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Sustainability-oriented Future EU Funding: A European Nuclear Power Tax

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Contents

Abstract

Nuclear power plays an important role in Europe’s energy mix today. Considering the manifold environmental and health hazards related to all phases of nuclear power production which may cause considerable negative externalities it is remarkable that the whole issue of using taxes as instruments to internalise the externalities associated with nuclear power is completely neglected in the literature. The paper provides a rationale for taxing nuclear power which is based on an analysis of its social costs and of potential windfall profits for the nuclear industry generated by EU policies. After giving an overview of existing nuclear taxes in the nuclear power-generating EU Member States, we elaborate the case for channelling revenues from a nuclear power tax into the EU budget as sustainability-oriented tax-based own resource replacing a part of national contributions within a fiscally neutral approach to reform the current system of own resources. Finally, the potential revenues from an EU-wide nuclear power tax are estimated.

Keywords: EU system of own resources, nuclear power tax, EU taxes, sustainability-oriented taxation

JEL classification code: H23, H87, Q58

1. Introduction[1]

Nuclear power plays an important role in Europe's energy mix today. In the EU it is the largest low-carbon source for electricity generation, contributing 27% of the electricity produced in the EU (European Commission 2016a). According to most of the scenarios considered in the EU Energy Roadmap 2050, nuclear power will be used in Europe at least until the year 2050 (European Commission 2011). The share of nuclear energy in the EU electricity mix is projected to decline from 30.5% in 2005 to 23.9% in 2020, and to stabilise at slightly above 20% in the period 2030 to 2050. At the same time, however, the overall production of electricity will have to increase, as electricity will have to make up for other fossil energy sources (for example the electrification of transport).

In mid-2016, there were 127 nuclear reactors with a mean age of 31.4 years in 14 EU Member States in operation, of which about 80 percent were located in the "old" Member States. These were 77 reactors less than in 1989, the year with the maximum number of operating reactors (Schneider and Froggatt 2016). 400,000 to 500,000 people are directly employed in the nuclear industry, with another 400,000 jobs depending on it (European Commission 2016a).[2] The quantitative significance of nuclear energy in the nuclear energy producing Member States varies considerably. With a share of about 80% in domestic energy production it is most important in France, but also in several other EU Member States up to one half of total electricity production rests on nuclear power. Since the beginning of the 1990s, only few new reactors have been built and connected to the grid in the EU; considerably more reactors were shut down in the last 25 years (Schneider and Froggatt 2016).

The Paris Agreement, which entered into force in November 2016 and is aiming at complete decarbonisation in the long run, as well as the 2030 Agenda for Sustainable Development coming into force in 2016 (European Commission 2016b) give fresh impetus also in the EU to the debate about a sustainable energy mix and about adequate instruments to promote it. In this respect, in particular two issues relevant in the context of efforts to make the energy mix more environmentally sustainable are disputed. First, there is no consensus whether

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[2] Bulgaria, Czech Republic, Finland, France, Hungary, Netherlands, Romania, Slovakia, Spain, Sweden, United Kingdom, Belgium, Germany, Slovenia (with the latter three EU Member States currently phasing out nuclear power).

nuclear power should gain in significance (further) as one relevant low carbon energy source besides low carbon renewable energy sources: not only because of the potential environmental hazards of nuclear power beyond greenhouse gas emissions, but also because there is disagreement about its carbon footprint.[3] Secondly, and related to the first issue: while there is broad agreement about the necessity and effectiveness of carbon pricing schemes to dampen carbon-intensive production and consumption activities involving fossil fuels (World Bank Group/Ecofys 2016), the implications for the tax treatment of non-fossil energy sources seem to be less clear. In particular carbon taxes levied exclusively on fossil fuels provide a competitive edge not only to renewables, but to nuclear power as well (OECD 2011), which is intensified further by the extensive subsidies (primarily consisting of tax breaks) granted to nuclear power production in many countries.

Considering the manifold environmental and health hazards related to all phases of nuclear power production[4], which may cause considerable negative externalities, it may appear amazing at first sight that there is practically no theoretical or empirical literature on taxes as instruments to internalise the externalities associated with nuclear power.

The paper first provides a rationale for taxing nuclear power which is based on an analysis of its social costs and of potential windfall profits for the nuclear industry generated by EU policies (chapter 2). After giving an overview of existing nuclear taxes and subsidies for nuclear power in the nuclear power generating EU Member States in chapter 3, we elaborate the case for channelling revenues from a nuclear power tax into the EU budget as sustainability-oriented tax-based own resource to replace a part of national contributions within a fiscally neutral approach. We also estimate the potential revenues from an EU-wide nuclear power tax (chapter 4). Chapter 5 concludes.

[3] See the meta-studies by Sovacool (2008a) and Warner/Heath (2012) for contradictory results concerning the carbon footprint of nuclear power determined in life cycle analyses.
[4] See Federal Environmental Agency (2014) for details.

2. Rationale for taxing nuclear power

From the very beginning of its use for commercial electricity production, nuclear power has been subject to intense (ideological) debates. There is no consensus neither in the literature nor in the public debate on a whole range of issues related to nuclear power, from safety to private and societal costs, windfall profits and government subsidies. Also, it is not clear how to judge nuclear power from a perspective of environmental sustainability. All these aspects matter, to a differing extent, when it comes to justifying a tax on nuclear energy, and will therefore be addressed in this chapter.

2.1 The social costs of nuclear power

Discussing the taxation of nuclear power requires the determination of its social costs in a first step. The social costs of nuclear power comprise the generation costs borne by producers and the external (in many Member States partially internalised) costs caused by the risk of accidents, nuclear waste and decommissioning and other issues such as the health impact of radioactivity spills, greenhouse gases or resource depletion.

2.1.1 The private costs of nuclear power

Understanding the private costs of nuclear power is important for two reasons. First, in order to be able to assess potential tax rates on nuclear power and their impact on the profitability of the nuclear power industry; secondly, as a prerequisite for making a rough guess of the supply elasticity of nuclear power. In addition, the considerable private costs of nuclear power generation explain the extensive subsidies granted by governments of all nuclear-power generating countries.

One specific characteristic of nuclear power generation are extraordinarily high up-front capital costs, ranging between 60% to 75% of total costs according to Rogner (2012), between 60% to 85% according to D'haeseleer (2013). In contrast, marginal costs of operation and maintenance are comparatively low (Rogner 2012, D'haeseleer 2013). The determination of the costs of capital for nuclear power is no straightforward exercise, as they crucially depend on a number of assumptions particularly for interest rates and interest paid during construction, the length of the construction period, and the load factor (D'haeseleer 2013).

Usually comparisons of the costs of different energy sources are based on levelised costs of electricity (LCOE).[5] LCOE estimates for existing power plants are usually rather favourable compared to other energy sources. The private costs of conventional energy sources are of an order of magnitude of 2.7 cents to 3.3 cents per kWh for coal, 4.8 cents to 6.6 cents per kWh for gas, and 6.6 cents to 9.9 cents per kWh for oil (CASES 2011). Estimates provided by the French Court of Audit for the existing French nuclear power park range between 3.1 cents and 4.9 cents per kWh, depending on the methodology to incorporate the costs of capital (Cour de Comptes 2012). The cost estimates for new reactors, however, are considerably less favourable. The new reactor designs, which are supposed to be much safer (for instance the European Pressurized Water Reactor (EPR)), have turned out to be very expensive at construction. The private costs of generating electricity at the new EPR reactors planned at Hinkley Point (United Kingdom), for example, are estimated at 92 GBP per MWh, which translates into roughly 11 cents per kWh (European Commission 2014). D'haeseleer (2013) estimates LCOE of newly-built reactors between 5 cents per kWh (assuming an interest rate of 5%) and 8.9 cents per kWh (for an interest rate of 10%). The very risky nature of investing in new nuclear power plants is a crucial determinant of the significantly increased private costs of electricity generation in newly-built reactors. In addition to a considerable regulatory and political risk (Davis 2012), there is the risk of price fluctuations, which in liberalised energy markets is fully imposed on the investor (Rogner 2012; D'haeseleer 2013). Moreover, the combination of large investment volumes and very long amortisation periods makes investing in nuclear power plants unattractive for typical private capital market investors (D'haeseleer 2013).

2.1.2 The external costs of nuclear power

As a basis for the assessment of the potential of nuclear power taxes aiming at the internalisation of external costs, this section gives a brief overview of existing estimates for the external costs of nuclear power. D'haeseleer (2013) provides a range between 0.1 cents and 0.4 cents per kWh for the total external costs of nuclear power. One important component of external costs considered is related to nuclear accidents. Other components stem from the storage and disposal of radioactive waste, radioactivity spills during routine operation, and CO_2 emissions in a lifecycle perspective. The remainder of this section reviews the existing estimations for the various components of the external costs of nuclear power.

[5] See D'haeseleer (2013) for details.

2.1.2.1 The external costs of nuclear accidents

One element of external costs of nuclear power are the risks and costs of nuclear accidents. The threat of a nuclear disaster as well as the associated costs[6] has been highlighted once more by the Fukushima Daiichi (Japan) accident in 2011, and has inspired fears concerning nuclear power also in many European countries, thus questioning the "Nuclear Renaissance" that had been invoked since the beginning of the 2000s (Kiyar and Wittneben 2012).

The first question of interest is the extent of the risk of such a disaster happening again. It is obvious that estimating the risk of nuclear accidents is a difficult undertaking. One first indication is the incidence of past nuclear accidents. So far, there have been two catastrophic nuclear power plant accidents worldwide, Chernobyl (in 1986) and Fukushima (in 2011). On the international nuclear event scale (INES) these are the only accidents ever receiving the highest rating of level 7. In Chernobyl the reactor No. 4 exploded, while in Fukushima three reactors suffered a core meltdown. From the beginning of the commercial use of nuclear power until to date, there have been 17,022 reactor operating years (IAEA 2017) within which catastrophic INES 7 accidents took place. This yields a ratio of 1 disastrous reactor accident for every 4,256 reactor operating years. This actual rate of accidents casts doubt on conventional estimates of nuclear accident risks specified as the probability of a catastrophic nuclear event for one reactor in one year, which often are in the order of magnitude of 1:1,000,000 (Lelieveld et al. 2012).

A generic estimate of the accident risk of one nuclear reactor in one year representing a pessimistic view of the existing reactor fleet is 1:10,000 (D'haeseleer 2013, Meyer 2012). A more optimistic estimate focusing on new third generation reactors is 1:1,000,000, but so far, there are no third generation reactors operating in the EU (D'haeseleer 2013). Wheatley et al. (2016) perform a statistical analysis of the nuclear accidents frequency based on cost data of documented nuclear accidents. They establish the distribution of accident costs, approximating its tail by a Pareto distribution (with parameter alpha=0.55), and conclude that an accident of the size of the Chernobyl accident or larger has a 50% probability of happening in the next 27 years. Overall, their work comes quite close to assuming a frequency for large accidents of 1:20,000.

Cost estimates for nuclear accidents differ widely. It is obvious that the costs of nuclear accidents do not only comprise the immediate economic and social costs in terms of fatalities and property damage, as recorded, for example, by Sovacool (2008b) for the period 1907 to 2007. However, it is neither clear where to draw the borderline regarding the additional cost

[6] For a recent stock-taking of the costs of the nuclear accidents in Chernobyl and Fukushima see Schneider and Froggatt (2016).

categories to be included in the external costs of nuclear accidents, nor how to value them adequately ex ante as well as ex post. Accordingly, there is only a small body of literature providing estimates for the costs of nuclear accidents. Here we briefly review some selected results to illustrate the potential order of magnitude of external costs of nuclear power.

Meyer (2012) presents a cost range of € 69 billion to € 343 billion for any nuclear accident in Western Europe,[7] thereby updating previous studies from the 1990s (CEPN 1995; Ewers and Rennings 1992). Hereby the major part of the costs of nuclear accidents is caused by the health impact of radioactivity.[8] Momal and Pascucci-Cahen (2012) present a cost range of € 120 billion to € 430 billion for any nuclear accident happening in France. A noteworthy difference between these estimates and those determined by Meyer (2012) is the inclusion of image costs. Momal and Pascucci-Cahen (2012) define image costs as the costs incurred by a demand drop for French agricultural products stemming from regions unaffected by radioactity spills and a decline of tourism and estimate them at € 47 billion to € 166 billion.

Based on the above cost and risk estimates, Meyer (2012) calculates the expected external costs of nuclear energy per kWh of electricity produced: she weights cost estimates by risk estimates for accident frequency and relates the result to the amount of nuclear energy produced in an average German reactor. Combining the maximum accident cost estimate of € 343 billion and the pessimistic accident risk estimate of 1:10,000 yields expected external costs of 0.34 cents per kWh. D'haeseleer (2013) arrives at external costs of nuclear accidents between 0.03 cents and 0.3 cents per kWh of nuclear energy produced.

Unlike other external costs transgressing national borders, the costs of a nuclear disaster fall disproportionately on a small part of the population that has to bear enormous costs not only in terms of material losses and fatalities, but also in terms of severe psychological problems (Hasegawa et al. 2015). At the same time, the costs are not incremental (like, for instance, the costs of air pollution). With people having to be evacuated and losing their homes, places of residence, personal belongings etc., a large part of the costs rather materialises at once.

In contrast to its external costs, the benefits of nuclear power are distributed more evenly. Only if people were risk neutral, it would be correct to compare the expected benefits of nuclear power with the expected value of its costs. As it has to be assumed, however, that there is strong risk aversion when faced with the prospect of a nuclear disaster, risk aversion has to be considered when contrasting the expected values of benefits and costs. The German

[7] For the assessment of the costs of a nuclear accident, population density close to the plant and in the area where most nuclear fallout occurs is an important factor.
[8] It is interesting to note that compared to other energy technologies, nuclear power does not fare so badly in terms of safety or casualties (see OECD 2010 for details).

Ministry of the Environment suggests a risk aversion factor of 100 for nuclear accidents (Federal Environmental Agency 2012), based on which Meyer (2012) arrives at an upper limit for external costs of 34 cents per kWh. As a lower bound the author estimates external costs of 10.7 cents per kWh, based on an approximation for unknown costs suggested by the German Ministry of the Environment. The method is based on the idea that, even if the exact costs of a technology are unknown, its relative ranking compared to other energy technologies can be established. Assuming that nuclear energy ranks worst of all alternatives, the lower bound of its unknown external costs should be drawn at the second worst alternative. The worst fossil fuel energy source in terms of external costs is lignite with external costs of 10.7 cents per kWh, and this value is taken as a lower bound for the external costs of nuclear power.

2.1.2.2 The costs of decommissioning and radioactive waste

The backend cycle of a nuclear power plant is cost intensive, while at the same time it does not generate any revenues. Thus, there is a considerable danger of private producers filing bankruptcy and leaving the costs of the clean-up to the public. It is the legislator's task to prevent this. The EU already plays an active role in providing directives for the decommissioning of nuclear power plants and the managing of radioactive waste and storage. The financing of these activities has to be provided by the nuclear plant operators, i.e. the polluter pays principle applies, following the Council Directive 2011/70/Euratom. Accordingly, Member States are obliged to put in place systems, e.g. funds, by means of which nuclear power plant operators will cover all decommissioning costs. Contributions to these funds should be reviewed on a yearly basis; the cost estimates of decommissioning should be provided by Member States and be reviewed by international and/or EU experts at least every 5 years (European Commission 2013).

By 2025 about one third of the nuclear reactors operated in the EU will have to be decommissioned. So far there is little experience with full-scale decommissioning: 89 reactors have been shut down in the EU by now, but only 3 German reactors have been fully decommissioned (European Commission 2016a). Current estimates of future decommissioning costs in the EU amount to € 253 billion, of which € 123 billion will have to be spent on the actual decommissioning and dismantling of nuclear power plants, while € 130 billion relate to radioactive waste management and final disposal (European Commission 2016a). Given the lack of experience with decommissioning and taking into account that there is still no final repository for high level radioactive waste anywhere in the world, these cost estimates are subject to considerable uncertainties (OECD 2016). In 2016 the funds collected so far in EU Member States operating nuclear reactors amount to € 133 billion (European Commission 2016a). Whether accrued funds will suffice to cover future decommissioning and waste management costs does not only depend on future costs but also on the interest rates nuclear power plant operators can achieve; both variables are subject to substantial uncertainties. Thus there is a non-negligible risk of the private costs of decommissioning and radioactive waste management eventually turning into external costs that burden tax payers.

2.1.2.3 CO2 emissions of nuclear energy generation

There is some disagreement in the literature regarding CO2 emissions during the nuclear power lifecycle. The major source of CO2 emissions of nuclear energy from a lifecycle perspective is uranium mining and enrichment. Usually uranium ores contain only about 0.2% or less uranium, and with the depletion of uranium stocks, the mining of still lower grade ores might become necessary (Sovacool 2008a). Also, the enrichment process is very energy intensive. Greater reliance on the more efficient technology of centrifuge enrichment as opposed to diffusion enrichment has the potential to reduce energy intensity and CO2 emissions. Also, the energy mix used for mining and enrichment (i.e. coal or diesel, versus renewable and nuclear energy) plays an important role in the lifecycle assessment of nuclear energy (Dones 2007; Warner and Heath 2012).

Sovacool (2008a) conducts a meta-analysis of life cycle studies and concludes that with 66 g of CO2 emitted per kWh, nuclear power fares worse than renewable energy technologies. This assessment, however, is not based on a thorough review of renewable energy technologies. Another recent meta-study by Warner and Heath (2012), which was part of the lifecycle assessment harmonisation project of the National Renewable Energy Laboratory (NREL) and compares different energy technologies, derives an estimate of 13 g of CO2 emitted per kWh. In comparison, the carbon footprint of a modern combined-cycle gas turbine is about 480 g of CO2 emissions per kWh (Sijm et al. 2006).

2.1.2.4 Other external costs of nuclear energy

The CASES[9] project estimates the external costs of nuclear energy at 0.2 cents per kWh. Hereby the major part of the external costs results from potential health risk, while 15%, i.e. 0.03 cents per kWh, are attributable to CO_2 emissions.

Another factor contributing to the external costs of nuclear energy is the depletion of global uranium stocks. As these stocks become scarcer, their harvesting becomes more difficult and the costs will increase. Most likely this is not properly reflected in resource prices today, which are probably too low therefore. Incorporating resource depletion following the ReCiPe method, the external costs of nuclear energy are estimated at 1.8 cents to 2.2 cents per kWh (Ecofys 2014).

Moreover there is the danger of nuclear weapons proliferation, terrorist attacks and war (Davis 2012). Radioactive waste could be stolen and used in dirty bombs. Nuclear power plants are not designed so as to withstand military bombardment (Kovynev 2015). Thus, the usage of nuclear power for commercial electricity production requires a long-term commitment to a stable political and regulatory environment without which the risk imposed by having nuclear power plants in operation will rise sharply. Obviously, is it impossible to estimate the potential external costs related to these additional risks of nuclear power.

2.2 Windfall profits for nuclear energy

Windfall profits accruing to nuclear energy due to regulatory measures are another argument for the taxation of nuclear power. In particular, such windfall profits are caused by the EU Emission Trading System (ETS) and by lifetime extensions for nuclear power plants.

2.2.1 Windfall profits generated by emission trading in the EU

An indirect subsidisation of nuclear power might result from the EU ETS. An increase of the price of carbon through the obligation to acquire emission certificates (or by the introduction of a carbon tax) would increase the price of electricity by increasing the marginal costs of fossil fuel electricity producers. The price of electricity in a liberalised energy market is

[9] CASES – Cost Assessment of Sustainable Energy Systems is an EU-financed research project completed in 2008, which aims at accumulating accurate and comparable data on private and external costs of energy technologies based on the ExternE methodology.

determined by the last unit produced, i.e. the marginal costs of the "marginal power plant".[10] This last unit (at least in Germany) is usually generated by a gas power plant (Küchler and Meyer 2010). Nuclear power plant operators, which are exempted from the ETS, would become more competitive and benefit from "windfall" profits.

In the literature several attempts have been made to quantify these windfall profits. Diekmann and Horn (2007) estimate the price increase of electricity due to carbon pricing as determined by the price of carbon times the factor 0.0005. Thus for each € per tonne carbon emissions, the price of electricity increases by 0.05 cents per kWh. Other estimates are of similar magnitudes: Schwarz and Lang (2006) estimate a price increase of 0.076 cents per kWh for each € per tonne carbon emissions. Based on the more conservative estimate of Diekmann and Horn (2007), potential windfall profits of the nuclear industry in the EU can be easily calculated. If the carbon price increased to 25 € per tonne of CO2, the electricity price would increase by approximately 1.25 cents per kWh. Assuming that the level of nuclear energy production remains approximately at the 2014 level of 830,000 GWh, this price increase will lead to about € 10 billion a year in extra profits for the nuclear industry.

The CO2 emissions of a gas plant amount to 0.48 t of CO2 per MWh of electricity on average (Sijm et al. 2006). Assuming a full cost pass-through, the costs of electricity will increase by 1.2 cents per kWh for a carbon price of 25 € per tonne of CO2 emissions, given that the electricity price is determined by the marginal costs of a gas power plant. Changes in the merit order of electricity pricing (e.g. when gas power plants are taken off the grid in times of lower demand) will influence the electricity price increases and thus windfall profits accordingly.

Whether the change in price relations in favour of nuclear power caused by the EU ETS is to be considered as distortive may be disputed. In principle carbon pricing can be seen as an instrument indirectly subsidising and thus promoting nuclear power. For this reason the European Commission had included an energy tax component in its initial proposal of a carbon tax so as to not unduly encourage nuclear power (Pearson and Smith 1991). Subsidising nuclear power through the EU ETS by exclusively targeting carbon-emitting energy sources against the background of a general policy context aiming at decarbonisation appears problematic beyond the substantial external costs associated with nuclear power addressed above. Potential steering effects of carbon pricing towards nuclear energy also depend on the general regulatory framework as argued by Diekmann and Horn (2007) for

[10] The supply curve of electricity, the so-called merit order, determines which plants are being connected to the grid. Power plants with low marginal costs like hydropower and nuclear, the baseload providers, are always connected, while those with more variable costs are only connected when electricity demand is high. Power plants are ordered by their merit, i.e. their marginal costs. The power plant with the highest marginal costs sets the wholesale electricity price for all providers.

Germany, which has initiated the phasing-out of nuclear power in the beginning of the 2000s, thus foreclosing any steering effects of the EU ETS in the form of causing more investment in nuclear power plants. In such a context windfall profits accruing to nuclear power plant operators will only have distributional effects, transferring money from energy consumers to nuclear power plant operators.

2.2.2 Windfall profits caused by long-term operation of nuclear power plants

Windfall profits may accrue to nuclear power plant operators also as a result of lifetime extensions for existing nuclear power plants. The LCOE after a lifetime extension are estimated to be of the order of 2.3 cents to 2.6 cents per kWh (D'haeseleer 2013). These costs already include the projected investments required for safety upgrades. Thus the LCOE of a nuclear power plant after a lifetime extension considerably undercut those of gas power plants, which are often seen as setting the wholesale price of electricity. The cost reduction achieved through lifetime extensions increases the competitiveness of nuclear power compared to other energy sources and creates windfall profits for nuclear power plant operators. Currently, lifetime extensions of nuclear power plants are regarded by the European Commission as a viable policy (European Commission 2016a). Otherwise, the share of nuclear power would decrease quite rapidly in the coming decades, which would adversely impact future energy scenarios of the EU, i.e. the ones laid out in the EU Energy Roadmap 2050 (European Commission 2011).

2.3 Conclusion: The case for taxing nuclear power

The considerations presented in this chapter suggest that there is some rationale for taxing nuclear power. First of all, a tax on nuclear power is able to internalise external costs of nuclear energy. These negative externalities may take the form of safety risks or of long term liabilities resulting from decommissioning and radioactive waste. The second type of liability should be internalised already in the EU via Council Directive 2011/70/Euratom, which puts the polluter pays principle into binding law. All Member States with nuclear power plants already have some national financing schemes to guarantee the financing of decommissioning and the management of radioactive waste. There is no obvious case for replacing these national financing provisions with an EU tax: different national financing systems would have to be aligned, and it seems unlikely that an EU tax would yield any significant improvement in terms of internalising externalities compared to the status quo.

Also, replacing the current system could transfer the risk of future cost overruns of decommissioning and waste management immediately to public budgets.

Theoretically it would be desirable to design a corrective tax on nuclear power so as to actually help reduce the risk associated with nuclear energy production. The conventional rationale for a Pigovian tax is that it will shift private marginal costs so that they equal social marginal costs, resulting in a level of pollution which is "efficient" from a social perspective (assuming that the polluting activity brings economic benefits, which consumers demand and are willing to pay for).

In the case of nuclear power, however, we are dealing with a small unknown accident probability, which can only be eliminated by shutting down nuclear power plants. A gradual adjustment of private costs after taxation and social costs, to achieve a socially "efficient" outcome, seems impossible. However, a tax on nuclear power might act as a deterrent to a short term licence renewal of a nuclear power plant. At the end of a nuclear power plant's operating period, there might be a real trade-off between implementing required investments and shutting down a plant early. A tax on nuclear power might tilt the balance in favour of early shut down. In particular, it might make life-time extensions, which are worsening the unfavourable age structure of EU nuclear reactors further, less attractive.

Taxing nuclear power, as well as removing the subsidies granted by EU Member States and at the EU level to nuclear power production, will remove the existing cost advantage nuclear power is enjoying vis-à-vis really renewable energy and conventional fossil fuels, which is exacerbated by (increasing) taxes on carbon emissions discriminating in favour of nuclear energy. In addition to the external costs of nuclear power production, windfall profits reaped by nuclear power plant operators due to carbon pricing driving up energy prices as well as lifetime extensions may justify nuclear power taxes.

In a liberalised energy market, a tax on nuclear power slightly increasing its marginal costs will not be passed on to the consumers as the market price of electricity is determined by the merit order of power plants. As nuclear power plants are relatively far down in the merit order, they are hardly ever decisive for the electricity price, but rather have to act as price-takers. A charge which increases their marginal costs, up to an extent which does not change their position in the merit order, can be expected to have no effect on consumers (D'haeseleer 2013; Küchler and Meyer 2010).Therefore undesirable distributional effects, which are usually associated with taxing electricity, are not to be expected.

3. Taxation of nuclear power in EU Member States

3.1 Nuclear taxes in EU Member States – an overview

8 of the 14 nuclear energy countries in the EU levy some nuclear tax, which generally do not generate substantial revenues (see table 1). These taxes differ particularly in three respects: in their design, particularly with regard to the tax base; in the effective tax burden they create per unit of electricity produced; and if and to what extent the revenues are earmarked.

This overview considers explicit nuclear taxes only.[11] Very minor taxes raising some million euros only, as the Finnish nuclear energy research levy or the Slovenian tax of the nuclear power plant to finance its decommissioning, are not included. We also do not report fees and charges which have no nationwide coverage but are levied by some jurisdictions only, as for example the compensation for nuclear exploitation nuisance levied by some Belgian municipalities, or the taxes on nuclear waste levied by two Autonomous Communities in Spain (Rozas 2014).

Mostly the revenues from nuclear power taxes accrue to the federal level. A few Member States in addition to federal taxes (Belgium, Slovakia, Spain) or excusively (Finland) levy taxes at the local or regional level, with revenues going into municipal or regional budgets.

In general, nuclear taxes are a politically very sensitive and debated issue, and tax provisions change rather frequently. One specific characteristic of the nuclear power producing sector legislators are facing when attempting to implement nuclear taxes is that the sector usually consists of only one or very few big electricity producing companies with considerable lobbying power. Therefore companies negotiating with the government about the tax, as for example in Belgium or Sweden, or even filing lawsuits against it, as for example in Germany, are not unusual.

Explicit taxes on nuclear power currently levied in Member States are using various tax bases. The main tax bases in use are electricity produced, thermal capacity, nuclear fuel, and nuclear waste. Of course, also other charges can be in place: sometimes lump-sum taxes per plant or plant operator, in some cases (increased) taxes on completely unrelated bases.

In Germany a tax on nuclear fuel (fissile uranium or plutonium) was in place in the years 2011 to 2016, making lifetime extensions of nuclear power plants less profitable for nuclear power plant operators. The tax was levied at a rate of € 145 per gram of nuclear fuel. The German nuclear fuel tax translated into a tax of approximately € 7.3 to € 15.8 per MWh

[11] Thus general electricity taxes are excluded: for example, the Climate Change Levy charged in the United Kingdom to electricity used by businesses regardless of its source.

(Fiedler 2016)[12]. The introduction of the German nuclear fuel tax was justified primarily by two arguments. The first one was the planned postponement of the nuclear phase-out which would have resulted in windfall profits for the nuclear industry.[13] A second motive was to cover the costs of decommissioning and decontamination of the Asse II mine, a site where experiments with long-term storage of radioactive waste had been conducted. Also in the Netherlands a tax on nuclear fuel was levied in the years 1997 to 2000, imposing 14.4 € per gram uranium-235 (Vollebergh 2008).

Thermal capacity, specified as the maximum amount of electricity which can be produced if a nuclear reactor runs at full capacity, is another potential base for nuclear power taxes. In Sweden a tax on thermal capacity has been in place from 2000 on, replacing a tax on produced electricity that had been levied since 1984. The tax was raised considerably in 2015 to € 7.50 per MWh; it is being phased out between 2017 and 2019.[14]

Several countries relate taxes, charges or fees levied on nuclear power plant operators to nuclear waste, with revenues mostly accruing to special funds: Finland, Hungary, Romania, Slovakia, Spain and Sweden apply charges based on nuclear waste production and/or dedicated to cover decommissioning costs. In addition to these earmarked charges, Spain introduced two new taxes on nuclear waste in 2012 whose revenues accrue to the federal level and are not earmarked (Rozas 2014). Germany has just established a decommissioning fund which (conditional on the European Commission's state aid approval) is supposed to take up its operations in 2017 and will be funded by the tax-free accruals for nuclear waste management and decommissioning accumulated by nuclear power plant operators.

Finally, a few Member States levy lump-sum-based nuclear taxes. The Belgian nuclear production charge is a lump-sum payment by nuclear power plant operators which is not related at all to any specific tax base. It was introduced in 2010, initially temporarily until 2014, to skim off windfall profits accruing from the extension of the license of the Belgian nuclear power plants by 10 years (Green 2015). The next government took back the license renewal and considerably increased the tax. In 2015 the new government again agreed on a ten-year license extension and reduced the tax drastically in two steps as of 2015 and 2016, respectively. From 2017 on a slightly higher amount will be charged. Originally the tax burden was € 5 per MWh; the modifications starting with 2015 more than halved it. One

[12] As refueling of a reactor is required every 18 to 24 months only (Rogner 2012), the tax burden varied from year to year and was not proportional to the energy produced.
[13] The postponement was taken back shortly after the introduction of the tax as a reaction to the Fukushima accident.
[14] By deciding to phase out the tax the Swedish government reacted to the threat of the Swedish energy provider Vattenfall to shut down all their Swedish nuclear power plants by 2020 because due to the tax and the low electricity prices these were no longer profitable. At the same time utilities were allowed to replace the existing nuclear fleet of ten reactors.

central justification for the tax are windfall profits resulting from the tifetime extension of the taxed nuclear plant. France levies a nuclear plant tax based on a lump sum basic amount of up to € 3.67 million per plant, which is multiplied by a coefficient between 1 and 4 differentiated according to type and power of the plant.

Several countries (Finland, Slovak Republic, Hungary, Romania, Sweden, Spain) levy nuclear waste management fees whose revenues are dedicated to special off-budget funds accumulating financial reserves for decommissing and storage of nuclear waste. France levies three lump-sum taxes to finance nuclear research. The revenues of the French basic nuclear power plant tax, however, go into the general budget; as do the revenues from the German, Belgian, Finnish, Slovak, Spanish and Swedish nuclear taxes.

Some Member States generating nuclear power introduced such charges on the nuclear sector – in particular earmarked fees for nuclear waste management – rather early (Sweden and Finland in the 1980s; France, Slovakia, and Hungary in the second half of the 1990s). In several other countries nuclear power taxes – mostly non-earmarked ones – were implemented during the last decade only; sometimes as fiscal consolidation measures (Belgium, Spain, France, Germany). In Belgium and Germany skimming off windfall profits due to lifetime extensions was put forward as one central justification of implementing the nuclear tax. Also in Finland taxing windfall profits accruing to the nuclear industry due to the introduction of the ETS has been discussed occasionally over the last years, without resulting in the adoption of such a tax, however.

Currently the level of taxation of nuclear power in Europe is the lowest in years. In several Member States nuclear energy taxes are reduced or phased out because of the heavy competition from other (renewable) sources for electricity generation. As of 2017, there is no nuclear tax in Germany, the Swedish nuclear tax is in the process of phase out, and the tax burden on nuclear energy produced in Belgium is substantially lower compared to previous years. Those nuclear taxes still in place in EU Member States mainly aim at accruing earmarked revenues to finance the management of radioactive waste and decommissioning.

Table 1: Nuclear power taxes and charges in the EU

Country	Tax design	Tax burden in € per MWh	Tax revenues in Mio. € (in % of GDP)	Introduced in	Modifications
Abolished nuclear power taxes					
Germany	Nuclear fuel tax; €145 per gram of fissile uranium or plutonium	7.30 -15.8 (2015)	1.018 (0.03%) (2015)	2011	Abolished in 2017
	lump-sum payments into decommissioning fund	n.a.	n.a.	2017[3)]	
Netherlands	Nuclear fuel tax; Dfl. 31.95 per gram uranium-235	n.a.	6.8 (0.002%) (1997)[2)]	1997	Abolished in 2000
Existing nuclear power taxes					
Belgium	Lump-sum nuclear plant charge	5 (2014)[1)]	200 (0.05%) (2015)	2010	Initially temporary for the period 2010 to 2014 Increased in 2012 Decreased in 2015, 2016 Increased in 2017
Bulgaria	Lump-sum nuclear plant charge	5 (2014)[1)]	200 (0.05%) (2015)	2010	Initially temporary for the period 2010 to 2014 Increased in 2012 Decreased in 2015, 2016 Increased in 2017
Finland	Higher property tax rate for buildings used for nuclear waste management, based on property value	0.4 (2012)	n.a.	n.a.	Increased in 2016
	lump-sum fee for nuclear waste management fund	1.6 (2012)		1987	contribution determined yearly
France	Lump-sum nuclear plant tax, multiplied by coefficient depending on type and power of plant	0.8 (2012)	350 (0.02%)) (2012)	2000	Increased in 2006, 2010, 2017
	3 additional taxes (research, support and technological transfer tax); lump sum multiplied by coefficients	0.3 (2012)	n.a.	2006	
Hungary	Fee for nuclear waste fund	n.a.	64 (0.06%) (2012)	1998	
Romania	Fee for nuclear waste disposal	1.40	n.a.	2007	
	Fee for decommissioning of nuclear power plants	0.60	n.a.	n.a.	
Slovakia	Nuclear facility tax and immovable property tax	0.31	n.a.	2004	
	levy of 10% on the wholesale price of electricity for state fund for radioactive waste and decommissioning	n.a.		1995	
Spain	Four charges related to nuclear waste management	n.a.	n.a.	1997	
	Nuclear waste taxes on nuclear waste generation and storage	6.60 – 7.80	n.a.	2012	

Sweden	Capacity tax based on thermal output	7.50	403 (0.09%) (2015)	2000	Increased in 2006, 2008, 2015 phased out between 2017 and 2019
	fee for final storage of spent fuel and decommissioning of nuclear power plants	4.40	n.a.	1982	Increased in 2015

Sources: Espensen et al. (2015); Finnish Energy Industries (2014); Eurelectric (2014); OECD (2016); Cour des Comptes (2012); Fiedler (2016); Zorn (1999); Rozas (2014); www.world-nuclear.org; own research and compilation. – [1]) More than halved after the modifications starting with 2015. – [2]) Projected revenues. – [3]) The state aid approval by the European Commission is still pending.

3.2 Subsidies for nuclear power

The flipside of only moderate specific nuclear power taxes in some EU Member States producing nuclear power and their absence in most other EU Member States relying on nuclear energy are substantial public subsidies from the EU budget and from national budgets. These public subsidies can be perceived as contributing to the social costs of nuclear energy. They are granted to decrease the substantial private costs accruing to private investors to make the construction and operation of nuclear power plants profitable at all. A comprehensive stock-taking of subsidies for electricity-generating technologies is a complex task (Badcock and Lenzen 2010), and the scope of this paper does not allow to go too much into detail. However, the selected results presented in this sub-section demonstrate that nuclear power is a rather heavily subsidised source of electricity.

Subsidies for electric power generation can take various forms. Kitson, Wooders and Moerenhout (2011) distinguish between the direct and indirect transfer of funds and liabilities, government revenue foregone (i.e. tax breaks), provision of goods and services, and income or price support. These can be directed at research and development (R&D), investment, generation, consumption or decommissioning, or they can be provided throughout the whole production cycle.

Obviously levying nuclear taxes and granting subsidies to the nuclear industry at the same time seems to be at odds. It is indeed crucial to align subsidies and taxes to avoid counter-acting effects. Subsidies should aim at supporting activities with positive external effects, e.g. research making nuclear reactors safer in the long term. Taxes should be directed at the internalisation of negative external effects of nuclear power and may in the specific case of the nuclear industry also be used to skim off windfall profits resulting from regulatory interventions.

The EU is a major player in the field of R&D expenditures for energy technologies. A closer look at subsidies granted from the EU budget to support research on individual energy technologies reveals an apparent imbalance between the research funding dedicated to nuclear power on the one hand and to all other energy technologies on the other hand. R&D on energy technologies excluding nuclear power received € 2.35 billion from 2007 to 2013 under the Seventh Framework Programme (FP7). This includes research for all renewable energy technologies, but also carbon capture and storage (CCS) and smart grids. At the same time, research funds granted to nuclear power comprising fission and fusion amounted to € 4.1 billion from 2007 to 2013 (European Commission 2017). The major part of the funding was dedicated to fusion technology - a technology of which the first prototype plant is expected to be connected to the grid by 2050 (European Commission 2015b). Nuclear fission alone received more research funding than any other of the so-called Strategic Energy Technology (SET) Plan technologies comprising low carbon energy technologies singled out by the European Commission as promising and thus eligible for subsidisation.[15] A further remarkable fact in this context is that the share of corporate investment in RD&D expenditures for nuclear power with 52% is low compared to the other SET technologies. Only CCS, which is in a very early stage of development, as well as grids technology show lower shares of corporate investment. Wind energy, in contrast, has a share of corporate investment in R&D of 76% (European Commission 2013). Nuclear power has also been a major beneficiary of EU research funding in the past. As part of the EU research programs FP1 to FP6, covering the period between 1984 to 2007, nuclear power received € 6.61 billion € (inflation adjusted for 2010) in research funding (Küchler and Meyer 2010).

An Ecofys study (2014) analyses energy subsidies and costs in the EU, taking into account current and historic state interventions with the character of subsidies. According to the study, energy subsidies in the EU28 amount to € 113 billion[16] in 2012, with subsidies to nuclear power reaching € 6.96 billion. Of these, € 3.7 billion stemmed from Member States (mainly the UK) and € 3.26 billion from the EU budget (Ecofys 2014). While current subsidies granted to nuclear power production are minor compared to other energy technologies (e.g. coal), historic subsidies directed towards nuclear energy are substantial. From 1970 to 2007 cumulative historic subsidies reached € 220 billion aiming at reducing cost of capital for state owned companies building nuclear power plants. Additionally, EU Member States spent € 84 billion on R&D on nuclear energy (mainly fission, but also fusion) between 1974 and 2007, which make up for 78% of overall R&D expenditures on energy technologies. Finally, € 87 billion were spent on RD&D for energy supply technologies, which, however, not solely benefitted nuclear power.

[15] For the SET Plan see European Commission (2015a).
[16] All figures cited in this section are inflation adjusted for 2012.

It ought to be stressed that the Ecofys (2014) study provides a conservative estimate of the subsidies for nuclear power granted by Member States, given that the magnitude of indirect subsidies in the form of tax exemptions and tax free accruals[17] for decommissioning and waste management is disputed. For Germany, Küchler and Meyer (2010) show that the latter can be substantial. Their analysis arrives at € 194.9 billion of overall subsidies for the nuclear power sector for the period between 1950 and 2010. The most important items include research expenditure (€ 55.2 billion), tax exemptions (€ 44.2 billion), and tax free accruals for decommissioning and waste management (€ 68.3 billion).[18]

Finally it is interesting to note that generally Member States' room for manoeuvre for granting subsidies to electricity providers is restricted by EU wide restrictions for state aid. In face of the increasing private costs of nuclear power generation, the European Commission's assessments of government subsidies are gaining in importance as possibly decisive factors for private investors' readiness to invest in nuclear energy in the future. One recent very prominent example is the European Commission's decision not to qualify guaranteed feed-in tariffs for Hinkley Point as state aid prohibited according to EU regulations.

[17] In several EU Member States decommissioning funding systems rely heavily on internal funds based on tax-exempted accruals, e.g. in Germany or France. In other Member States, like Sweden, Finland, the Slovak Republic or Spain, the nuclear power plant operators have to contribute to a national fund for decommissioning and waste management. Exempting accruals for decommissioning and waste management from taxation on the one hand represents a hidden indirect subsidy and a distortion of competition on the other hand.

[18] For a detailed presentation of the methodological approach to calculate the volume of tax exemptions see Küchler and Meyer (2010).

4. Potential revenues of an EU-wide nuclear power tax

This chapter briefly sketches the main arguments for an EU-wide nuclear power tax as one tax-based own resource to finance the EU budget. We then present the key features of such a tax and provide a rough estimate of the revenues to be expected by the introduction of this nuclear power tax in the 14 EU Member States operating nuclear power plants.

4.1 The case for an EU-wide nuclear power tax

In the EU there is a strong case for introducing nuclear power taxes on a harmonised basis. Very generally, assigning a role to the EU in the taxation of nuclear power may be justified by the fact that the EU already is a major player in the field of nuclear policy.[19] On the one hand, the EU is an important provider of subsidies especially for research. On the other hand, the EU established the regulatory framework regarding safety provisions for nuclear power plants and radioactive waste repositories in Europe. In addition, a nuclear power tax aiming at siphoning off windfall profits linked to carbon pricing is closely linked to an existing EU policy, namely the ETS.

Unilateral introduction of nuclear power taxes at Member State level may lead to a distortion of competition in the internal market for energy (which the EU Energy Taxation Directive aims to avoid). The externalities associated with nuclear power generation, in particular safety risks, but also the challenges posed by decommissioning and nuclear waste management, do not stop at the borders of nuclear power producing Member States, but are cross-border in nature. Unilateral tax rate setting will therefore lead to under-taxation from a European perspective, as externalities affecting third countries won't be considered by national governments when determining tax rates of unilaterally implemented nuclear power taxes.

Revenues of a nuclear power tax should be assigned to the EU as one sustainability-oriented tax-based own resource partially replacing national contributions by Member States.[20] As pointed out above, the externalities of nuclear power are cross-border in nature. In a liberalised energy market with cross-border electricity trade also the benefits of nuclear power generation in terms of contributing to the security of electricity supply are not confined to national borders. Thus the potential revenues of nuclear power taxes levied at

[19] For a brief overview of the engagement of the EU in European nuclear energy policy see Kiyar and Wittneben (2010).
[20] See for a detailed criticism of the current system of own resources and the concept of sustainability-oriented tax-based own resources for the EU budget Schratzenstaller et al. (2016 and 2017) and HLGOR (2016).

the level of individual Member States are hardly attributable to them, which speaks in favour of assigning revenues to the EU level.

4.2 Design of an EU-wide nuclear power tax

4.2.1 Tax base of an EU-wide nuclear power tax

Nuclear power taxes can be levied on various tax bases. Currently EU Member States are (or have been in the past) taxing different bases related to nuclear energy production: electricity produced, thermal capacity, nuclear fuel, or nuclear waste (see section 3.1 for details). The EU Energy Taxation Directive 2003/96/EC does not provide any guidelines regarding the taxation of nuclear power (Küchler and Meyer 2009). The directive sets legally binding minimum tax rates for different energy products including electricity, for which the minimum tax rate is 0.1 Cent per kWh. According to article 14 of the directive, the minimum tax rates do not apply to energy products serving as inputs in electricity production: in principle these should not be taxed at all, although exemptions due to environmental concerns are possible. At first sight this provision seems to prohibit the taxation of nuclear fuel. However, in fact nuclear fuels are not covered by the directive at all, as they are not included in the energy products listed in article 2 of the directive.

A tax on nuclear fuel is most likely to have steering effects by incentivising the efficient use of nuclear fuel (Küchler and Meyer 2009). Also, it is clearly an environmental tax and as such its introduction would be compatible with European law (Küchler and Meyer 2009). In the case between the German state and the German nuclear power plant operator RWE, the European Court of Justice ruled that the German nuclear fuel tax, in place between 2011 and 2016, was not at odds with the EU Energy Taxation Directive 2003/96/EC, as nuclear fuel is no energy product listed in the directive. Also, the court stated that the tax does not violate provisions of the Euratom Treaty or the EU Excise Duty Directive 2008/118/EC. Moreover, the tax cannot be seen as prohibited state aid (European Court of Justice 2015).

Another possible tax base for a nuclear power tax is thermal capacity, i.e. the maximum amount of electricity which can be produced by a reactor running at full capacity. During times of normal operation, thermal capacity is proportional to electricity produced, depending on the load factor. Compared to a tax on nuclear fuel, a tax on thermal capacity – similar to a tax on electricity produced – has the clear advantage of administrative simplicity (Küchler and Meyer 2009).

Charges on nuclear waste may be levied to reimburse funds for the management of radioactive waste. Currently, Member States are in charge of the management of radioactive waste and decommissioning of nuclear power plants, within the general rules (e.g. the polluter pays principle) set up by the EU. Nuclear waste as a tax base may have ambivalent effects. On the one hand, taxes levied on the amount of nuclear waste could encourage the development of new fuel cycle technologies (Rogner 2012). On the other hand, a tax on nuclear waste might entail the danger that it could be used as an argument by the nuclear industry later to circumvent the polluter pays principle and have society pay for the disposal of nuclear waste. Given the diverse strategies for generating funds for the back-end fuel cycle currently pursued in the Member States operating nuclear power plants, the implementation of an EU-wide radioactive waste tax may be difficult.

4.2.2 Tax rate of an EU-wide nuclear power tax

In principle, corrective Pigovian taxes aim at creating a socially efficient outcome by gradually adjusting the tax rate and thus the taxed externality until an optimal level is reached. When it comes to nuclear power, however, there is no easy way to gradually adjust the risk so as to eventually achieve a socially efficient outcome, as the nuclear industry lacks flexibility. The construction of a nuclear power plant creates a substantial risk, whereby the actual accident probability is very uncertain. It is impossible to calculate solidly the gradual impact of safety measures on risk, which would then justify graduated tax rates. Naturally, safety regulations at a given pre-determined level have to be followed, and investments in safety upgrades have to be made. Such safety regulations are nothing optional but are of an "all-or-nothing" nature: we do not want firms to choose an "efficient" trade-off between investing in nuclear safety and risk reduction. Rather a nuclear plant which does not follow safety regulations simply has to be shut down.

Nonetheless, there may be some scope for imposing differentiated tax rates on individual nuclear power plants in theory. For example, the potential costs of an accident depend a lot on the population density in the area where a nuclear power plant is located, as this determines how many people will have to be evacuated in the case of a major accident etc. In practice, however, such a tax design does not appear to be practicable, not least due to the difficulties to determine the external costs of nuclear power.

For ease of exposition, we will therefore consider only a uniform tax rate per kWh of electricity produced. We suggest a flexible tax rate with up to three components. The first tax component is a Pigovian tax of 1 cent per kWh aiming at the internalization of the risk of nuclear accidents. Nuclear power does not have to carry the full costs of insurance against nuclear accidents, which may be considered as distortion of competition.[21] Therefore one major objective of the tax is to level the playing field between nuclear energy and other industries.

As a Pigovian tax rate, we propose a symbolic tax rate of 1 cent per kWh. This is more than double the maximum expected external costs of a nuclear accident as presented in the studies reviewed in section 1.2.1.2, but staggeringly little when compared to the risk aversion adjusted external costs. Still, a tax rate of 1 cent per kWh means a significant increase of the LCOE of nuclear energy (which range between 3 cents to 5 cents per kWh for the existing fleet and 4 cents to 9 cents per kWh for newly built nuclear reactors (CASES 2011; D'haeseleer 2013; Cour des Comptes 2012)), while not rendering nuclear power uncompetitive.

The second component of our nuclear power tax concept relates to windfall profits due to carbon pricing. We suggest a flexible tax rate which depends on the price of carbon: It would be applied only above a certain threshold for the price of carbon, as below this threshold it can be expected that carbon pricing won't influence electricity prices significantly. The price of carbon is multiplied by 0.0005 to derive the tax rate per kWh of electricity produced. A carbon price of 25 € per tonne of CO2 would thus lead to a windfall profits tax on nuclear power of 1.25 cents per kWh. This tax would only be charged if the carbon price exceeds 15 € per tonne carbon emissions. A carbon price of 25 € per tonne of CO2 would result in tax revenues of approximately € 10 billion per year in the whole of the EU.[22] The actual effect of the carbon price on the wholesale price of electricity will require close monitoring and possibly adaptations of the tax rate.

The third component of the nuclear power tax proposed here consists in a tax on windfall profits due to long term operation of nuclear power plants, which is currently proposed by the European Commission as a way to bridge capacity gaps in its Energy Roadmap 2050. As explained above, long term operation of nuclear power plants is expected to yield considerable profits, which we suggest to tax at a rate between 90% and 100%. This tax should be linked to the license granting process. Each nuclear power plant seeking to obtain a renewal of its licence should be obliged to pay extra fees of the order of magnitude of the expected windfall profits. Based on a very cautious first rule of thumb calculation these

[21] See Heyes (2002), see also D'haeseleer (2013) and Meyer (2012) and the literature cited herein.
[22] This calculation assumes no changes in production of nuclear power with respect to the year 2014. As nuclear capacity is projected to decrease until 2025, the revenues of any nuclear tax will decrease accordingly.

profits can be estimated at € 200 million per year for a nuclear reactor with 1,000 MWh of installed capacity.[23]

Estimating potential revenues of the proposed nuclear power tax needs to rest on some assumption on the elasticity of the tax base. In principle, the more capital intensive an industry is, the smaller is its short-term price elasticity of supply (Dahl 2002). As nuclear power is extremely capital intensive, we can expect the short term supply elasticity to be close to zero. In particular, the supply of nuclear energy cannot be increased quickly. The building of a nuclear reactor from licensing of the project to connection to the grid can easily take more than a decade. Nevertheless, if the situation were such that the operation of a nuclear power plant would result in losses only, a plant could be shut down quite quickly. The question is whether a newly introduced tax on nuclear power would lead to plants being shut down.

A closer look at the cost structure of nuclear plants can help to clarify matters. The operating costs of nuclear power plants are low and stable, leading to marginal costs of electricity production far below the market price of electricity in most countries (D'haeseleer, 2013). An EU-wide tax on nuclear power will increase operating costs. However, 60% to 85% of the total generating costs of nuclear energy are due to the construction of the reactor (D'haeseleer 2013). As soon as construction of a reactor is completed, it is in the interest of its operator to keep the reactor running in order to pay off investment costs. Moderate tax increases should not affect the decision of whether to keep an existing plant open, but it is possible that the math on future plants might change.[24]

The introduction of a tax rate of 1 cent per kWh will raise generating costs of nuclear power by 20% to 33%. This will decrease the profitability of nuclear power plants accordingly and will as well reduce corporate tax revenues. However, for plants currently in operation and requiring little additional inputs now, profitability per se is not in danger. Fluctuations in the producer price of electricity have the potential to be more harmful for nuclear power plant operators (D'haeseleer 2013).

[23] A nuclear power plant with 1,000 MWh capacity and a typical load factor of 80% (meaning that it is running at full capacity 80% of the time) produces about 7 million MWh per year. If we assume that the average price at which the electricity can be sold is 5.5 cents per kWh (somewhere within the range of the LCOE of gas), the nuclear power plant will make a yearly profit of about € 200 million after lifetime extension.

[24] In Spain the Garoña Nuclear Power Plant was closed down in 2012, with the operator arguing that newly introduced taxes were part of the problem. In fact, the operating license of the plant was about to expire in 2013, and a license renewal until 2019 would only have been granted if considerable upgrades had been carried out. The plant was shut down, but a year later the operator asked for a new license until 2031. So far, no final decision has been taken (Stibbs 2016). This particular episode shows that at the end of a licensing period, nuclear power plants might be more sensitive to taxation, and maybe old plants might be shut down earlier because of a tax on nuclear power.

However, a tax on nuclear power will affect the profitability assessment of new nuclear power plants. Currently, five EU Member States (Bulgaria, the Czech Republic, Lithuania, Poland, and Romania) plan to build new reactors; however, the projects are still in a preparatory state (European Commission 2016a). In three EU Member States new reactor projects are in a licensing process (United Kingdom, Finland, and Hungary). These projects might be affected by the introduction of a nuclear power tax. Four reactors are currently under construction in the EU (one each in Finland and France, and two in Slovakia).

4.3 Potential revenues of an EU-wide nuclear power tax

As stated above, our tax proposal comprises three elements. The windfall profits component relating to carbon pricing will only be introduced if the ETS starts working properly and carbon prices rise above a threshold value of 15 € per ton of carbon emissions. Given the current state of affairs, only the Pigovian tax component would be introduced. The expected revenues amount to approximately € 8.3 billion per year, assuming that the introduction of the tax leaves the current level of nuclear power production unchanged. As the nuclear power tax will reduce plant operators' profits corporate tax revenues of the Member States affected by it will be reduced accordingly. Thus, the estimated potential revenues presented in Table 2 do not represent the net increase of fiscal revenues in the EU but will be lower if tax payments may be deducted from the corporate tax base.

Table 2: Potential revenues of an EU-wide nuclear power tax

	Nuclear electricity production in 2014, GWh	**Pigovian Tax revenues in € million**	**Windfall profits tax: 25€/t CO_2 revenues in € million**	**Total revenues in € million**	**EU contributions in 2015 in € million**
Tax rate		1 cent/kWh	1.25 cent/kWh		
Belgium	31,969	319.69	399.61	719.30	3,691.9
Bulgaria	15,014	150.14	187.68	337.82	424.1
Czech Republic	28,636	286.36	357.95	644.31	1,315.2
Germany	91,800	918	1147.50	2,065.50	24,283.4
Spain	54,961	549.61	687.01	1,236.62	8,772.5
France	415,857	4,158.57	5,198.21	9,356.78	19,012.5
Hungary	14,778	147.78	184.73	332.51	945.8
Netherlands	3,873	38.73	48.41	87.14	6,391.0
Rumania	10,739	107.39	134.24	241.63	1,319.4
Slovenia	6,061	60.61	75.76	136.37	340.7
Slovakia	14,420	144.2	180.25	324.45	607.9
Finland	22,646	226.46	283.08	509.54	1,729.1
Sweden	62,185	621.85	777.31	1,399.16	3,513.3
UK	57,903	579.03	723.79	1,302.82	18,209.4
Total	830,842	8,308.42	10,385.53	18,693.9	90,556.2

Source: Eurostat, European Commission, own calculations.

Compared to Member States' current national contributions to the EU budget, the potential revenues of a tax on nuclear power are rather moderate. Total national contributions to the EU in 2015 amount to € 118.6 billion, while the nuclear power tax would generate no more than € 8.3 billion. If the carbon price rose to 25 € per tonne of CO2 and the windfall profits tax on nuclear power was levied, tax revenues would increase to € 18.7 billion. Hereby it has to be kept in mind that tax revenues would diminish as nuclear power is being phased in the medium-term, for example in Germany and Sweden.

5. Conclusion

Overall, an EU-wide nuclear power tax is to be assessed favourably in terms of sustainability-orientation. First of all, it impacts positively on environmental sustainability. Moreover, it should score well with regard to the social dimension of sustainability: in the current system of energy pricing taxing nuclear power is attractive as the tax is unlikely to hit consumers. Of course, tax incidence issues at the level of the EU Member States can be expected to be the subject of intense debates among Member States, considering that only one half of them is generating nuclear power at all and that only 20 percent of nuclear power reactors are located in "newer" Member States. Against the backdrop of interconnected national electricity markets in the EU, a challenging task for future research is the determination of actual regional incidence of a EU-wide nuclear power tax, as revenues cannot simply be attributed to those Member States where nuclear power reactors are located. Furthermore, depending on how tax revenues will be spent, it may be hard to convince EU Member States with large shares of nuclear power to give up completely or partially the revenues from a nuclear power tax; and obviously particularly those Member States already taxing nuclear power: also against the backdrop of rather diverging perspectives on and prospects of nuclear power across Member States.[25] Future research should address the implications of financing the EU budget partially from a tax on nuclear power for EU expenditures. Moreover, it should be kept in mind that in the medium-term nuclear power is being phased out and thus the tax base will disappear accordingly in several Member States, as Germany and Sweden, with possibly additional Member States to follow. Finally it has to be stressed that the tax could be implemented without assigning own taxing powers to the EU itself: the 14 Member States producing nuclear power could transfer the tax revenues completely or partially (to provide an incentive for tax collection at Member State level) to the EU based on a remittance system.

[25] See Thomas (2012) for a presentation and discussion of the prospects of nuclear power in the European countries producing nuclear energy.

6. References

Badcock, Jeremy and Lenzen, Manfred. 2010. Subsidies for Electricity-Generating Technologies: A Review. *Energy Policy* 38(9): 5038-5047.

CASES – Cost Assessment of Sustainable Energy Systems. 2011. *Results of the Project*. www.feem-project.net/cases/

CEPN – Centre d´étude sur l´evaluation de la protection dans le domaine Nucléaire. 1995. *ExternE Externalities of Energy. Vol. 5: Nuclear*. Luxembourg: European Commission.

Cour des Comptes. 2012. *Die Kosten der Kernenergie. Zusammenfassung des öffentlichen thematischen Berichts des Cour des Comptes*. Paris: Cour des Comptes.

Dahl, Carol A. 2002. Energy Demand and Supply Elasticities. In *Encyclopedia of Life Support Systems (EOLSS)*. Oxford, UK: EOLSS Publishers (online). http://www.eolss.net/Sample-Chapters/C08/E3-21-02-04.pdf.

Davis, Lucas W. 2012. Prospects for Nuclear Energy. *Journal of Economic Perspectives* 26(1): 49–66.

D'haeseleer, William D. 2013. *Synthesis of the Economics of Nuclear Energy. Study for the European Commission, DG Energy, Final Report*. Brussels: European Commission.

Diekmann, Jochen and Horn, Manfred. 2007. *Abschlussbericht zum Vorhaben "Fachgespräch zur Bestandsaufnahme und methodischen Bewertung vorliegender Ansätze zur Quantifizierung der Förderung erneuerbarer Energien im Vergleich zur Förderung der Atomenergie in Deutschland"*. Berlin: Deutsches Institut für Wirtschaftsforschung.

Dones, Roberto. 2007. *Critical Note on the Estimation by Storm van Leeuwen J.W. and Smith P. of the Energy Uses and Corresponding CO2 Emissions from the Complete Nuclear Energy Chain*. Villigen: Paul Scherrer Institute.

ECOFYS. 2014. *Subsidies and Costs of EU Energy. Final Report*.Brussels: Ecofys.

Espensen, Anders, Kohopää, Antti, Pierre, Inge and Solberg, Ingvar. 2015. *Nordic Tax Report 2014*. http://188.117.57.25/sites/default/files/sk-15-nordenergi-tax-2014.pdf

Eurelectric. 2014. *Taxes and Levies on Electricity in 2012*. Brussels: Eurelectric.

European Commission. 2011. *Impact Assessment Accompanying the Cocument Energy Roadmap 2050. SEC(2011) 1565*. Brussels: European Commission.

European Commission. 2013. *EU Decommissioning Funding Data. SWD(2013) 59 final*. Brussels: European Commission.

European Commission. 2014. *Commission Decision of 08.10.2014 on the Aid Measure SA. 34947 (2013/C) (ex 2013/N) Which the United Kingdom is Planning to Implement for Support to the Hinkley Point C Nuclear Power Station. C(2014) 7142 final cor*. Brussels: European Commission.

European Commission. 2015a. *Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation.C(2015) 6317 final.* Brussels: European Commission.

European Commission. 2015b. *Ex-post Evaluation of indirect actions of the Euratom Seventh Framework Programme and of the Euratom 2012 - 2013 Framework Programme.* Brussels: European Commission.

European Commission. 2016a. *Nuclear Illustrative Program. COM(2016) 177 final.* Brussels: European Commission.

European Commission. 2016b. *Next Steps for a Sustainable European Future. European Action for Sustainability. COM(2016) 739 final.* Brussels: European Commission.

European Commission. 2017. Research and Innovation. FP7. Budgets. https://ec.europa.eu/research/fp7/index_en.cfm?pg=budget

European Court of Justice. 2015. *Die deutsche Kernbrennstoffsteuer ist mit dem Unionsrecht vereinbar. Urteil in der Rechtssache C-5/14 Kernkraftwerke Lippe-Ems GmbH / Hauptzollamt Osnabrück. Pressemitteilung Nr. 62/15.* Luxemburg: Gerichtshof der Europäischen Union.

Federal Environmental Agency. 2012. *Methodenkonvention 2.0 zur Schätzung von Umweltkosten.* Dessau-Roßlau: Umweltbundesamt.

Federal Environmental Agency. 2014. *Environmentally Harmful Subsidies in Germany.* Dessau-Roßlau: Federal Environmental Agency.

Fiedler, Swantje. 2016. Kernbrennstoffsteuer nach 2016? Berlin: Forum Ökologisch-soziale Marktwirtschaft.

Finnish Energy Industries. 2014. Nuclear Power in Europe. Brussels: Finnish Energy Industries.

Ewers, Hans-Jürgen and Rennings, Klaus. 1992. Abschätzung der Schäden durch einen sogenannten "Super-GAU". In PROGNOS Schriftenreihe Band 2. *Identifizierung und Internalisierung externer Kosten der Energieversorgung.* Basel: PROGNOS.

Green, Jim. Belgium and the End of Nuclear Power. Nuclear Monitor, 4453. https://www.wiseinternational.org/nuclear-monitor/800/belgium-and-end-nuclear-power.

Hasegawa, Arifumi, Tanigawa, Koichi, Ohtsuru, Akira, Yabe, Hirooki, Maeda, Masaharu, Shigemura, Jun, Ohira, Tetsuya, Tominaga, Takako, Akashi, Makoto, Hirohashi, Nobuyuki, Ishikawa, Tetsuo, Kamiya, Kenji, Shibuya, Kenji, Yamashita, Shunichi and Chhem, Rethy K. 2015. From Hiroshima and Nagasaki to Fukushima 2. Health Effects of Radiation and Other Health Problems in the Aftermath of Nuclear Accidents, with an Emphasis on Fukushima. *The Lancet* 386(9992): 479–488.

Heyes, Anthony. 2002. Determining the Price of Price-Anderson. What is the Cost of Federal Liability Protection for Nuclear Power? *Regulation* 25(4): 26-32.

HLGOR – High Level Group on Own Resources. 2016. *Future Financing of the EU.* Brussels: HLGOR.

IAEA – International Atomic Energy Agency. 2017. *PRIS – Power Reactor Information System*. https://www.iaea.org/pris/.

Kitson, Lucy, Wooders, Peter and Moerenhout, Tom. 2011. *Subsidies and External Costs in Electric Power Generation: A Comparative Review of Estimates*. Geneva: International Institute for Sustainable Development.

Kiyar, Dagmar and Wittneben, Bettina F. 2012. Nuclear Energy in the European Union After Fukushima: Political and Economic Considerations. *CESifo DICE Report* 10(3): 9-15.

Kovynev, Alexey. 2015. Nuclear Plants in War Zones. *Nuclear Engineering International*. 2015, March 19th. http://www.neimagazine.com/features/featurenuclear-plants-in-war-zones-4536247/.

Küchler, Swantje and Meyer, Bettina. 2009. *Atomsteuer: Konzept für die verursachergerechte Anlastung von Folgekosten der Atomenergie und für die Abschöpfung von leistungslosen Zusatzgewinnen*. Berlin: FÖS - Forum ökologisch-soziale Marktwirtschaft.

Küchler, Swantje and Meyer, Bettina. 2010. *Staatliche Förderungen der Atomenergie im Zeitraum 1950-2010*. Berlin: FÖS - Forum ökologisch-soziale Marktwirtschaft.

Lelieveld, Jos, Kunkel, David and Lawrence, Mark G. 2012. Global Risk of Radioactive Fallout after Major Nuclear Reactor Accidents. *Atmospheric Chemistry and Physics* 12(9): 4245-4258.

Meyer, Bettina. 2012. *Externe Kosten der Atomenergie und Vorschläge zur Reform des Atomhaftungsrechts. Hintergrundpapier zur Dokumentation von Annahmen, Methoden, und Ergebnissen*. Berlin: FÖS - Forum ökologisch-soziale Marktwirtschaft.

Momal, Patrick and Pascucci-Cahen, Ludivine. 2012. *Massive Radiological Releases Profoundly Differ from Controlled Releases*. Fontenay-aux-Roses: EUROSAFE Conference.

OECD. 2010. *Comparing Nuclear Accident Risks with those from other Energy Sources*. Paris: OECD NEA (Nuclear Energy Agency).

OECD. 2011. *Carbon Pricing, Power Markets and the Competitiveness of Nuclear Power*. Paris: OECD NEA (Nuclear Energy Agency).

OECD. 2016. *Costs of Decommissioning Nuclear Power Plants*. Paris: OECD NEA (Nuclear Energy Agency).

Pearson, Mark and Smith, Stephen. 1991. *The European Carbon Tax: An Assessment of the European Commission's Proposals*. London: The Institute for Fiscal Studies.

Rogner, Holger. 2012. Green Growth and Nuclear Energy. *CESifo Dice Report* 10(4): 39-49.

Rozas, José A. 2014. Taxation on Nuclear Waste in Spain. *International Journal of Environmental Protection and Policy* 2(2): 96-103.

Schneider, Mycle and Froggatt, Antony. 2016. *The World Nuclear Industry Status Report 2016*. Paris: Mycle Schneider Consulting.

Schratzenstaller, Margit, Krenek, Alexander, Nerudová, Danuše and Dobranschi, Marian. (2016). *EU Taxes as Genuine Own Resource to Finance the EU Budget – Pros, Cons and Sustainability-oriented Criteria to Evaluate Potential Tax Candidates*. FairTax Working Paper 03.

Schratzenstaller, Margit, Krenek, Alexander, Nerudová, Danuše and Dobranschi, Marian. 2017. *EU Taxes for the EU Budget in the Light of Sustainability Orientation – a Survey*. Journal of Economics and Statistics (forthcoming).

Schwarz, Hans-Günter and Lang, Christoph. 2006. *The Rise in German Wholesale Electricity Prices: Fundamental Factors, Exercise of Market Power, or both?* IWE Working Paper 2006(02). Erlangen: Institut für Wirtschaftswissenschaft.

Sijm, Jos, Neuhoff, Karsten and Chen, Yihsu. 2006. CO2 Cost Passthrough and Windfall Profits in the Power Sector. *Climate Policy* 6(1): 49-72.

Sovacool, Benjamin K. 2008a. Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey. *Energy Policy* 36(8): 2940-2953.

Sovacool, Benjamin K. 2008b. The Costs of Failure: A Preliminary Assessment of Major Energy Accidents, 1907 to 2007. *Energy Policy* 36(5): 1802-1820.

Stibbs, Jon. 2016. Spain Nuclear Plant Fate Hangs in Balance. *ICIS*. 2016, February 15th. http://www.icis.com/resources/news/2016/02/15/9969409/spain-nuclear-plant-fate-hangs-in-balance/.

Thomas, Steve. 2012. Energy: Sources and Strategies. *CESifo DICE Report* 10(3): 3-8.

Vollebergh, Herman R.J. 2008. Lessons from the Polder: Energy Tax Design in The Netherlands from a Climate Change Perspective. *Ecological Economics* 64(3): 660-672.

Warner, Ethan S. and Heath, Garvin A. 2012. Life Cycle Greenhouse Gas Emissions of Nuclear Electricity Generation. Systematic Review and Harmonization. *Journal of Industrial Ecology* 16(1): S73-S92.

Wheatley, Spencer, Sovacool, Benjamin and Sornette, Didier. 2016. Of Disasters and Dragon Kings: A Statistical Analysis of Nuclear Power Incidents and Accidents. *Risk Analysis* 37(1): 99-115. doi:10.1111/risa.12587.

World Bank Group - ECOFYS. 2016. *Carbon Pricing Watch 2016*. Washington/DC: World Bank.

Zorn, Anthony. 1999. Report on the Concrete Steps of Green Budget/Tax Reform in the Netherlands – Retrospective and Outlook. In Schlegelmilch, Kai (ed.): *Green Budget Reform in Europe: Countries at the Forefront*. Berlin et al.: Springer, 109-120.

7. Project information

FairTax is a cross-disciplinary four year H2020 EU project aiming to produce recommendations on how fair and sustainable taxation and social policy reforms can increase the economic stability of EU member states, promoting economic equality and security, enhancing coordination and harmonisation of tax, social inclusion, environmental, legitimacy, and compliance measures, support deepening of the European Monetary Union, and expanding the EU's own resource revenue bases. Under the coordination of Umeå University (Sweden), comparative and international policy fiscal experts from eleven universities in six EU countries and three non-EU countries (Brazil, Canada and Norway) contribute to FairTax research.

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