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Carbon Leakage of Nuclear Energy – The Example of Germany

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1. Introduction

Carbon leakage is the increase in emissions outside a region as a direct result of the policy to cap emissions in this region.

Nuclear energy is a low carbon technology but it is not emission free. Lifecycle analyses of nuclear energy find an average carbon intensity of 66g CO_2/kWh of which the largest part (38%) is generated in the front end of the nuclear fuel cycle (uranium mining and milling). Besides the CO_2 emission there are also other environmental and health impacts that are associated with the uranium milling and mining activities.

In Germany nuclear energy use is a controversially discussed topic. In 2002 the out-phasing of nuclear energy by 2022 was decided. In 2010 a new government passed a life time extension of the 17 power plants by on average 12 years, seeing nuclear energy as an important bridging technology to reach Germany's ambitious climate goals. This chapter calculates the carbon leakage that is expected to result from the 2010 life time extension. Due to the nuclear incident in Japan in March 2011 the debate about the time plane for the out-phasing for nuclear energy started again in Germany. At the time of writing, it is unclear when and how the out-phasing process in Germany will take place. This work is therefore to be seen as an exemplary study on the issue. Uranium is not mined in Germany and it is not easy to trace the origin of the imported uranium. But it can be said that close to 100% originate from outside of Europe.

This work calculates the expected amount of carbon leakage from German nuclear energy use until 2036. The calculations are based on an energy scenario of the German government, the lifetime extension of nuclear power plants and carbon emission resolved by region for each production step from life cycle analyses.

It is important to incorporate the aspect of carbon leakage in the international discussion about climate friendly energy solutions. This assures fairness and transparency and avoids that countries with emission limits gloat over mitigation achievements whose burden has to be carried by other regions.

2. Carbon leakage - definition and importance

Carbon leakage is the increase in emissions outside a region as a direct result of the policy to cap emissions in this region.

International climate agreements like the Kyoto Protocol and the Copenhagen Accord apply the principle of "common but differentiated responsibility" taking into account a country's economic capability and past accumulated emissions. The Kyoto Protocol sets binding targets for 37 industrialized countries for reducing greenhouse gas emissions by on average 5% against 1990 levels over the five-year period 2008-2012 (United Nations Framework Convention on Climate Change [UNFCCC], 2010). Germany is one of the 37 countries listed in Appendix B of the Protocol which have capped emissions. In the following, countries with emission reduction targets or capped emissions are referred to as constrained countries, while the others are referred to as unconstrained countries. To reach their targets some countries have implemented or are going to implement climate policies and incentives. Carbon leakage provides a loophole in unilateral climate policies and leads to a loss of their effectiveness if viewed from a global level.

The IPCC defines carbon leakage as follows:

"Carbon leakage is the increase in CO_2 emissions outside the countries with emission constraints divided by the reduction in the emissions of these countries, as a result of climate policy in constrained countries." (Intergovernmental Panel on Climate Change [IPCC], 2010)

Viewed mathematically, carbon leakage i.e. the leakage rate L is simply a ratio which is usually given as a percentage.

$$L = \text{emission increase in unconstrained country} / \text{emission reduction in constrained country} \tag{1}$$

L>100% indicates an increase in total emission due to the climate policy. Here the reduction in constrained countries is less than the increase in unconstrained ones. This may be the case because energy and carbon efficiency in unconstrained countries are usually lower than in constrained countries hence more emissions are offset to produce the same amounts of goods (Babiker, 2005). This clearly counteracts the aim of the climate policy.

0%<L<100% represents a loss in effectiveness of the climate policy. Some of the emissions reduced in the constrained countries cannot be counted as eliminated because they caused an increase in emissions in unconstrained countries (Demailly & Quirion, 2008; Gielen & Moriguchi, 2002).

L<0% implies negative carbon leakage, which means that constrained as well as unconstrained countries attained emission reductions. This is found to be possible due to the effect of induced technology transfer (DiMaria & van der Werf, 2008; Golombek & Hoel, 2004; Gerlagh & Kuik, 2007).

L does not give information about the total change in emissions but only about the relative changes in the two countries. To make quantitative statements one still needs to know the emissions in total numbers.

Most studies about carbon leakage consider energy-intensive products as the commodity that causes the leakage. The production of those products is relocated to unconstrained countries and imports to constrained countries increase.

Theoretical studies on the topic come to a wide range of results depending on the model and assumptions. Everything from over 100% to negative carbon leakage has been found possible.

Empirical studies on carbon leakage usually investigate the effect of the European Union's Emission Trading Scheme (EU-ETS) on internationally traded, energy-intensive products

like aluminum, steel, cement and paper. The conclusion is often that there is not much empirical evidence of carbon leakage yet. Different reasons for that can be named. The probably most important one is that the EU-ETS is still a young incentive that has not yet fully developed its impacts on trade flows and production patterns in the concerned countries (Reinaud, 2008; European Comission et. al, 2006).
In this work a new commodity regarding the carbon leakage discussion is studied – the nuclear energy lifecycle.

3. The German energy strategy with focus on the role of nuclear energy

Germany has high ambitions regarding German emission mitigations. But as an industrial country energy supply security and economic energy prices are two very important factors in the discussion about Germany's energy mix. Nuclear energy is a controversially discussed topic in German politics as well as in the population. In 2002 the out phasing of nuclear energy by 2022 was decided (Atomgesetz Novelle, 2002). In 2010 this decision was revised and the life times of nuclear reactors were extended by on average 12 years (Atomgesetz Novelle, 2010). The reason for that is the current government's stance that sees nuclear energy as a necessary bridging technology to reach Germany's ambitious climate goals while securing energy supply and economic energy prices. The lifetime extension can thus be seen as a climate policy. Due to the nuclear incident in Japan in March 2011 the debate about the time plane for the out-phasing for nuclear energy started again in Germany. At the time of writing, it is unclear when and how the out-phasing process in Germany will take place. All data used in this work is from before March 2011.

3.1 The German nuclear law

The German nuclear law (Das deutsche Atomgesetz (AtG)) is the legal basis for nuclear energy use in Germany. It first came into power in 1960. Since then several revisions (AtG Novells) of this law where passed. The 2002 AtG Novell introduced by the SPD/"Bündnis 90 die Grünen" government concluded the phase-out of German nuclear energy. The construction of new nuclear power plants was hereby prohibited and the lifetimes of the existing plants were limited to on average 32 years after commissioning. From this lifetime restriction and the capacity of the different power plants the rest amount of energy that each power plant can produce was calculated. These rest amounts sum up to 2620 TWh of electricity that can be produced by German reactors after 1 January 2000. It is possible to transfer parts of these rest amounts from one reactor to another if favourable. Because of this flexibility it is not possible to state exact date for the out phasing. But the estimated end of lifetime after the 2002 AtG Novell can be seen in Table 1.
In September 2010 the CDU/FDP government introduced a new energy concept for Germany; part of this energy concept is the extension of the life times of the 17 remaining nuclear power plants by on average 12 years. The lifetime extension is established in the 2010 AtG Novell. The life times of power plants which came into operation by 1980 will be extended by 8 years, all younger power plants will operate for an additional 14 years beyond 2022.
Table 1 shows a list of all German nuclear power plants, their annual capacity, the year they were expected to be shut down after the 2002 AtG Novell, the year they are expected to terminate operations after the 2010 AtG Novell. Further the table shows the life time extension and the additional amount of electricity is expected to be produced during this additional life time.

Powerplant	Capacity* [TWh/ year]	Year of operation start	End of lifetime 2002 AtG Novell**	End of lifetime 2010 AtG Novell	LT extension [years]	Capacity extansion [TWh]
Neckarwestheim 1	7.36	1976	2010	2018	8	58.88
Biblis B	11.39	1977	2010	2018	8	91.12
Isar 1	7.99	1979	2011	2019	8	63.92
Biblis A	10.73	1975	2010	2018	8	85.84
Brunsbüttel	7.06	1977	2012	2020	8	56.48
Philippsburg 1	8.11	1980	2012	2020	8	64.88
Unterweser	12.35	1979	2012	2020	8	98.80
Grafenrheinfeld	11.78	1982	2014	2028	14	164.92
Gundremmingen B	11.77	1984	2016	2030	14	164.78
Gundremmingen C	11.77	1985	2016	2030	14	164.78
Philippsburg 2	12.77	1985	2018	2032	14	178.78
Krümmel	12.28	1984	2019	2033	14	171.92
Grohnde	12.53	1985	2018	2032	14	175.42
Brokdorf	12.61	1986	2019	2033	14	176.54
Isar 2	12.92	1988	2020	2034	14	180.88
Emsland	12.26	1988	2020	2034	14	171.64
Neckarwestheim 2	12.22	1989	2022	2036	14	171.08
Total						2240.66

* Source: German Atomforum
** Source: Bundesumweltministerium, 2009

Table 1. Life time extension and yearly capacity of German nuclear power plants

4. Carbon emission of nuclear energy - a life cycle analysis

Nuclear energy is a low carbon technology but it is not emission free. Nuclear power does not directly emit greenhouse gas emissions, but lifecycle emissions occur through plant construction, operation, uranium mining and milling, and plant decommissioning. Life cycle analysis (LCA) is a method to account for the emissions offset during each life phase of a products lifecycle, including the production of the product and its raw material, its use and disposal.
Many life cycle analyses of nuclear energy have been conducted and they come to a wide range of emission intensities. The emission intensities used in this work are based on an analysis of Svacool (2008), who screened 103 life cycle studies of GHG emission for nuclear power plants. As a result 66g CO_2/kWh is the average emission intensity. The lifecycle analysis resolves the emission intensity by steps of the life cycle. The study concludes that on average 38% of the emissions are generated in the front end of the nuclear fuel cycle (uranium mining and milling). This means that the front end of the nuclear fuel cycle which takes almost completely place outside of Europe has an emission intensity of 25.1 CO_2/kWh. In the discussion about carbon leakage these front end emissions are the focus. These

emissions occur outside of Germany and outside of Europe and are due to the life time extension of German nuclear power plants.

4.1 Other environmental impacts and risks in the front end of the nuclear fuel cycle

To have a more comprehensive view on the problem, sections 4.1. will elaborate further environmental impacts and life-threatening risks connected with the front end of the nuclear fuel cycle. These factors do not fall under the issue of carbon leakage but they pose a severe disadvantage to the countries in which the uranium for German power plants is mined and milled.

Uranium mining causes a lot of different disadvantages to employees and the local population as well as to the environment besides the carbon emission from the mining, transportation, power use and building of the facilities. The mineworkers are affected by radiation contamination. The alpha radiators radium-226 and its daughter radon as well as thorium-232 can cause diseases like lung cancer. A more indirect contamination to the human population occurs form the tailings. After the milling process the wet tailings are typically stored somewhere above ground without any further protection. The drying process leads to radiating dust, which is easily spread by wind. Rainfalls sweep the radiation into the soil and groundwater. Even if there is some kind of protection it is often just an earthy coating and not really effective against heavy rainfall. A problem that could occur after the mine is abandoned is the formation of stagnate water pools from rainwater. Those could especially in Africa become hatcheries for mosquitoes that spread water-borne diseases like malaria (South Virginia Against Uranium Mining, 2008). These environmental impacts and life-threatening risks are not in the attentions of official institutions. In many countries safety guidelines for the mining companies exist on a voluntary basis. No controls or sanctions for non compliance are executed. Very little data is available on the actual impact of the problem. There are no new statistics published by governmental organisations. Most data are collected by the industries themselves and do not represent an independent assessment of the issue (Kalinowski, 2010).

5. Regional resolution of the German uranium imports

Germany has terminated its domestic uranium exploration. All uranium required for German nuclear power plants is imported. To trace the origin of the material is very difficult due to intransparent accounting methods and data confidentiality of certain countries in the trading chain. However, this is required to understand to which country CO_2 emissions are exported. More precisely, the exact carbon leakage depends on the methods applied for uranium mining and milling and these vary significantly by country.

A study conducted by the International Physicians for the Prevention of Nuclear War (International Physicians for the Prevention of Nuclear War [IPPNW], 2010) attempted to resolve the German uranium imports by country of origin.

The largest part of the imported uranium is natural uranium (4.662 t in 2009). Only 897 t of enriched uranium were imported in 2009 (Statistisches Amt der europäischen Union / Statistisches Bundesamt, as cited in IPPNW, 2010).

The uranium demand of German nuclear power plants was 3.398 t natural uranium in 2009. (World Nuclear Power Reactors & Uranium Requirements, Website of the World Nuclear Association, as cited in IPPNW, 2010). The amount of fuel that can be produced from that is between 297 t (5% enriched) and 517 t (3% enriched). Germany is exporter of enriched uranium. Eurostat statistics show that Germany exported 671 t enriched uranium in 2009 to mainly Belgium, France, Sweden and the USA, as well as small quantities to Brazil and South Korea. (Statistisches Amt der europäischen Union / Statistisches Bundesamt, as cited in IPPNW, 2010)

The enriched uranium Germany imported in 2009 came from: France (575t, 64%), Russia (160t, 18%), Netherlands (94t, 10%), USA (41t, 5%), UK (18t, 2%), Belgium (9t, 1%). The enriched uranium from Russia comes from dismantled nuclear weapons.

The countries Germany imports natural uranium from in 2009 are France (2109t, 45%), UK (1914t, 41%), USA (491t, 11%), Canada (134t, 3%) and Netherlands (13t, 0%) (Statistisches Amt der europäischen Union / Statistisches Bundesamt, as cited in IPPNW, 2010).

France and the UK like Germany no longer exploit own uranium resources that means they only function as trader and consumer. Information about the import countries of uranium to France are known, this information is not available for import to the UK. It is not known whether those countries are the original producers of all the uranium or if they also function as traders. Assuming France supplied the uranium in the same shares as it received, the origin of natural uranium used in German power plants in the year 2009 would look the following: Unknown (1914t, 41%), USA (597t, 13%), Australia (569t, 12%), Canada (514t, 11%), Niger (485t, 10%), Kazakhstan (190t, 4%), Uzbekistan (148t, 3%), Russia (84t, 2%), Others (148t, 3%). Since the larges fraction of uranium imports by Germany are from France and given the in-transparency of material flows the best estimate for the distribution of countries of origin is the one presented in Fig. 1.

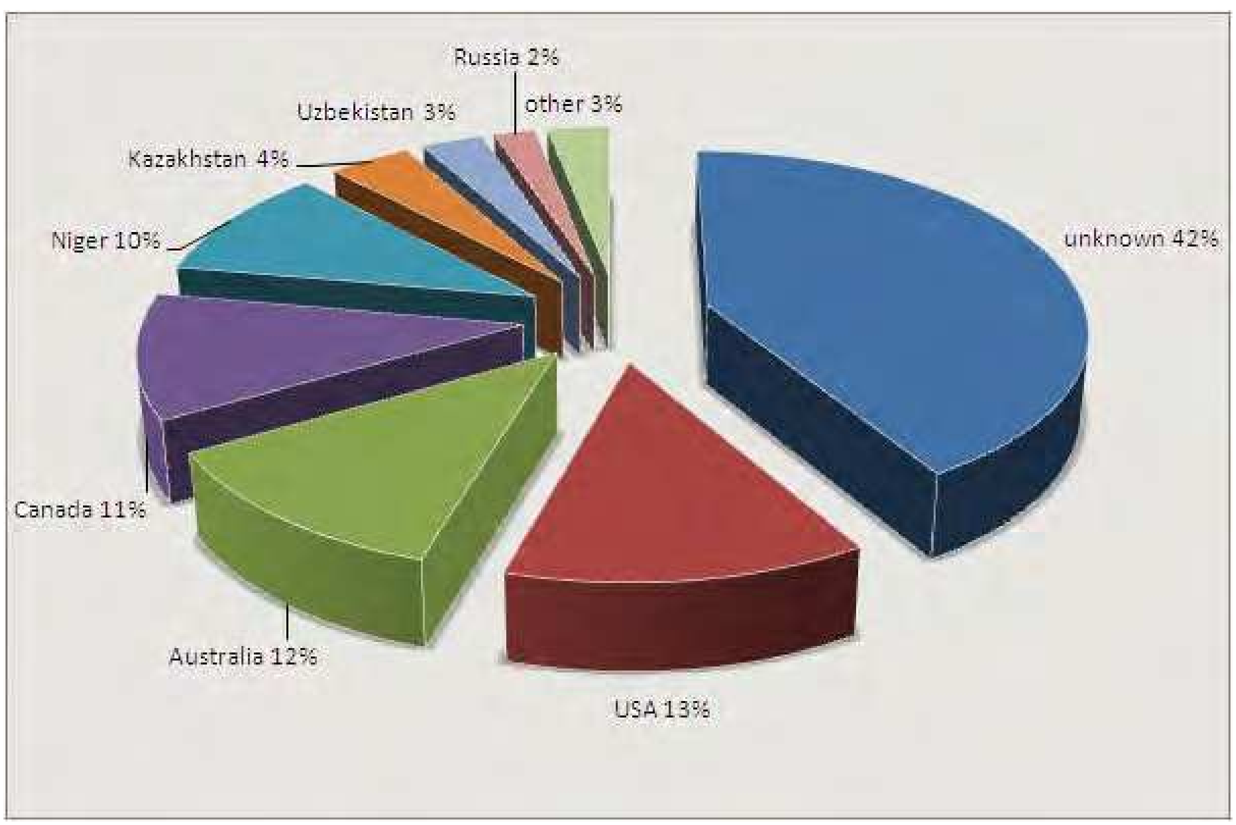

Fig. 1. Assumed origin of natural uranium used in German power plants in the year 2009

With the available data the countries from which the uranium is imported for use in Germany cannot be fully identified. It is however possible to identify the most important mining countries for uranium imports to the EU. These countries are Australia, Russia, Canada, Niger, Kazakhstan, South Africa, Namibia, Uzbekistan and USA. It can be assumed that those countries are also the countries of origin for the German imports but the shares of uranium purchased from the single countries are different between the EU and Germany.

The EURATOM Supply Agency (ESA) 2009 report identified Australia, Canada and Russia as most important suppliers for Europe. Because of the large amounts of trading the ESA has to admit that the origin of all Russian uranium cannot be definitely determined. Whether the origin of Canadian and Australian uranium can be definitely determined is unclear.

Three main conclusions can be drawn from the IPPNW investigations.

The available data are highly inconsistent and intransparent and incomplete. This makes it very hard to answer the question of where does the uranium used in German nuclear power plant originate from. IPPNW contacted the German government to provide information and the conclusion drawn from the answers of the requests was that it seems as if the government tries deliberately to obscure the origin of the uranium.

The second conclusion is that the supply security of uranium from OECD states is not provided. The USA, Australia and Canada are uranium mining countries but those countries were in the last years only responsible for less than 50% of the German uranium imports. The production in these three countries is declining (World Nuclear Association, as cited in IPPNW, 2010). If the global uranium demand rises it is probable that countries like Kazakhstan and Namibia increase their mining activities. A consequence of this is that the German supply with uranium is as unsecure and as dependent of partners outside the OECD as the supply with conventional, fossil energy sources.

The third conclusion is that Germany does not comply with its own pledge not to purchase uranium from countries like Niger in which severe human rights violations and environmental damage occur (Greenpeace "Left in the dust"; Der Spiegel "Der gelbe Fluch", 29.03.2010, as cited in IPPNW, 2010). Also in the past German companies were not able to meet its demand by import from „politically stable" countries. One example is the import of uranium from Namibia in time of apartheid, which is not only morally unacceptable but also violated the UN-resolution *Decree No. I on the Natural Resources of Namibia*, which forbids the prospecting, mining, processing, selling, exporting, etc., of natural resources within the territorial limits of Namibia without permission of the Council (Dumberry, 2007). This historical evidence leads to the belief that German nuclear power plants will also in the future depend on uranium from "politically unstable" countries. Whoever runs nuclear power plants in Europe is responsible for environmental damage and health impacts in the uranium mining countries (IPPNW, 2010).

6. Carbon leakage calculations

In this section the amount of carbon leakage from German nuclear energy use from 2010 until 2036 is calculated based on the facts and data presented in the previous sections. The decrease in emission in Germany and the increase in emission in the uranium mining countries is based on the life time differences of the 2002 and the 2010 AtG Novell and the regionally resolved life cycle analyses.

The formula for carbon leakage is:

$$L = \text{emission increase in unconstrained country} / \text{emission reduction in constrained country} \quad (1)$$

The "emission increase in unconstrained countries" are the emissions that the climate policy, hence the extended lifetimes of the nuclear power plants caused outside Europe. In section 3 we calculated that the lifetime extension leads to an additional 2240.7 TWh of electricity that are produced by nuclear power. The review of the life cycle analyses in section 4 revealed the emission intensity of nuclear energy is on average 66 g CO_2/kWh whereof 25.1 g CO_2/kWh are emitted in the front end of the nuclear energy cycle. As has been explored in section 5, the front end of the nuclear fuel cycle for German nuclear energy does not take place in Germany. The front end emissions that are caused by the 2240.66 TWh of electricity are emissions that are offset outside Europe due to the lifetime extension of nuclear energy in Germany. These 2240.7 TWh * 25.1 g CO_2/kWh = 56.2 Mt CO_2 are the emission increase in unconstrained countries.

The "emission reduction in constrained countries" are the emissions that are not released due to the climate policy, hence due to the extended life times of the nuclear power plants. The extended lifetimes result in a total of 2240.7 TWh of electricity that is produced through nuclear power. As stated in section 4 life cycle analyses show that the emission intensity of nuclear energy is 66 g CO_2/kWh, of these 66 g CO_2/kWh only 40.9 g CO_2/kWh are off set in Germany. 2240.7 TWh * 40.9 g CO_2/kWh = 91.7 Mt CO_2 is the amount of CO_2 that 2240.7 TWh of electricity produced by nuclear power offset in Germany.

It is assumed that the emission intensity with which the 2240.7 TWh would have been produced if there was no lifetime extension is the average emission intensity of the reference scenario taken from the energy scenarios of the German government (Schlesinger, 2010). The emission intensity for the electricity mix is calculated for the years 2008, 2020 and 2030. Table 2 shows the shares of the different primary energy sources for the years 2008, 2020 and 2030 and the emission intensities of those primary energy sources.

The emission intensity that result from the primary energy shares of the reference scenario of the German government after the 2002 AtG Novell is 547.6 g CO_2/kWh for 2008, 520.6 g CO_2/kWh for 2020 and 438.3 g CO_2/kWh for 2030. The emission intensities are multiplied by the power that is after the 2010 AtG Novell produced by nuclear energy. This is 273.7 TWh in the period 2010-2015 which is multiplied by the 2008 emission intensity. The 1076.7 TWh produced in the period 2016-2025 are multiplied by the 2020 emission intensity and the 890.3 TWh produced in the period 2026-2036 are multiplied by the 2030 emission intensity. This results in 1100.6 Mt CO_2 that will be exhausted if the 2240.7 TWh would be produced by using the average emission intensity of the German electricity mix.

Subtracting the emissions resulting from nuclear energy from the ones resulting from the average energy mix, one ends up with the emission reduction that the life time extension of nuclear power plants caused in Germany. This is 1100.6 Mt CO_2 - 91.7 Mt CO_2 = 1008.9 Mt CO_2.

An other interesting figure to look at is the percentage of emission that are causes by nuclear energy in relation to its total emission savings. 91.7 Mt CO_2 /1100.6 Mt CO_2= 0.09, hence 9% of the emissions that are not exhausted by other primary energy sources because they are replaced by nuclear energy are now exhausted by nuclear energy itself.

To calculate carbon leakage the emission increase in unconstrained countries is divided by the emission reduction in Germany:

$$L = 56.2 \text{ Mt } CO_2/1008.9 \text{ Mt } CO_2 = 0.056 \quad (2)$$

The carbon leakage ratio is often presented as a percentage. The carbon leakage for nuclear energy in Germany is 5.6%.

Primary energy sources	2008 [%]	2020 [%]	2030 [%]	Emission intensities [g CO2 / kWh]
Nuclear	23.69	8.5	0	66
Hard coal	19.84	20.76	17.36	1100
Braun coal	23.98	25.08	15.01	950
Gas	13.81	6.98	16.01	600
Pumpreservoirs	0.99	1.3	1.59	15
other combustion materials	2.98	3.65	4.6	15
Hydro	3.23	4.34	4.93	10
Wind onshore	6.43	11.75	14.34	20
Wind offshore	0	4.49	9.43	20
Biomass	4.33	6.39	7.86	15
Photovoltaic	0.7	5.36	7.07	15
Geothermie	0	0.35	0.59	15
Other renewable combustion materials	0	1.07	1.22	15
Average emission intensity of the electricity mix [g CO_2/kWh]	547.6	520.6	438.3	
Electricity produced by nuclear power [TWh] after 2010 AtG Novell	2010-2015 273.7	2016-2025 1076.66	2026-2036 890.3	

Table 2. Shares of different primary energy sources for the years 2008, 2020 and 2030 and their emission intensities for electricity production.

7. Discussion

The calculations are an estimate. Nuclear energy is substituted by the average energy mix. The average emission intensity of the German electricity mix is based on the reference scenario of the energy scenarios of the German government. The actual rate of carbon leakage depends on the emission intensity of the primary energy source that really is replaced by nuclear energy. A replacement of coal could lead to less carbon leakage then a replacement of low carbon primary energy source. The reference scenario assumes that the policies that were in place at the time the study was conducted (August 2010), would continue. The reduction goals of the German government cannot be meet with such a slow decrease in emission intensity of the energy mix. The study about the energy scenarios was conducted to develop an energy concept that can meet the reduction goals. The 2010 AtG Novell is part of this new energy concept.

For countries with large total emissions the emissions offset in through uranium milling and mining of exported uranium do not present a large share of the total emission. In countries with less total emissions countries like Niger for example this situation looks different. Niger's annual emissions are about 870 times less than the German emissions and 6500 times less than the emissions of countries like USA and China. 2009 Niger exported 485 t of natural uranium to Germany. 55.85 kWh of electricity can be produced with one g natural uranium. With a front end emission intensity of 25.1 g CO2/kWh the mining and milling of 485 t uranium result in 642,000 t CO_2. Niger's total emissions in 2007 were 909,000 t (Google public data from World Bank). This data suggests that 70 % of Niger's emission were produced only from uranium produced for German use.

This is an unrealistically high number. If we assume that the front end emission intensity of 25.1 g CO2/kWh is not significantly over estimated other reasons for this high share have to be found. It is for example probable that the CO_2 balance of Niger is incomplete and does not include all emissions from Uranium mining.

Considering that Niger also exports to other countries, CO_2 emission from uranium exports seem to represent a significant share of Niger's total emissions.

8. Conclusion

The amount of carbon leakage from nuclear energy is not big but carbon leakage does exist. Compared to empirical studies on energy-intensive products which have often found no evidence of carbon leakage yet this is a significant finding. Besides the CO_2 emissions offset outside of Germany there are also other risks and environmental contaminations related to the front end of the nuclear fuel cycle. The supply security of uranium which is an often mentioned plus of nuclear energy compared to fossil fuels is eroding as shown in section 5.

The more obvious downsides of nuclear energy use like safety of operation and storage of waste material are in the centre of the public discussion. The downsides presented in this chapter have not been in the centre of attention yet. An increased awareness for those topics might increase the data availability and transparency. Focusing on climate goals without evaluating the impacts that the execution of these goals bring along is not a responsible or sustainable move and might lead to further problems as described in this chapter. In regard of all the downsides causes by uranium mining compensation should be offered by Germany to the uranium exporting countries.

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10. References

Atomgesetz Novelle (2002). Gesetz zur geordneten Beendigung der Kernenergienutzung zur gewerblichen Erzeugung von Elektizität, 22. April 2002, Available from: <http://www.bgbl.de/Xaver/start.xav?startbk=Bundesanzeiger_BGBl>

Atomgesetz Novelle (2010). Elftes Gesetz zur Änderung des Atomgesetzes, 8. December 2010, Available from: <http://www.bgbl.de/Xaver/start.xav?startbk=Bundesanzeiger_BGBl>

Babiker, M.H. (2005). Climate change policy, market structure and carbon leakage. Journal of International Economics, 65:421–445

Bundesumweltministerium. Stand: March 2009 Available from: <www.bmu.de>

Carbon Dioxide Information Analysis Center, March 2011, Available from: <http://cdiac.ornl.gov/trends/emis/nig.html>

Demailly, D. & Quirion, P. (2002). European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry. Energy Economics, 30:2009–2027

Di Maria, C. & van der Werf, E. (2008). Carbon leakage revisited: unilateral climate policy with directed technical change. Environ Resource Econ, 39:55–74

Dumberry, P. (2007). State succession to international responsibility, Martinus Nijhoff Publishers Leiden Boston, ISBN 978 90 04 15882 5, Netherlands

European Comisson, McKinsey & Ecofys (2006). EU-ETS Review; Report on International Competitiveness

German Atomforum. January 2011, Available from: <http://www.kernenergie.de/kernenergie/Themen/Kernkraftwerke/Kernkraftwerke_in_Deutschland/>

Gielen, D. & Moriguchi, Y. (2002). CO2 in the iron and steel industry: an analysis of Japanese emission reduction potentials. Energy Policy, 30: 849–863

Golombek, R. & Hoel, M. (2004). Unilateral Emission Reductions and Cross-Country Technology Spillovers. Advances in Economic Analysis & Policy, Volume 4, Issue 2, Article 3

Google public data from World Bank. May 2011, Available under: <http://www.google.com/publicdata/explore?ds=d5bncppjof8f9_&ctype=l&strail=false&nselm=h&met_y=en_atm_co2e_kt&hl=de&dl=de#ctype=l&strail=false&nselm=h&met_y=en_atm_co2e_kt&scale_y=lin&ind_y=false&rdim=country&idim=country:NER&hl=de&dl=de>

Gerlagh, R. & Kuik, O. (2007). Carbon leakage with international technology spillovers. Workingpaper, 2007

Intergovernmental Panel on Climate Change IPCC (2007). Fourth Assessment Report, Working Group III: Mitigation of Climate Change

IPPNW (2010). Die Versorgung Deutschlands mit Uran, deutsche Sektion der Internationalen Ärzte für die Verhütung des Atomkrieges (IPPNW) Ärzte in sozialer Verantwortung e.V. 21.07.2010

Kalinowski, M. (2010). Life-threatening risks from uranium mining, ZNF Occasional Paper No. 11

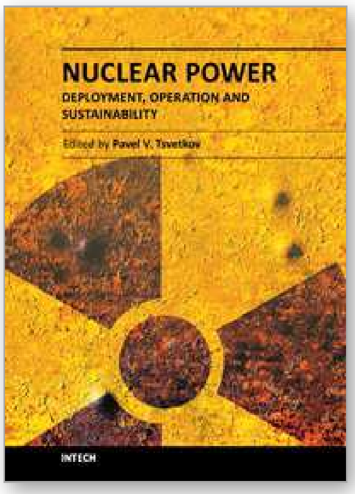
Reinaud, J. (2008). Issues behind Competitiveness and Carbon Leakage Focus on Heavy Industry. IEA, 2008

Schlesinger, M. et al. (2010). Studie Energieszenarien für ein Energiekonzept der Budesregierung, Projekt Nr. 12/10 es Bundesministeriums für Wirtschaft und Technologie, August 2010

South Virginia Against Uranium Mining: How does mining affect people (2008), March 2010, Available from: <http://sccagainsturanium.blogspot.com/2009/02/how-does-mining-affect-people.html>

Sovacool, B. K. (2008). Valuing the greenhouse gas emissions from nuclear power: A critical survey. Energy Policy, Vol. 36, (April 2008), pp. (2940-2953)

United Nations Framework Convention on Climate Change UNFCCC (2010). Available from:<http://unfccc.int/2860.php>



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We are fortunate to live in incredibly exciting and incredibly challenging time. Energy demands due to economic growth and increasing population must be satisfied in a sustainable manner assuring inherent safety, efficiency and no or minimized environmental impact. These considerations are among the reasons that lead to serious interest in deploying nuclear power as a sustainable energy source. At the same time, catastrophic earthquake and tsunami events in Japan resulted in the nuclear accident that forced us to rethink our approach to nuclear safety, design requirements and facilitated growing interests in advanced nuclear energy systems. This book is one in a series of books on nuclear power published by InTech. It consists of six major sections housing twenty chapters on topics from the key subject areas pertinent to successful development, deployment and operation of nuclear power systems worldwide. The book targets everyone as its potential readership groups - students, researchers and practitioners - who are interested to learn about nuclear power.