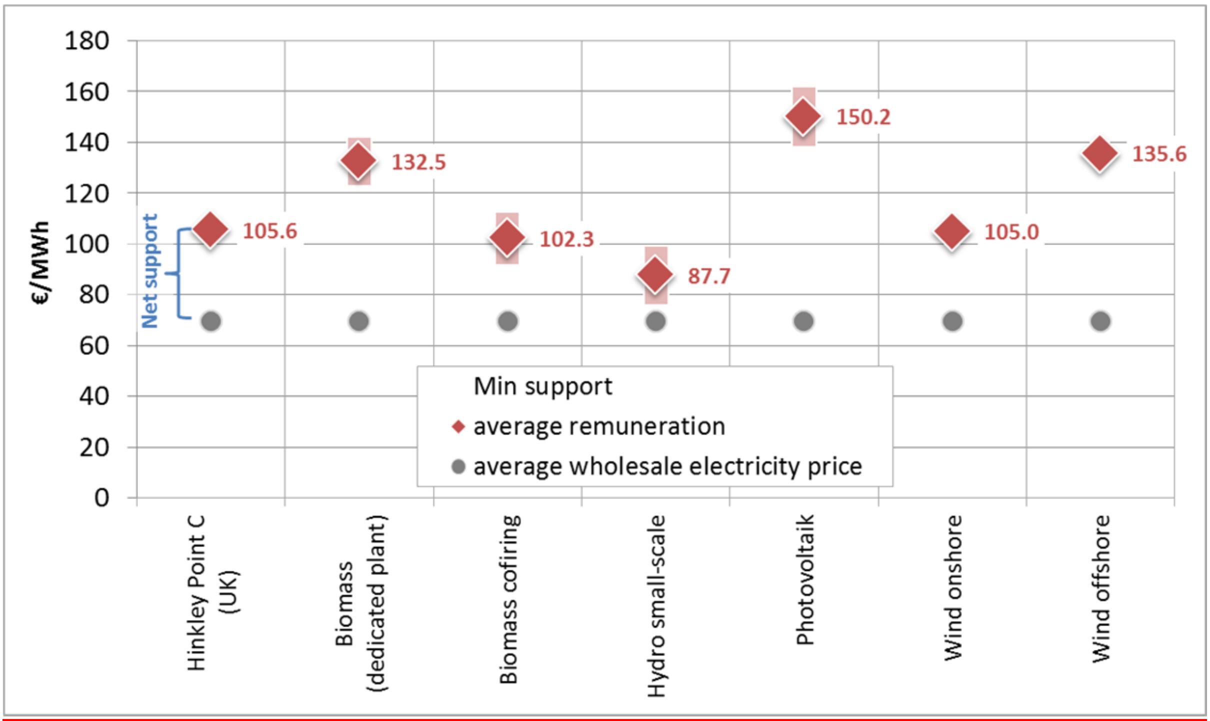
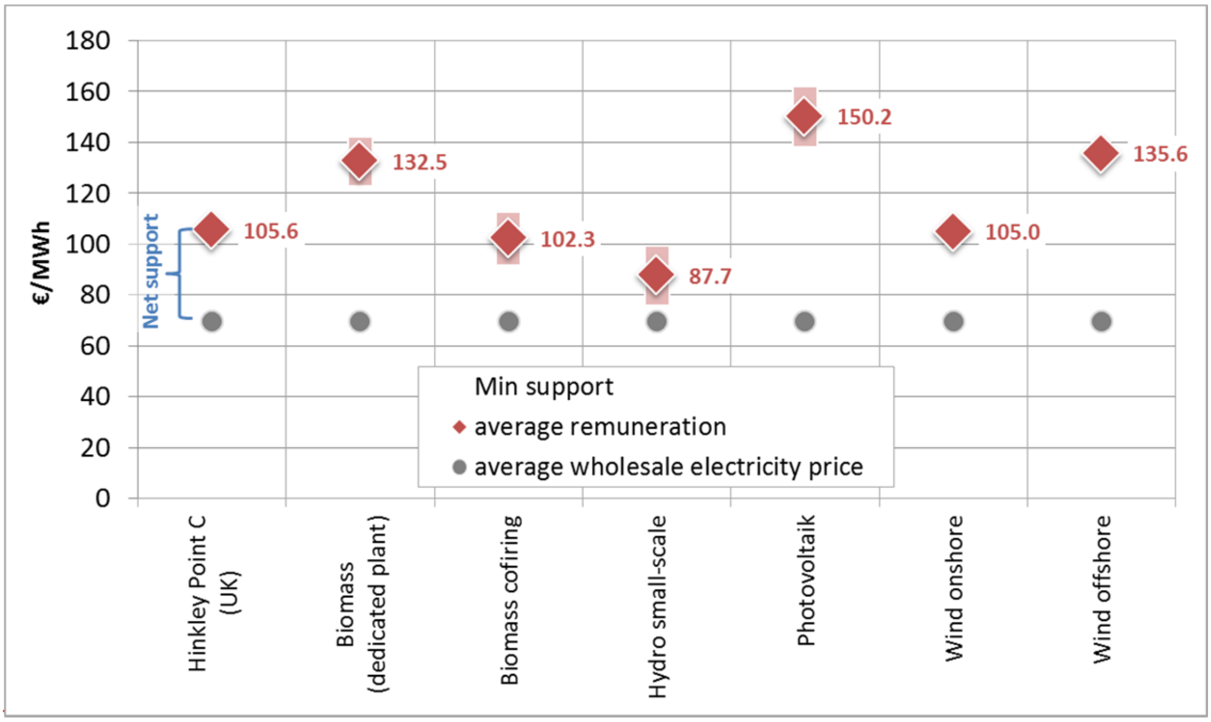


Figure 4



~~Figure 4~~ shows a result of the static approach, comparing existing support schemes for renewable energies in the UK with the contract for difference that shall be granted for the new nuclear build-up at Hinkley Point C. As can be seen in the graph, in the UK the remuneration level for hydro-small scale, wind onshore and biomass cofiring is lower than the strike price of Hinkley Point C. This implies that, given that there is enough potential for those three technologies, it would require less net support for hydro-small scale, wind onshore and/or biomass cofiring to produce the same amount of electricity that would be produced by Hinkley Point C.

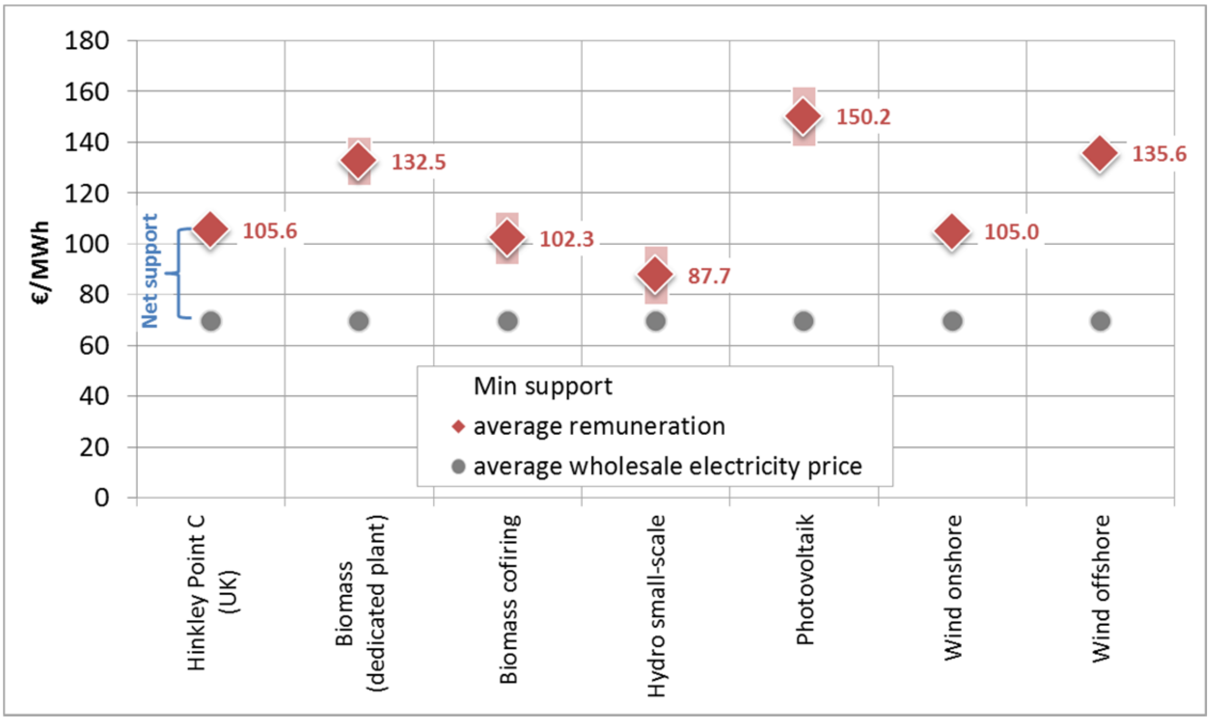


Figure 4: Comparison of support scheme of Hinkley Point C and support schemes for renewables in the UK (Source: Mraz et al., 2014)

Furthermore, the report shows, that *"in the five countries examined, under the same budgetary conditions it is almost always possible to generate more electricity from renewable sources than from nuclear power".* Consistent with the assessment in chapter 3.2, this report also identifies wind onshore (and hydro power as well) as the least expensive renewable options to generate electricity. The report also states, that following a static approach *"Potential savings achieved by generating a set quantity of electricity from renewables rather than nuclear power range from 2% (Great Britain) to 63% (France) for onshore wind parks, and from 31% (Poland) to 51% (France) for small hydro power plants."*

The results of the dynamic approach show an even bigger potential for cost savings using renewable energies instead of nuclear power. Even though the dynamic approach also considers the decreasing market value of renewables (due to the increasing penetration of the electricity market by renewables) the remuneration needed for renewables is lower than for nuclear power, due to the impact of technological learning on the cost of renewable electricity deployment.

Figure 5 shows the range of cost savings that can be reached by deploying renewables instead of nuclear power. For the UK, which is the most relevant comparison, the cost savings would be slightly above eight percent, but within the assessed countries this number was the lower limit. The most extreme examples would be Poland and Czech Republic that could produce the same amount of electricity as Hinkley Point C with a quarter or a half of the costs respectively, due to large and cheap potentials of biomass and on shore wind power. The report finally concludes that for each analysed country and for the EU at large it is more expensive to produce electricity using nuclear power than using renewables.

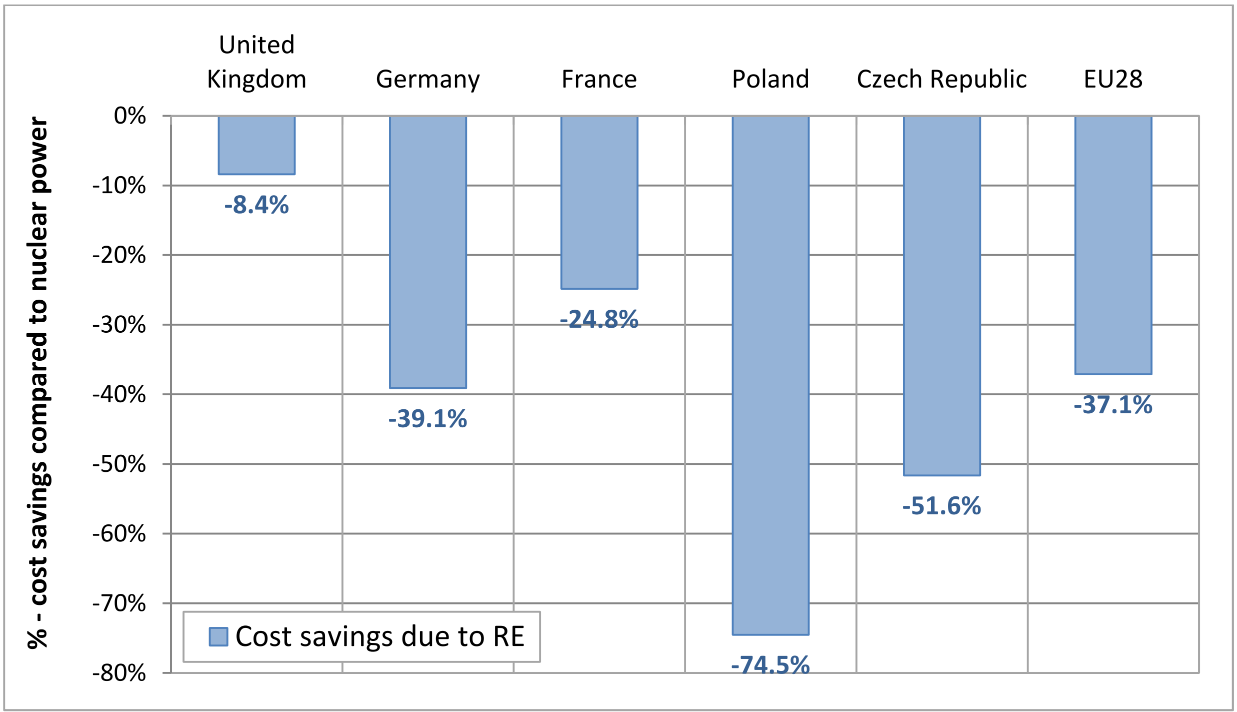


Figure 5: Comparison of potential cost savings due to renewable energies compared to nuclear power (Source: Mraz et al., 2014)

4 Conclusions

As of today, nuclear power plays a significant role in the European power system and provides more than one quarter of the EU's electricity supply and accounts for approximately one eight of the EU's gross inland energy consumption. However, uncertainty remains if it will keep the same role in the future. Despite plans of many European countries to develop and build new reactors it appears unlikely, that they can compensate the shutdown of old reactors, which reach the end of their life time, and the politically decided phase out of nuclear power in Germany. Lifetime extension of old reactors, which are very common in Europe, can postpone this development, but without further investments in new reactors the proportion of nuclear power in the European energy mix will diminish.

From an economic point of view it has to be questioned if a nuclear replacement of these reactors is reasonable. The nimbus of nuclear power being a cheap source of energy has, at least in Europe, severely been threatened by massive cost increases of the currently constructed power plants in Flamanville and Olkiluoto. Over the last two decades nuclear power and renewable energies have faced opposite developments in the total electricity generation cost. While renewable technologies have seen a steady decline in electricity generation cost due to technological learning and the fast deployment all over the globe, nuclear power has experienced the opposite. Ever increasing security standards and a missing standardization of power plants, as well as extensive delays of construction periods, led to increasing cost. Already today some renewable technologies, especially solar PV, biomass and onshore wind power, can compete with nuclear power on a cost level in all European countries. This fact was underlined with the publication of the support scheme for Hinkley Point C, which is more expensive than comparable support schemes for certain renewable technologies.

Another advantage of those technologies is their comparatively short construction time. The enormous number of new installations of solar PV plants and onshore wind farms over the last two decades led to a knowhow gain and standardized construction processes. Nowadays, the average construction time of solar PV plants and onshore wind farms is around one year (IEA, 2015). These short construction times and the small, modular character of renewable energies allows for a flexible, quick adaptation to a changing power demand and a manageable project risk.

Finally, it has to be questioned if nuclear power fits to the existing climate and energy targets of the EU. In October 2014 the European Commission published the '2030 Climate and Energy Policy Framework' which contains beside a target of a 40% domestic reduction of greenhouse gas emissions until 2030 compared to 1990 an additional target regarding renewables. Until 2030 a 27% share of renewable energies in gross final energy demand shall be reached (European Council, 2014), which implies an even higher target for renewables in the electricity sector: according to recent studies (e.g. (Knopf et al., 2015) a renewables share in electricity demand of about 50% corresponds to the overall 2030 RES target. Even though nuclear power is able to contribute to the decarbonisation of the electricity sector, it is not an appropriate complimentary technology for an electricity system that builds massively on renewables. The variable nature of renewable energies demands for complimentary technologies that are dispatchable and can ramp up and down relatively quickly in order to balance generation and demand at any given moment. Nuclear power plants in particular are considered as base load units and do not easily ramp up and down instantaneously.

Given the fact that, despite the downward trend of the overall risk of nuclear power, a disastrous event cannot be completely excluded and the yet still open question about the final radioactive waste storage, a recommendation for nuclear power can only be made if it offers significant economic benefits over alternative technologies. This appears doubtful unless the current direction of the cost development of nuclear power and renewable energies changes.

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