COSTS AND FINANCING
OF DECOMMISSIONING AND NUCLEAR WASTE MANAGEMENT

WITH SPECIAL FOCUS ON GERMANY, FRANCE AND SWITZERLAND

COMMISSIONED BY THE GREENS/EFA GROUP IN THE EUROPEAN PARLIAMENT

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1. Costs and Financing

Due to its high capital intensity and long-term nature, reactor decommissioning and especially radioactive waste management are intimately related to financial issues. There are many different approaches to provide the financing of both processes in the 31 countries employing nuclear power for electricity generation. The goal of this chapter is to provide first an overview of the different funding systems in place for financing decommissioning of the reactors, (intermediate) storage, and final disposal. In a second step, the cost estimates for these processes and when, possible, realized costs are given. As all of the European countries have signed the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the first legal instrument to address the issue of spent fuel and radioactive waste management safety on a global scale. They are obliged to provide adequate financial resources for decommissioning (Article 26), spent fuel and radioactive waste management (Article 22). However, the scope of and the ways how financial resources are accumulated, secured, and managed vary between different countries. Nonetheless, every country faces more or less the same challenges, e.g., risk of insufficient or not available financial resources to cover the costs, underperformance of the funded resources, financial problems or a possible bankruptcy of the operator that could lead to the total or partial loss of already accumulated funded resources, and foremost the risk that the future costs are underestimated.

2. Funding Systems

2.1 Nature of the funds

The most comprehensive study on the different decommissioning and waste management funds methodoliges for nuclear installations was done on behalf of the European Commission by Wuppertal Institut, et al. (2007), the definitions used in that report, were mainly based on definitions used by the European Commission for financing decommissioning and waste liabiliites.

The liability for decommissioning and waste disposal can be *private* or *public*. In the latter case a public entity or state-governed organization is responsible for the funding, while in the former the organization is owned by private entities. The mangamement of the funds can be, from the view point of the operator, *external* or *internal* to the operator's accounts. An external fund is not managed by the operators and can exist with or without transfer of the liabilities, and with or without ashort-fall guarantee by the operator. The fund can be *restricted*, the liable organization is not fully free in using the accumulated money, this means there are legal requirements beyond standard accounting principles. Possbile restricitions can be imposed with respect to the accumulation, management, and investment of the funds; restrictions can be imposed on internal or external funds. On possible restriction can be segregation, decommissioning and waste management funds are identified separately (Wuppertal Institut 2007, 8–10).

Four primary approaches for accumulation and management of financial resources are observable (Wuppertal Institut 2007; OECD/NEA 2016b):

- Public budget: State authorities take over the responsibility and with that the accumulation of financial resources (e.g. via taxes or levy). This option is typically used for legacy NPP fleets or orphan sites. Beside the high costs for the taxpayers, also problems with competition policies of the EU could arise, as the financial support for the operators by the individual government could be seen as a forbidden subsidy (OECD/NEA 2016b, 125–26).

- Internal unrestricted fund: The operator of a nuclear facility, usually a private company, is obliged to form and manage funds autonomously. Here, the operator manages the financial resources, which are held within their own accounts as reserves and discloses the accumulated reserves as liabilities on its balance sheet. It is not required that the assets are segregated from other businesses or earmarked for decommissioning and waste management purposes. In the case of insolvency, the bill falls to the taxpayer.
- Internal restricted fund: The operator feeds a self-administrated fund, which is segregated from the other businesses; e.g. in France, Japan, and Canada. The funds are earmarked for decommissioning and waste management purposes and investment restricitons are imposed.
- External restricted fund: The operators pay their financial obligation into an external fund. Here, private or state owned external independent bodies manage the funds, e.g. centralized funds for the whole industry or decentralized for each operator.

Arguable advantages of the external management are a higher degree of transparency, the protection against the shortfall of financial resources caused by the bankruptcy of operators, and an improved public confidence. Restricited fund management can also be done internally; however, this approach also faces a lack of control and cannot protect the funds against shortfall in a sufficient manner (see the case of EDF). Especially, before the background of the very long timeframes, the aim of any management strategy should be to match the full costs of decommissioning and storage and to ensure the availability of the financial resources at the time when they are needed. The International Atomic Energy Agency (IAEA) as well as the Nuclear Energy Agency fo the OECD (NEA) formulated detailed minimum criteria for financing of the nuclear back-end in decommissioning fund:

- The operators or licensees of nuclear facilities have to pay contributions to the fund during the time of operation to ensure sufficient funds at the time of final shutdown.
- The funds need to be accumulated in line with the estimated operation time of the facilities, the time schedule and the chosen decommissioning and waste management strategy.
- There has to be a periodically management and review of the fund to ensure liquid financial resources compatible with the timetable of the nuclear back-end activities and its costs. The funds only purpose should be the coverage of the nuclear back-end costs.[1]

[1] This is for example not the case in Japan, where money from the funds can be deinvesteed (e.g. in Japan an issue for the decommissioning process is that under the ministry's guidelines,

Both agencies even argue, that there have to be legal and administrative remedies for national authorities if the responsible operators do not meet the minimum criteria of decommissioning funds (OECD/NEA 2016b, 119).
As funding became an important factor for implementation of new nuclear power plants, it became evident that both government-owned and private utilities in some countries were treating these funds as a source of monies for new development, operating costs, and collateral for loans (LaGuardia and Murphy 2012, 55). Control mechanisms needed to be installed to make sure these funds meet basic requirements of sufficiency, transparency, and assurance. For the costs of financing a conflict of interest arises between the operator and the regulator. The former will typically prefer riskier investment strategies with higher rates of return, while the latter will typically prefer a more secure investment strategy with lower return rates. There are many conceivable situations when funds are not able to meet the nuclear back-end costs. Insufficiency or unavailability could be caused for example by unplanned earlier shutdowns of reactors or a change of the ownership. To provide protection against these kinds of problems a supplementary alternative financing system could be established by the utilities i.e. by insurance policies, bank guarantees or the obligation to pay additional contributions by the operator.

2.2 Scope of the funding systems

These main funding systems can be applied to the processes of decommissioning, storage, and disposal. Looking at the different national decommissioning and waste management policies in place, it is not always clear, what decommissioning includes. Radioactive waste management is an important part of decommissioning, the same applies for spent fuel management. In short, the *scope* of the funds is not always clear, which is one of the many reasons why it is so difficult to compare costs among different countries. For example, the United States of America includes low-level waste management as part of decommissioning to be funded by decommissioning money, the same for storing spent nuclear fuel until it can be handed over to the Depratment of Energy for disposal (Album, Braend, and Johnson 2017). epositing. In Germany however, the utlitiies are only responsible for paying with their decommissioning funds the conditioning of the wastes, storage and disposal will be paid by an external, segregated public fund. Sweden, on the other hand has one trust fund for both decommissioning and handling of waste and spent fuel. In most of the observed countries, several different funding schemes are in place.

2.3 Basic liability for decommissioning and waste management

One unifying concept, observed in nearly every country, is the polluter pays principle, which makes the operator of a facility liable for paying for the costs caused by his commercial activities. In some countries, some additional grants or subsidies are available to reduce the polluter liability and in some cases the liability is taken into public ownership and tax payer’s money is used to cope with decommissioning and waste storage; this is isually the case for orphan sites, areas that do not have a responsible party or where the polluter cannot pay (IAEA 2015, 9). This is for example the case for the former East German reactors, for which the federal government has taken over the decommissioning responsibilities after the German reunification.
In reality, it seems that the polluter pays priniciple applies in most cases only for decommissioning and scrapping of the reactors and not for the long-term storage of

companies are permitted to temporarily divert decommissioning funds for other business purposes, see the case with Japan Atomic Power Co using its decommissioning fund to cover costs of building nuclear power station, See Schneider, et al. (2018).

radioactive wastes. For the latter, a variety of organizational models has evolved in which the national authorities more or less take over technical and financial responsibility for managing the very long-term issues of waste management from the operator of the nuclear facility (e.g., in the US, Germany, France). Hirschhausen (2017) notes, that conflict arises between the "polluter pays principle" embedded in many countries' legislation and the implementation in reality: "These long-term costs and risks are instead socialized, whereas the private investor may be required to contribute to the financing of the long-term costs" (Hirschhausen 2017, 18–19).

2.4 Cost estimation and cost reviews

Wuppertal Institute et al. (2007) differentiate three cost estimation methods:

- *order-of-magnitude estimate:* this is a rough calculation without detailed engineering data (for example by taking some cost figures in international literature for granted and only slightly adapting them to the situation in the country, i. e. by scaling up or down factors and approximate ratios)
- *budgetary estimate*: this estimation is based on the use of flow sheets, layouts and equipment details, where the scope has been defined but the detailed engineering has not been performed, e. g., modelling based on reference cases or differentiated modelling for every individual facility)
- definitive estimate: for this estimate, the details of the project have been prepared and its scope and depth are well defined (Wuppertal Institut 2007, 73–74).

The review of costs and funds is crucial to meet the goal of adequacy and security of funds. Such reviews can be executed by the operator or the decommissioning entity or by both of them. Another option is the review by the government or nuclear regulator. If an administrative body is responsible for the accumulation of the financial resources this body could also be responsible for the cost reviews, which are usually provided by the operator. The timing of such reviews is also crucial and varies for example between annual reviews in France or the USA or longer review periods like six years in Finland (OECD/NEA 2016b, 122).

2.5 The uncertainty of longtime time frames (inflation, and interest rate of investments)

Due to the long time frames involved, a crucial financing point are the assumptions about the future inflation and discount rates. Already little changes in the assumptions has tangible effects on the present value of the funded financial resources, which have to be set aside. For the case that the real future discount rates are smaller as well as for the case where the real cost increase for nuclear back-end services is larger than assumed, the present value of the financial resources has to be higher today. In the case studies presented in the following section, the assumed discount and inflation rates vary between the evaluated countries. Especially the case, where the nuclear-specific inflation rate is much higher than the former expectations, could lead to a fundamental underestimation of the needed financial resources.

The assessment of very long-run external costs of nuclear power from a social welfare perspective raises interesting economic issues with respect to the discount rate applied. This discussion goes back at least to the 1970s and the attempts of the US government to license a site for storing highly radioactive waste in Carlsbad, New Mexico. In a detailed analysis of the approach and the expected externalities, Schulze et al. (1981) explore economic and ethical arguments based on different principles (see annex for the full model): From a libertarian perspective, creating risks (nuclear waste, etc.) that will be inherited by future generations is unethical since a long-term compensation of future generations over hundreds of thousands of years is deemed impossible. From a utilitarian perspective, the benefits of using nuclear power accruing to generation I (early users) can compensate for the risks to future generations, which depend largely on the chosen social rate of discount. Whereas traditional cost-benefit analysis would assume a social rate of discount in the range of 2-4%, Schulze et al. (1981) argue that "assuming future generations are unlikely to be compensated for risk of nuclear waste storage, rejection of nuclear waste storage, a zero percent rate of discount may be appropriate from a consequentialist ethical perspective." In that case, future potential costs are not discounted away, and thus the social welfare case for "economic" nuclear power is significantly weakened (See Hirschhausen 2017 for more details).

3. Financing Decommissioning

3.1 Liability for decommissioning

The polluter pays principle is a applied in most nuclear countries to decommissioning. Although, there are some cases, where the State takes over the liability for decommissioning. This is for example the case for the former East German reactors, for which the federal government has taken over the decommissioning responsibilities after the German reunification or the legacy fleet in the U.K., where the public agency, the National Decommissioning Authority is responsible for the decommissioning of the mostly Magnox reactors. Wuppertal Institute, et al. (2007, 14) note that the organization being principally liable is not always the organisation that fully pays for decommissioning activities. This is for example the case for Bulgaria, Lithuania, and the Slovak Republic, where in the context of the countries' accession to the European Union, it was agreed that the countries would get EU support for decommissioning in exchange for shutting down the older Soviet NPPs by the European Bank for Reconstruciton and Development. In Spain, the facility is (after defuelement) as well as the liability for decommissioning transferred to ENRESA, the state-governed radioactive waste management agency (Spain 2017, 91). After this transfer of liabilities, the former operators do not have to further contribute to the decommissioning fund even if decommissioning costs exceed the provisions made (Wuppertal Institut 2007).

3.2 Accumulation of the decommissioning funds

Before the funds can be managed, they need to be accumulated. One crucial factor is timing, as the funds need to be available when they are needed. The main scenario is to build up a fund year by year over the entire expected lifetime of a nuclear power plant or facility. However, shorter periods of time are also conceivable (e.g. 25 years in Germany), especially as more and more reactors are shutting down before they reach their licensed end (e.g. the USA, See Schneider, et al. (2018). Since 2006, in France, since 2006, provisions for decommissioning and decontamination of a NPP have to be fully collected already with start of operation (OECD/NEA 2016b).

The funds can be fed by a charge or fee, included in the electricity price or a compulsory government charge. Some countries have both mechanisms in operations for example for different generations of NPPs. When, national authorities take over the liability and with that the accumulation of financial resources, the fund could aslo be fed via taxes (e.g. the German government, which executes and pays for the decommissioning of the reactors constructed in the former GDR). In these cases, the taxpayers mainly fund the financing of the decommissioning.

3.3 Cost structure and future cost estimations

The Nuclear Energy Agency (NEA) of the OECD recognized different approaches to estimate the decommissioning costs:

- The **bottom-up technique** breaks down the process into its smallest components. For each component the amount of labour, materials, and consumables is estimated as well as the duration. All these elements will be aggregated into a full estimate. This technique is very detailed an can be exact, but requires detailed descriptions of the site inventory, the site-specific labour, material and equipment is required.
- The **specific analogy** approach uses a similar past project to estimate the cost of the actual project, while adjustments are made to account for differences between the projects (e.g. size, complexity, regulatory differences).
- The **parametric approach** uses historical databases on identical systems to find correlations between cost drivers or other parameters with statistical methods. This approach is i.e. suitable for large sites where detailed data about the inventory is not available.
- **Expert opinion:** This approach can be seen as the "last fragile hope" if the required data for all other approaches are not available.

The bottom-up approach is the most common one, where the project is divided into discrete measurable work activities (OECD/NEA 2016b, 11–15). In order to make different estimates between different countries comparable, NEA (2012, 21) developed the International Structure for Decommissioning Costing (ISDC). The ISDC reporting scheme recommends to categorize decommissioning costs into the following categories:
01 – Pre-decommissioning actions.
02 – Facility shutdown activities.
03 – Additional activities for safe enclosure and entombment.
04 – Dismantling activities within the controlled area.
05 – Waste processing, storage and disposal.
06 – Site infrastructure and operation.
07 – Conventional dismantling, demolition and site restoration.
08 – Project management, engineering and support.
09 – Research and development.
10 – Fuel and nuclear material.
11 – Miscellaneous expenditures.
However, still most cost estimation methodologies don't use this classification and the cost estimations also depend on the decommissioning strategy and the reactor technology. In addition to physical differences among plants, national decommissioning practices also influence the affordability of decommissioning[2] and specific country regulations contribute to original cost estimations being underestimated by margins as large as 50% (Album, Braend, and Johnson 2017). For example, at some plants in the U.S., large components such as the reactor pressure vessel or the steam generators were removed and disposed of as one-piece, a strategy that can dramatically reduce costs. However, in Germany, large components by law must be taken apart on site.
The company *Siempelkamp/NIS Ingenieurgesellschaft mbH*, who gained some experiences in decommissioning projects worldwide, provides an analysis of

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decommissioning projects and the related costs. For a complete decommissioning project for a NPP with a capacity of 1 GW, decommissioning costs of € 1 bn, a duration of 20 years and a required staff of around 400 people are expected (Hippauf 2015). The analysis showed that the most expensive decommissioning sub-project is the post-operational phase[3], which causes 49% of the total project costs, followed by the dismantling activities (37%) and waste management activities (14%). For the cost types, the most expensive part are the personnel costs with 69% of the expenses. This analysis provides just one example for the cost distribution of decommissioning projects. Another analysis provided by the *plenum AG,* which also analyses the cost drivers of decommissioning projects, showed that the fixed-costs of a project are enormous. These costs, which arise from expenses for the internal staff, the site operations and the overhead of a project, represent more than 50 percent of the total costs. Especially the costs for the internal staff are hard to reduce, because the staff has to be available during the entire decommissioning project.
In the first quarter of 2018, the WNISR counted a total number of 154 units globally undergoing decommissioning while only 19 reactors or ca. 5,951 MW_e have been fully decommissioned (Schneider et al. 2018). This poor outcome and missing national specific decommissioning experiences also leads to rather underestimated decommissioning costs. In Germany for example, there were annually cost increases between 2.9 and 6 percent in decommissioning projects, which were much higher than the general inflation rate or the assumed nuclear-specific inflation rate (Warth & Klein Grant Thornton AG Wirtschaftsprüfungsgesellschaft 2015a). In realitiy, most cost estimates are based on budgetary estimates, especially on older engineering cost studies and estimates from the 1970s and 1980s, which are then extrapolated. In France for example, the cost estimations for the legacy reactors are based on actual contractor quotes, while the basis for the estimation of the future costs for decommissioning the 58 PWRS is more or less an engineering decommissioning study by the French Ministry of Trade and Industry from 1991, that set an estimated benchmark cost for decommissioning expressed in €/MW, confirming the assumptions defined in 1979 (!) by the PEON commission. EDF confirmed these estimates in a representative study for decommissioning the site of Dampierre (four 900MW units). These results were corroborated by an intercomparison with the study carried out by consultants LaGuardia, based mainly on the Maine Yankee reactor in the US (EDF 2019). In short, the cost estimates are based on theoretical engineering studies and not on experiences or "real" data. This also applies for the U.S., a recent audit by the US Office of the Inspector General concludes that the estimates should be based on the best available knowledge from research and operational experience, but the NRC formula is based on studies conducted between 1978 and 1980 leading to the possibility that the actual costs might be significantly higher. The audit recommended among other things that the funding formula be reevaluated to determine whether a site-specific cost estimate would be more efficient (Office of the Inspector General 2016; Wealer et al. 2017).

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3 During the post-operational phase, which follows immediately after the shutdown of an NPP, the SNF will be unloaded from the reactor and reloaded into storage containers or on-site interim storage facilities. The level of hazard drops significantly with removal of SNF. The post-operational phase could also include the removal of operational wastes, the decontamination of systems and components and the taking of samples required for the application for decommissioning. Usually this phase is covered by the operating license of a NPP and lasts for around five years.

3.4 Funding systems for decommissioning in Europe

Table 1 gives an overview of the funding systems, the total cost estimation, the specific cost estimation per installed capacity in kW as well as the underlying cost estimation methodology in selected countries in Europe.

	France	UK	Germany	Sweden	Switzerland
Funding System	Internal Restricted	Public (legacy); External restricted (new NPPs)	Internal unrestricited	External restricted	External restricted
Total Cost stimations	€31.7 billion EUR for decommissioning (and removing laste cores) for its entire fleet				
Specific Cost Estimations	400 €/kW (operational); 1,200 €/kW for legacy	2,700 €/kW	1,250 €/kW		
Cost Estimation Methodolgy					

Table 1: Funding Systems for Decommissioning in Selected Case Studies in Europe

Source: Own depiction.

In *France*, the operators of nuclear power plants or nuclear facilities, are responsible to bear all costs related to decommissioning and EDF and Areva have set up internal, segregated funds for decommissioning of their facilities (Article 20/II of the 2006 Waste Law). In 2018, EDF estimates, according to its latest financial statements for FY 2018, total costs of around €31.7 billion EUR for decommissioning (and removing laste cores) for its entire fleet (EDF 2019). This includes the costs for the nine shutdown reactors[4] which are around €6.6 billion (which corresponds to around €1,800/kW of installed capacity), while EDF has only set aside €3.5 billion in provisions. The costs for the legacy fleet have increased steadily and doubled since 2001, when they were estimated to be around €3.3 billion (Cour des Comptes 2014), although no real decommissioning work has been done and the decommissioning start is postponed until the mid of the century. For the 58 operational reactors, EDF expects currently total costs for the decommissioning of the operational fleet of around €27 billion[5] (25.1 billion EUR in 2015, which corresponds to around €400/kW of installed capacity, quite low by international standards). **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the development of the total cost estimates by EDF for decommissioning, waste management and storage since 2010. In 2010, total

[4] 1 FBR, 1 HWGCR, 1 PWR, 6 GCR UNGG.

decommissioning costs (for the operational and the shutdown reactors) were around 21 billion EUR. Only in 2014, the cost categories were separated and the costs for the legacy fleet were introduced with 3.3 billion. Already one year later, these costs were doubled and have since then remained constant, as for the actual decommissioning. Only removing of the last cores has increased by 15% since 2010. In a recent report on the technical and financial feasibility of the decommissioning process, the French National Assembly alleged that EDF shows "excessive optimism". The report concluded that decommissioning and clean-up will take more time, that the technical feasibility is not fully assured, and that the process will cost overall much more than EDF anticipates. **Fehler! Verweisquelle konnte nicht gefunden werden.** provides the current cost estimation and the provisions set aside by EDF. A detailed report about the estimated costs, the timing and the value of the provisions has to be presented at least every three years (European Commission 2013).

The funding system in *Germany* differs between purely public-owned facilities, facilities with mixed-ownership and the facilities in private ownership. The costs for the decommissioning of the former owned nuclear facilities are financed from the current public budget; the Federal Government covers the majority of the costs, while some are covered by State Governments. The most common examples for public funding are the former GDR NPPs Greifswald and Rheinsberg, the decommissioning of which is totally funded by the Ministry of Finance. For the facilities in mixed-ownership, there is a proportional split of the costs between the public and the private utilities clarified by special arrangements.[6] However, the majority of the costs are related to the nuclear back-end of the privately-owned NPPs. In 2015, the auditing company Warth & Klein Grant Thornton AG provided on behalf of the German government an estimation of the whole costs for the nuclear back-end of 23 commercial NPPs: 47.5 billion in 2014 Euros. After transferring the provisions to the funds, the utiltites only set up provisions for "Decommissioning and Dismantling" and "Casks, Transport, Operational Wastes", totalling around 24.2 billion EUR in 2017 (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). Comparing the set aside provisions, this increases the around specific costs for decommissioning to around €1,000/kW from the Warth & Klein estimate of around €830/kW. Although, considerable decommissioning expenses have been done in 2017 by RWE and EnBW (around 5-6 billion EUR).

Company	31.12.2016	31.12.2017
E.ON	11,199	10,455
RWE[7]	12,699	6,005
EnBW	10,972	5,803
Vattenfall		1,490

[6] (European Commission 2013)

[7] RWE estimates in its provision the full costs for the decommissioning of Biblis-A, Biblis-B, Mülheim-Kärlich, Emsland, and Lingen for 100% and Gundremmingen A/B/C for 75%,

Stadtwerke München	818	399.7
Total	**35,688**	**24,153**

Table 2: Provisions of German Operators end of 2016 and 2017 in Million EUR.

Source: Own depiction based on annual reports by operators.
In addition, there are costs the for the public funded decommissioning of Greifswald and Rheinsberg and for research facilities: The initial decommissioning costs for Greifswald were estimated to be about 4 billion EUR and for Rheinsberg 600 million EUR; the latest cost estimate in 2016 was around 6.5 billion for both facilities. As always, all cost estimations are subject to many uncertainties related to expectations about future inflation rates, cost increases, and time delays. The estimation of Warth & Klein Grant Thornton AG considered this by a computation of the estimated costs with a nuclear specific inflation rate of 1.97% until 2099, which resulted in total discounted costs of around 169.8 billion EUR. The audit concluded that the effect of changing the estimated nuclear-specific inflation rate on future costs is strong and causes the most uncertainties.
In *Switzerland*, the decommissioning expenses will be paid by the external and restricted Decommissioning Fund established in 1984. The legal foundations of the funding system are determined in the Nuclear Energy Act of 21st March 2003 in article 31 and 77 – 82 and in the Regulation for the Funding of Decommissioning and Waste Disposal of 7th December 2007. According to these regulations, all operators of nuclear facilities are obligated to dispose all upcoming wastes in a safe manner on their own costs. The Decommissioning Fund is filled by contributions of the operators during the operational time of the facility; the is public and under supervision of the Federal Assembly of Switzerland (Bundesamt für Energie 2015).[8]

4. Financing Disposal

4.1 Liability for disposal

According to international law, the state has the responsibility for final disposal of radioactive waste. Therefore, financial liabilities for final disposal (and partly waste management, too) are not always with the 'polluters' but in some cases transferred to a state-governed organisation after transferring the responsibility for radioactive waste to this organisation (Wuppertal Institut 2007, 13).

4.2 Funding systems for disposal in Europe

Table 1 gives an overview of the funding systems, the total cost estimation, as well as the underlying cost estimation methodology in selected countries in Europe.

	France	UK	Germany	Sweden	Switzerland
Funding System	Internal Restricted, External	External restricted	External restricted	External restricted	External restricted

[8] The two external segregated funds have three organizational bodies. The main body is a commission with nine members coming from the operators, the authorities and independent experts. The commission also forms two committees, which are responsible for the cost estimations and for the investment strategy of the funds. The other bodies of the funds are the administrative office, which is operated by the company ATAG Wirtschaftsorganisationen AG, and the auditor operated by PricewaterhouseCoopers AG.

	France	UK	Germany	Sweden	Switzerland
	restricted construction begins				
Total Cost stimations	€30.97 billion EUR		23.6 billion EUR		
Cost Estimation Methodolgy					

Table 3: Funding Systems for Decommissioning in Selected Case Studies in Europe

In *France*, the operators of nuclear power plants are responsible to bear all costs related to waste management. An external fund to for the construction and operation, final closure, maintenance, and monitoring of the intermediate- or high-level waste storage or disposal installations built and operated by the radioactive waste management agency ANDRA; the latter holds and manages the fund (Article 16 of the 2006 Waste Law) (République Française 2006). Besides that, there is also an internal restricted ANDRA funds for research for future storage facilities. The two funds set up by the waste management agency ANDRA are fed by payments from the operator's internal funds at the time they are needed. Altough, the only fund fed right now is the research fund. As there is not yet a construction license, the construction fund is currently not fed. Instead, the operators make payments from their internal fund (for waste management) to ANDRA's general budget to finance operations related to the storage facilities for short-lived, medium-level wastes. AREVA and EDF were forced to advance their back-end provisions and accountancy practice because of partial privatizations. Both have now set up restricted internal segregated funds for the financing of the nuclear back-end. EDF feeds its fund by a charge of 0.14 Eurocent/kWh included in the price of electricity. Due to the Waste Law of 2006, the assets in the funds of EDF and Areva have to be accounted separately and the market value has to be at least as high as the provisions to be covered. In cases of insolvency or bankruptcy of an operator, the state can claim right over the assets. The internal funds are supervised by an administrative authority, who is authorized to impose corrective measures. This also includes the right to impose payments to ANDRA's budget.

Fehler! Verweisquelle konnte nicht gefunden werden. shows the development of the total cost estimates by EDF for decommissioning, waste management and storage since 2010. Since 2010, the total costs have increased by 33% (from around 62 billion in 2010 to 83 billion in 2017); with the biggest increase in long-term radioactive waste management with 35%.

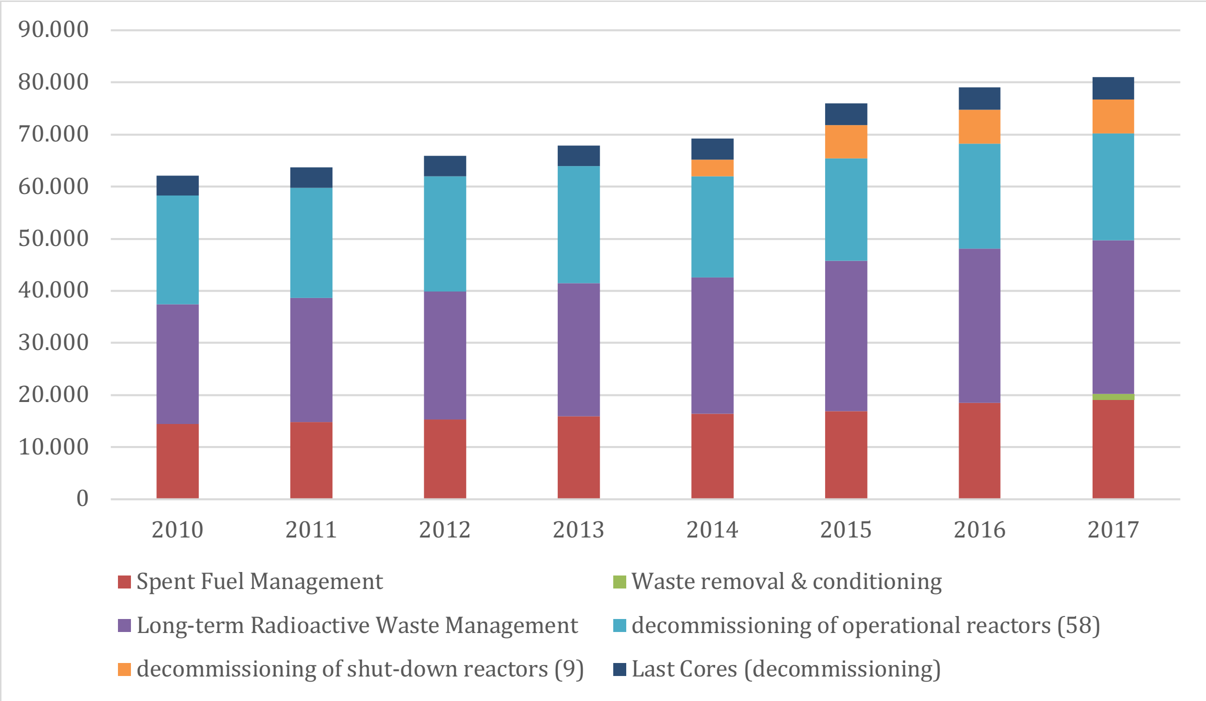

Figure 1: The development of EDF's cost estimates for decommissioning and storage.

Source: Own depiction based on the annual reports 2010-2018 published by EDF SA.

In Germany, in the old financing system, the financial resources to cover decommissioning and waste disposal were managed by the private companies in internal non-segregated funds with no public authority controlling them. The companies set up the provisions according to international accounting standards and were free to choose where to invest it. The OECD/NEA (2016) highlighted the unregulated and uncontrolled system of internal non-segregated funds itself as the most critical aspect of the German system. In the case of a bankruptcy of the operator, the financial resources to cover future costs would probably have been lost. The financial situation of the utilities was and still is not secured to exclude the risk of bankruptcy in the future. In the case of the loss of the funded provisions, the public budget would have been obliged to cover the costs. **Fehler! Verweisquelle konnte nicht gefunden werden.** presents the provisions of the companies as mentioned in their annual financial statements at the end of 2014, and their current estimates. The calculations of the private companies were based on an average interest rate of 4.58% and the before mentioned nuclear specific inflation rate of 1.97%; both are highly uncertain. A lower real interest rate on the provisions set aside would have had a crucial effect. With an average interest rate of 2.03 %, the present value of the set provisions would have to be today around 77 billion EUR to cover the future costs.[9] The estimation of Warth & Klein Grant Thornton AG considered this by a computation of the estimated costs with a nuclear specific inflation rate of 1.97% until 2099, which resulted in total discounted costs of around 169.8 billion EUR. The audit concluded that the effect of changing the estimated nuclear-specific inflation rate on future costs is strong and causes the most uncertainties.

[9] (Warth & Klein Grant Thornton AG Wirtschaftsprüfungsgesellschaft 2015b)

The new law published in December 2016 (BT 768/16) led to a fundamental change of the German funding system. This change was also motivated by concerns that the private utilities would not be able to cover all future liabilities with their internal non-segregated financial resources due to the experiences with high cost increases in former decommissioning waste disposal projects. There were annually cost increases between 2.9 and 6 percent, which is much higher than the general inflation rate or the assumed nuclear-specific inflation rate. Based on the reform proposals, an external segregated fund was implemented in 2016, which will have to finance all aspects related to waste disposal, i.e. interim and final storage. The fund was fed by the former provisions for these tasks totalling arounc 23.6 billion EUR[10], including a risk premium. The utilities are still responsible for decommissioning and for the conditioning of waste, but all tasks as well as the operation of the interim storage facilities will be done by public companies and paid from the fund. The responsibility as well as risks, including the financial ones in the case of insufficient set-aside money, will have to borne by the public, which infringes the polluter-pays-principle.[11] Not accounted for are: the retrieval of Asse II with more than 5 billion EUR and the decommissioning of Morsleben, which will the cost the public at least 2.4 billion EUR.
In Switzerland, the final disposal of nuclear wastes will be paid by the external and segregated Waste Disposal Fund established in 2000, which will have to be filled by contributions of the operators during the operational time of the facility and has to cover all expenses for the disposal of all radioactive waste. As the Decommissioning fund, the Waste Disposal Fund is public and under supervision of the Federal Assembly of Switzerland (Bundesamt für Energie 2015).

6. Conclusion on Financing Decommissioning and Storage

Due to its high capital intensity and long-term nature, reactor decommissioning and especially radioactive waste management are intimately related to financial issues. Approaches to provide the financing of waste management differ extensively across the 31 countries employing nuclear power for electricity generation, as is the scope of and the ways how financial resources are accumulated, secured, and managed. Nonetheless, every country faces more or less the same challenges, like the risk of insufficient or not available financial resources to cover the costs, underperformance of the funded resources, financial problems or a possible bankruptcy of the operator that could lead to the total or partial loss of already accumulated funded resources, and foremost the risk that the future costs are underestimated, infringing the polluter-pays-principle.

[10] E.ON: 10,179 million EUR, RWE: 6,800 million EUR, EnBW: 4,800 million EUR, and Vattenfall: 1,790 million EUR. All figures include the risk premium.
[11] (Jänsch et al. 2017)