ARIZONA STATE UNIVERSITY

SCHOOL OF SUSTAINABLE ENGINEERING AND THE BUILT ENVIRONMENT

CESEM

Center for Earth Systems Engineering and Management

Life cycle Assessment on the effectiveness of Germany's energy and climate policy

Christine Sturm

SSEBE-CESEM-2012-CPR-010
Course Project Report Series

May 2012

Ira A. Fulton Schools of Engineering

Christine Sturm

Executive Summary - Life cycle Assessment on the effectiveness of Germany's energy and climate policy

1. Project background

The new German energy legislation introduced by the end of 2011 stipulates the shut-down of all German nuclear power plants until 2022, a new more expensive incentives program for subsidizing electricity production from renewable energy sources, as well as a modified and more cost intensive emission trading system. To ensure a sustainable development in the sense of the Brundland's report definition [16] Governments, politicians and decision makers should concentrate their efforts in order to reestablish a healthy balance between ecology, the economy and social needs. Assuming that economic success is a relevant condition for a sustainable development and therefore companies as well as consumers of goods and services should be able to cover the costs of this sustainable development, environmental and resource protection at all costs would be as unsuccessful as decisions taken on economic considerations alone [17].

2. Research statement

This study aims to assess the effectiveness of Germany's energy policy with respect to the carbon footprint for the entire electricity generation life cycle.

3. System boundary

Total amount of CO2 and other greenhouse gases responsible for global warming effects, emitted over the entire electricity life cycle and expressed as million of metric tons of CO2 equivalents per year and its economic implications.

4. Methodology

The goal of this study is to assess the effectiveness of Germany's energy policy mix with respect to the carbon footprint for the entire electricity generation life cycle, in a "cradle-to-grave" manner, by comparing different policy scenarios. Its scope is to identify and analyze past, current and potential life cycle impacts of GHG emissions of electricity generation from nuclear, coal, natural gas and renewable energies between 1990 and 2050 in the context of the German policy mix and to find out if Germany's policy towards a structural change in the energy sector is sustainable with respect to the entire carbon life cycle of the electricity production.

Therefore, the historical greenhouse gas emissions as well as following alternative energy policy scenarios, were analyzed and compared:

- Baseline Scenario – German Policy from October 2010 – Lifetime prolongation for the nuclear power plants (8 years for nuclear power plants with the first operation date before 1980 for and 14 years for power plants operated first after 1980).
- "After Fukushima" Scenario - March 2011 - corresponding to the current policy (shut down of all nuclear power plants until 2022)

5. Life Cycle Inventory Results / Impact assessment

The lifetime prolongation has, compared with the "after Fukushima scenario" economical benefits (electricity import isn't required). Furthermore, Germany has to replace in the "After Fukushima" scenario its low carbon nuclear electricity production (nearly zero in the "use" phase) with other forms of electricity generation, which are either more carbon intensive (fossil based electricity production) or extremely difficult to structure (electricity production based on renewable energies with extreme capacity fluctuations and reduced utilization hours: wind, solar, etc.). Therefore, the current policy scenario is more likely to be more expensive than the "baseline" scenario (higher electricity prices, higher investment)

6. Conclusion

Considering only the assessed pollutants one should conclude, that Germany's current policy is not likely to deliver a healthy balance between ecology, economy, and social needs with respect to the entire carbon life cycle of the future electricity mix. (Note: The data quality is poor and implies high uncertainty).

However, the integration of other environmental aspects (human health, final disposal of nuclear waste) in the life cycle assessment could eventually lead to the conclusion that Germany's complex transition towards a "neutral" carbon footprint is not only ambitious but also the most sustainable one.

Despite of the high uncertainty of the presented results, LCA remains a very important tool for assessing different decision making processes, a tool which should be better used on a regular basis before and not after taking important political decisions.

Life cycle Assessment on the effectiveness of Germany's integrated energy and climate policy

1. Project background

Although Germany decided in October 2010 to extend the life span of its nuclear power plants by 8 to 14 years (Nuclear Act 2010) it reviewed this decision only six month later, after the nuclear accident from Fukushima, Japan (March 2011) stipulating in its new Nuclear Act released the decommissioning of all German nuclear power plants until 2022. Germany declared furthermore, that this decision will not jeopardize the fulfillment of its Kyoto greenhouse gas reduction commitment.

The new German energy legislation introduced by the end of 2011 stipulates besides the shut-down of all German nuclear power plants until 2022, a new more expensive incentive program for subsidizing electricity production from renewable energy sources, as well as a modified and more cost intensive emission trading system.

To ensure a sustainable development in the sense of the Brundland's report definition [16] Governments, politicians and decision makers should concentrate their efforts in order to reestablish a healthy balance between ecology, the economy and social needs.

Assuming that economic success is a relevant condition for a sustainable development and therefore companies as well as consumers of goods and services should be able to cover the costs of this sustainable development, environmental and resource protection at all costs would be as unsuccessful as decisions taken on economic considerations alone [17].

2. Research statement

In the context of recent German political decisions, questions about the impact of these decisions on Germany's future energy mix and energy prices, on Germany's economy and its development and last but not least on Germany's population impose themselves. Does Germany's policy deliver a healthy balance between ecology, economy and social needs with respect to the entire life cycle - from "cradle to grave"- of the future electricity production? Is it, in other words, a sustainable policy? And if yes, to what extend does it contribute to a sustainable world policy?

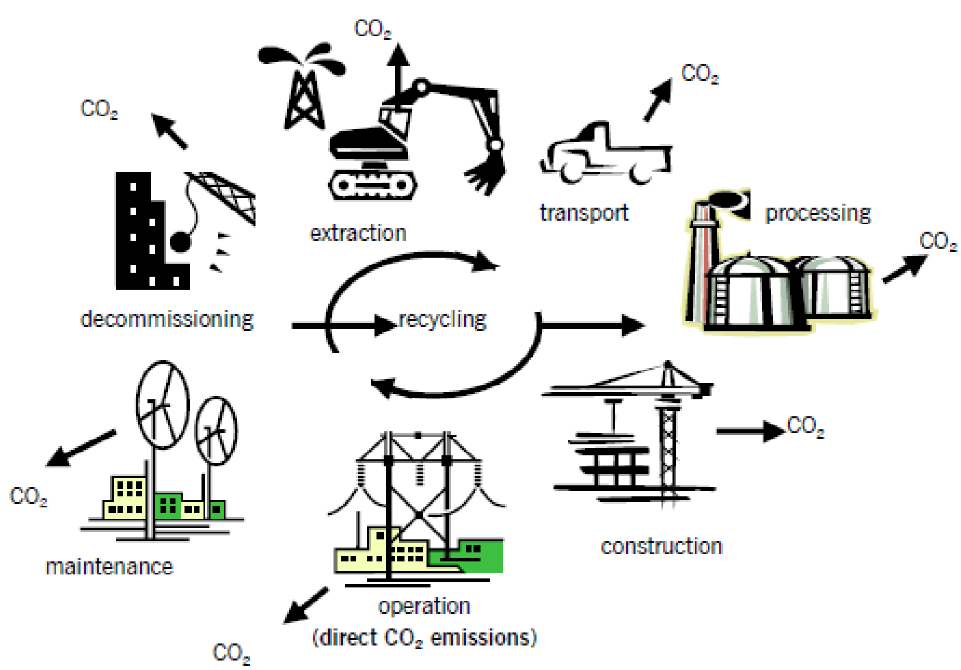
This study aims to assess the effectiveness of Germany's energy policy with respect to the current and potential carbon footprint for the entire electricity generation life cycle, using different methodological approaches to compute and validate the status quo greenhouse gas emissions, as well as two policy scenarios.

3. System boundary

The system boundary includes the total amount of CO2 and other greenhouse gases (GHG) responsible for global warming effects over the entire electricity generation life cycle, expressed in million of metric tons of CO2 equivalents per year as well as the related economic value of the greenhouse gas emissions expressed in €.

Following greenhouse gas emissions: carbon dioxide (CO2 : 1kg CO2 = 1 kg CO2 eqiv.), methane (CH4 1kg CH4 = 21 kg CO2 eqiv.), and nitrous oxide (N2O: 1kg N2O = 310 kg CO2 eqiv.) expressed in CO2 equivalents were taken into consideration among the entire life cycle. The other Kyoto greenhouse gases (hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulphur hexafluoride (SF6) were not subject of this study.
As shown in **Figure 1** emissions can arise directly, during the electricity generation phase (operation) and indirectly during other phases of their life cycle such as extraction, construction, maintenance and decommissioning.

Figure 1. Life cycle CO_2 emissions for electricity generation technologies



Source: UK Parliamentary Office of Science and Technology, Postnote 268,
Carbon footprint of the electricity production, 2006, [14]

Technologies based on fossil fuels (coal, natural gas, oil) release high amouts of CO2 eq because they burn fossil fuels during their operation phase. “Carbon neutral” technologies, such as nuclear, wind, photovoltaic, or biomass electricity generation are not based on the combustion of fossil fuels and do not emit CO2 eq during their operation phase. However, since they emitt CO2 eq in other phases of their lify cycle , these technologies are not completely “carbon free”.

4. Methodology

The goal of this study is to assess the effectiveness of Germany’s energy policy mix with respect to the carbon footprint for the entire electricity generation life cycle, in a “cradle-to-grave” manner, by comparing different policy scenarios.

Its scope is to identify and analyze past, current and potential life cycle impacts of GHG emissions of electricity generation from nuclear, coal, natural gas and renewable energies between 1990 and 2050 in the context of the German policy mix and to find out if Germany’s policy towards a structural change in the energy sector is sustainable with respect to the entire carbon life cycle of the electricity production.

First, a detailed assessment of the relevant policy measures between 1990 and 2012 was made [1, 2, 3, 4]. The results of this assessment are described in 4.1. (Figures 2 and 3)

Second, historical data about Germany’s GHG emission 1990 - 2009 for the energy sector differenciated for each life cycle phase (1. Operation and maintenance – “Use”-phase; 2. Manufacturing - Iron, Aluminum, Glass, Fuel, etc.; 3. Transportation; 4. Construction & Disposal; 5.Fugitive emissions during fuel production) were collected from the National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2009 [5]. Germany’s GHG emissions for the electricity production were calculated from these data using a linear approach. The historical data and the calculated GHG electricity emissions for each life cycle phase are presented in 4.2. (Figures 4, 5, and 6)

Third, the historical electricity mix data 1990 – 2011 (total and renewable) from- Workgroup Energy Balances [6- Arbeitsgruppe Energiebilanzen] were collected and presented in 4.3. (Figures 7 and 8)

Next, the historical energy mix was utilized to validate the life cycle carbon footprint for Germany’s electricity production described in 4.2 using another, more accurate LCA approach. Therefore the specific GHG emission expressed in grams of CO2 eq from several literature LCA approaches were taken into consideration for computing the status quo greenhouse gas emissions of Germany's renewable [7,8,14] (wind power, hydro power, photovoltaic power, biomass and geothermal energy), nuclear [9, 14], and fossil (coal [10, 11, 12, 14] , natural gas and oil [13, 14]) electricity production. The results of are presented in 4.4.

With the specific GHG emissions per kWh el from the literature the status quo of the GHG-Emissions and the two selected future scenarios were calculated. To assess the data quality Germany's yearly GHG emissions computed as described in 4.2 and 4.4 were compared with the official figures of the Federal Environmental Agency. The results of the data quality assessment are presented in 4.5.

Finally, the GHG emissions for two energy scenarios representing Germany's policy "before" and "after" the Fukushima accident were computed using Pehnts dynamic LCA approach, the same literature LCAs, and the technical data from similar Prognos scenarios [14]. These scenarios and the computing assumptions are described in 4.6.

Germany's GHG were calculated using historical emission data, as well as speciffic life cycle emissions for different electricity generation technologies, from several literature sources and expressed as grams of CO2 equivalent per kilowatt hour of electricity generation (gCO2eq/kWh).

4.1. Germany's energy and climate policy

Europe adhered to the Kyoto Protocol [20] adopted in Japan in December 1997 and released until 2012 three Emission Trading Directives according to the "Marrakesh Accords" (2001) stetting binding targets for its Member States for reducing greenhouse gas (GHG) emissions. Furthermore, the European Community released several Directives and Guidelines for minimizing the environmental impact of its Member States by increasing efficiency, promoting renewable energies, combined heat and power production as well as other "low" carbon technologies (Carbon Capture and Storage - CCS).

Germany transposed all these Directives, except the CCS-Directive in national legislation, meeting and often exceeding their requirements. Furthermore, Germany committed itself within the "EU15 – Burden-Sharing-Agreement" [21] to reduce its greenhouse gas emissions until 2012 by 21%, while Europe's average reduction commitment is only 8% for the same period of time.

Figure 2 shows a simplified representation of the international instruments implementted for reducing the greenhouse emissions.

Overview of the Various Categories of Instruments Discussed

International Instruments		National Instruments				
Global Instruments	EU Instruments	Instruments with Global Effects		Specific Instruments		
Kyoto mechanisms Development co-operation	European system of tradable emission permits	General instruments	Specific global warming management instruments	Sector-specific	Technology-specific	Player-specific
External energy and environmental policies	Directives and funding programmes	For example:	For example:	Electricity	EEU[1]	Plant operators
				Heat	CHP[2]	End users
	EURATOM revision	liberalisation	ecological tax reform	Transport	RES[3]	Manu-facturers
Other global governance structures	Energy competence of the EU	reduction of subsidies	local global warming management activities			
Policy Mix						

1) EEU stands for efficient energy use.
2) CHP stands for combined heat and power.
3) RES stands for renewable energy sources.

In order to reduce Germany's environmental impact and to meet the environmental goals set by the Kyoto-Protocol [20] and the EU Burden Sharing Agreement [21] Germany's decision bodies stipulated between 1990 and 2010 extensive incentive programs for promoting cogeneration and renewable energies, prohibited waste disposal and land filling, implemented a complex emission trading system –ETS- and released or modified important energy acts (Energy Economy Act - EnWG, Renewable Energy Acts: EEG- for electricity production and EEWärmeG – for heat production, Cogeneration Act - KWKG, Imission Act -BImSchG, Greenhouse Gases Emission Trading Act – TEHG, CO2 Allowances Allocation Act – ZuG, Nuclear Act, etc).

After the Fukushima nuclear disaster from March 2011 the German government revoked its decision taken only six month earlier (October 2010) to extend the life span of Germany's nuclear power plants by 8 to 14 years. In the mean time Germany decided to restructure the entire energy sector and to enlarge the incentive program for subsidizing renewable energies and to achieve at least a 60% reduction of GHG emission by 2020 and a 80% one by 2050. In this context the Nuclear Act and all Energy Acts listed above were modified by the end of 2011 and entered into force in January 2012.

A brief overview of Germany's legislation with major impact on the energy markets is presented in **Figure 3**.

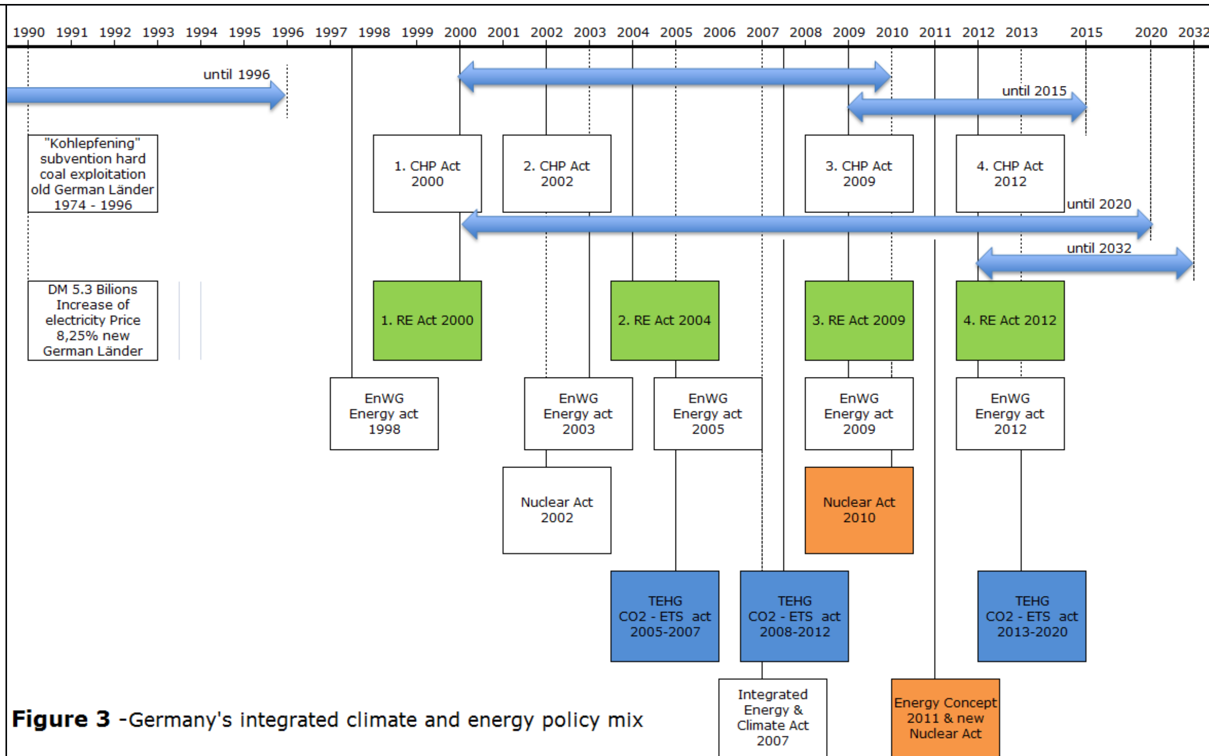


Figure 3 -Germany's integrated climate and energy policy mix

EnWG – Energy Economy Act (liberalization and third party access)
TEHG – Grennhouse Emission Trading Act (2005, 2008, 2013)
EEG – Renewable energy act (2000, 2004, 2009, 2012)
KWKG- CHP Act (2000, 2002,2009, 2012)

4.2. Historical data - GHG Emission 1990 -2009

Figure 4

Germany's historical greenhouse gas emissions between 1990- 2009 are presented in Figure 4. The Diagramm showes that the average historical reduction between 1990 - 2009 is not sufficient for achieving Germany's ambitiouse reduction goal.

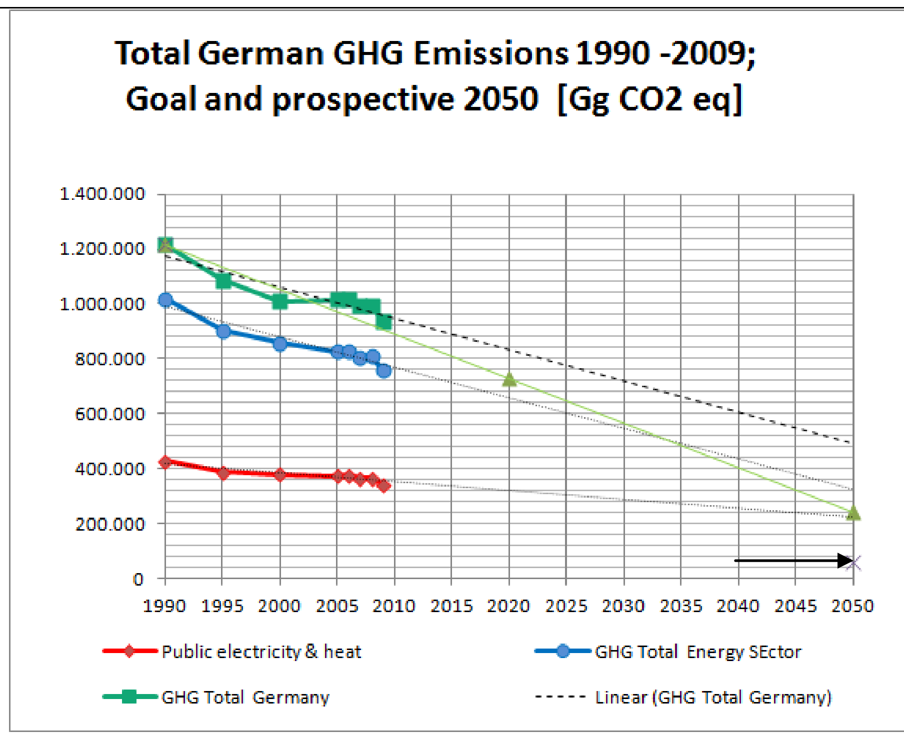
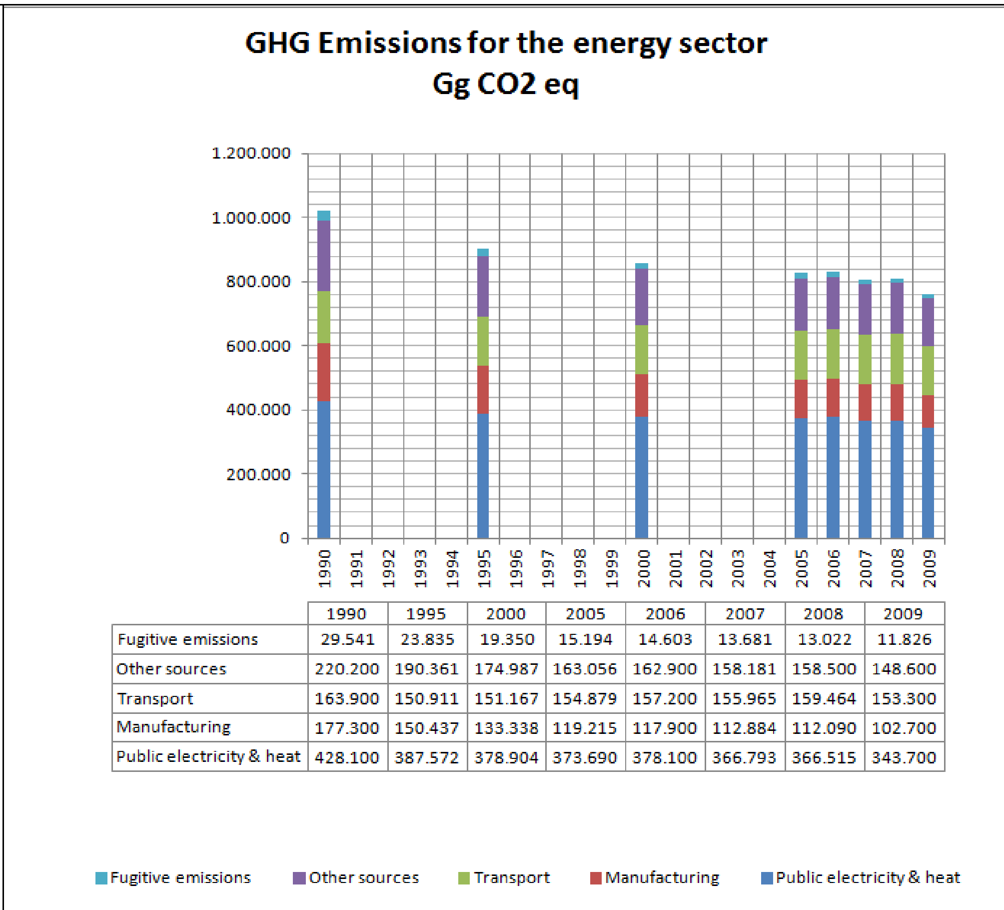


Figure 5

Germany's historical life cycle greenhouse gas emissions between 1990- 2009 for the energy sector are presented in Figure 5. These GHG emissions include the electricity and the heat production.

Sourse: National Inventory Report for the German Greenhouse Gas Inventory [5]



	1990	1995	2000	2005	2006	2007	2008	2009
Fugitive emissions	29.541	23.835	19.350	15.194	14.603	13.681	13.022	11.826
Other sources	220.200	190.361	174.987	163.056	162.900	158.181	158.500	148.600
Transport	163.900	150.911	151.167	154.879	157.200	155.965	159.464	153.300
Manufacturing	177.300	150.437	133.338	119.215	117.900	112.884	112.090	102.700
Public electricity & heat	428.100	387.572	378.904	373.690	378.100	366.793	366.515	343.700

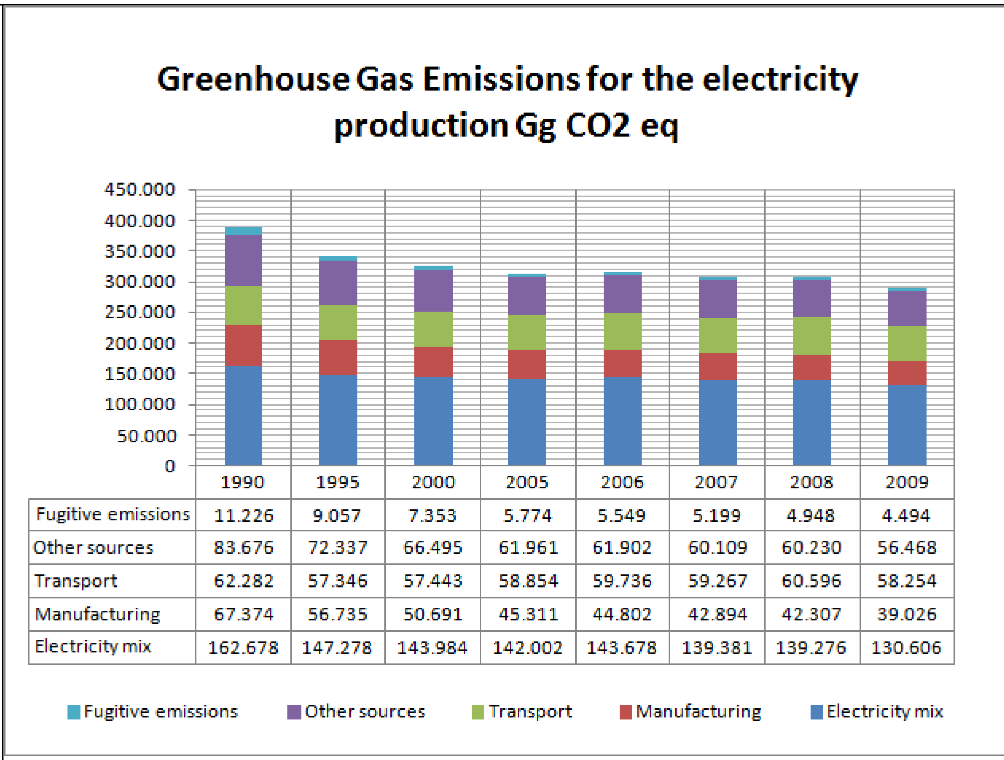
Figure 6

Germany's historical life cycle greenhouse gas emissions between 1990- 2009 for the electricity production.

Own computing using a linear approach (electricity share at the total GHG emission for the energy sector 38%) for all live cycle sub-processes

<u>Comment</u>

Data not sufficient for estimating the GHG emission for each category of fuel.



	1990	1995	2000	2005	2006	2007	2008	2009
Fugitive emissions	11.226	9.057	7.353	5.774	5.549	5.199	4.948	4.494
Other sources	83.676	72.337	66.495	61.961	61.902	60.109	60.230	56.468
Transport	62.282	57.346	57.443	58.854	59.736	59.267	60.596	58.254
Manufacturing	67.374	56.735	50.691	45.311	44.802	42.894	42.307	39.026
Electricity mix	162.678	147.278	143.984	142.002	143.678	139.381	139.276	130.606

4.3. Germany's energy mix

The historical electricity mix 1990 – 2011 (total and renewable) as calculated by the Workgroup Energy Balances [6 – Arbeitsgruppe Energiebilanzen] was further used in the calculations [Figure 7; Figure 8].

Figure 7 - Germany's electricity mix – AGEB [2]

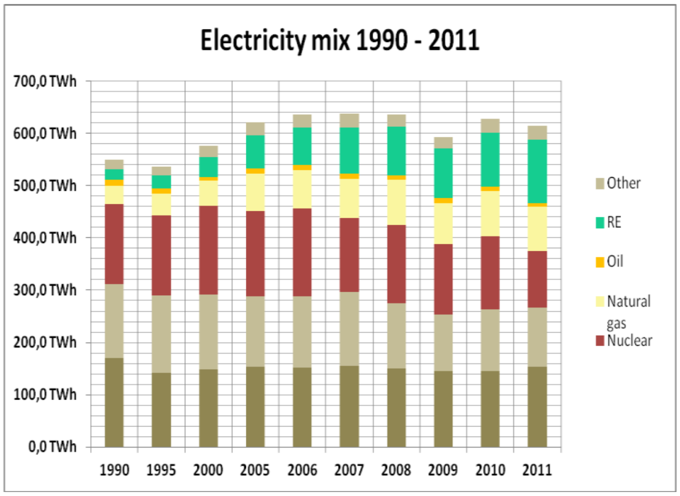
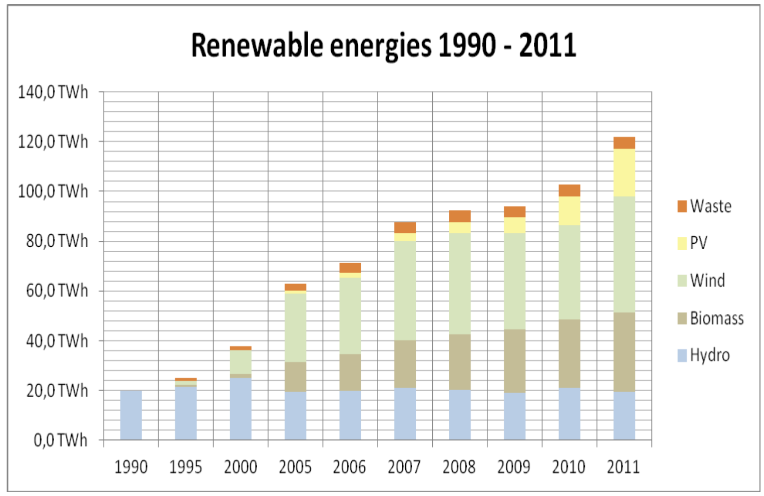


Figure 8 – Germany's renewable electricity mix [2]

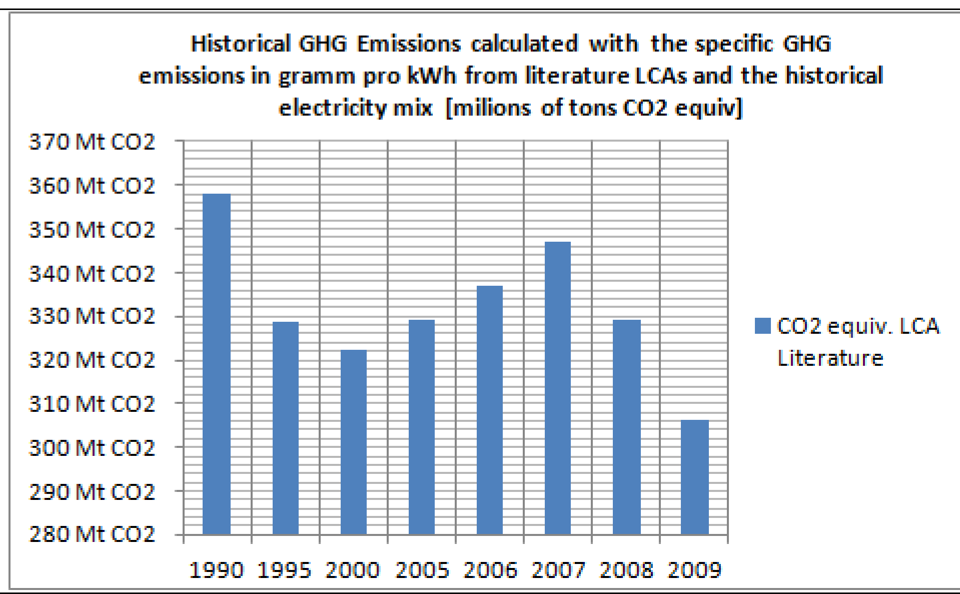


The German renewable Energy Acts submitted before Fukushima (EEG 2000, EEG 2004, EEG 2009) led to a significant increase of the renewable energy quota (from 3.2% in 1991 up to 15.6% in 2009 and nearly 20% in 2010). In spite of these programs fossil and nuclear fuels are still dominating the current electricity production accounting about 80% of Germany's primary energy in 2010.

4.4. Historical life cycle GHG emissions based on literature LCAs

Figure 9

Alternative computing of Germany's historical life cycle greenhouse gas emissions between 1990- 2009 using the historical electricity mix and specific greenhouse gas emissions from several literature sources



4.5 Data quality and uncertainty analysis

Figure 10 - Data quality

Comparison between the historical GHG for electricity production calculated with the described methods:

1) 38% GHG Emissions of the energy sector
2) Literature LCA
3) Official figures of the Federal Environmental Agency

The Approach based on the literature LCA is very close to the official figures (average deviation 2.3%) which probably do not include the up-stream life cycle emissions.

But!!
GHG from electricity and heat production – non linear relationship

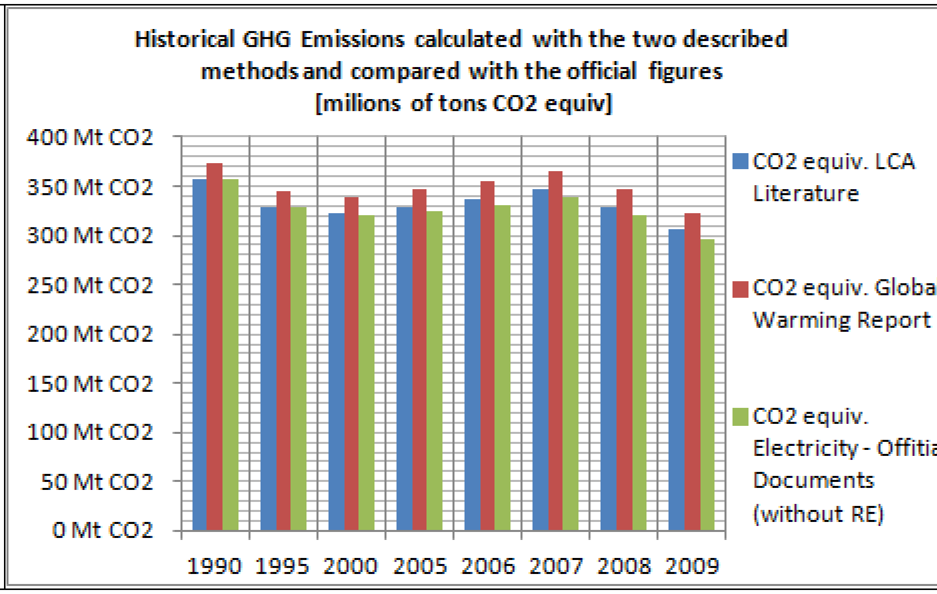


Figure 11 – Criteria Matrix

Comments

- Huge quantity of data is available - not sound, not complete, not presented in a way which allows a clear cost-benefit analysis (measures/GHG reduction)
- Multiple data sources, complex measures & many assumptions
  - Allocation of GHG emissions to LC sub-processes difficult
  - May lead to an incommensurate system boundary

Impact on Final Result	2,00	Parameter is within the top 5 contributors to final result
Acquisition Method	2,50	measured & Calculated Data
Independence of Data Supplier	3,00	Independent source, but based on nonverified information from industry
Representation	3,00	Representative data from adequate number of sites, but from shorter periods
Temporal Correlation	2,50	Less than five/ ten years of difference
Geographical Correlation	2,00	Average data from larger area in which the area of study is included
Technological Correlation	3,00	Data from processes and materials under study, but from different technology
Range of Variation	2,00	Estimate is likely to vary within a 5% range

4.6. Future scenarios

On the one side the impact of the already implemented climate and energy policies were assessed, on the other side two energy policy scenarios were selected based on the technical economical Prognos Study [15] :

- The Baseline Scenario – German Policy from October 2010 – Lifetime prolongation for the nuclear power plants (8 years for nuclear power plants with the first operation date before 1980 for and 14 years for power plants operated first after 1980). This Scenario corresponds to the Scenario IIA from the Prognos Study [15].

- "After Fukushima" Scenario - March 2011 - corresponding to the current policy (shut down of all nuclear power plants until 2022) – identical with the Baseline scenario from the Prognos Study [15].

The Prognos study [15] served as decision basis for Germany's Nuclar Act stipulated by October 2010 (lifetime prolongation for nuclear power plants).

To simulate the future GHG emissions for the electricity production Pehnt dynamic life cycle approach [7] with an increased efficiency and a lifetime extension over the time for renewable technologies was chosen.

The study assumes furthermore that new technologies (for example CCS) will be implemented according to the Prognos scenarios [15] and that the efficiency measures implemented 2011 will decrease the total energy demand according to Germany's integrated Climate and Energy Program [1] and the Prognos Study [15] from 565 TWh in 2008, to 553 TWh in 2020, to 522.3 TWh in 2030, to 491 TWh in 2040, and to 461 TWh in 2050.

5. Life Cycle Inventory Results / Impact assessment

The energy balance and the GHG emission balance 2008 – 2050 are represented in Figure 12 and Figure 13.

Figure 12

					Baseline - Prognos Scenario II A				After Fukushima Policy - Prognos Scenario "Referenz"			
					Lifetime prolongation Nuclear Power 12 Years				Shut Down Nuclear Power untill 2022			
	2008	2009	2010	2011	2020	2030	2040	2050	2020	2030	2040	2050
Total	637,0 TWh	592,4 TWh	628,1 TWh	614,5 TWh	587,5 TWh	500,7 TWh	421,1 TWh	381,9 TWh	578,9 TWh	509,1 TWh	540,4 TWh	555,6 TWh
Nuclear	148,8 TWh	134,9 TWh	140,5 TWh	108,0 TWh	148,6 TWh	83,7 TWh	0,0 TWh	0,0 TWh	49,2 TWh	0,0 TWh	0,0 TWh	0,0 TWh
Hard coal	124,6 TWh	107,9 TWh	117,0 TWh	114,5 TWh	69,6 TWh	56,2 TWh	52,9 TWh	29,9 TWh	120,2 TWh	88,4 TWh	90,0 TWh	60,3 TWh
CCS					0,0 TWh	7,4 TWh	16,4 TWh	27,4 TWh	0,0 TWh	0,0 TWh	13,0 TWh	20,3 TWh
Lignite	150,6 TWh	145,6 TWh	145,9 TWh	153,0 TWh	121,9 TWh	46,1 TWh	17,9 TWh	2,0 TWh	145,2 TWh	76,4 TWh	47,7 TWh	55,7 TWh
CCS					0,0 TWh	0,0 TWh	2,1 TWh	2,0 TWh	0,0 TWh	0,0 TWh	6,4 TWh	49,9 TWh
Natural gas	86,7 TWh	78,8 TWh	86,8 TWh	84,0 TWh	14,4 TWh	28,9 TWh	17,6 TWh	0,0 TWh	40,4 TWh	81,5 TWh	96,5 TWh	69,1 TWh
Oil	9,2 TWh	9,6 TWh	8,4 TWh	7,0 TWh	0,0 TWh	0,0 TWh	0,0 TWh	0,0 TWh	0,0 TWh	0,0 TWh	0,0 TWh	0,0 TWh
Pump storrag	6,2 TWh	6,3 TWh **	6,4 TWh **	6,5 TWh **	8,3 TWh	8,2 TWh	9,5 TWh	7,5 TWh	7,5 TWh	8,1 TWh	9,7 TWh	8,5 TWh
Other fuels	18,7 TWh	15 TWh **	19 TWh **	20 TWh **	21,1 TWh	23,4 TWh	25,7 TWh	27,9 TWh	21,1 TWh	23,4 TWh	25,7 TWh	27,9 TWh
RE	92,4 TWh	94,1 TWh	102,8 TWh	122,0 TWh	203,5 TWh	246,8 TWh	278,9 TWh	285,2 TWh	195,3 TWh	231,3 TWh	251,4 TWh	263,9 TWh
RE	93,0 TWh	94,6 TWh	104,3 TWh									
Hydro	20,4 TWh	19,0 TWh	21,0 TWh	19,5 TWh *	25,1 TWh	25,1 TWh	25,1 TWh	24,5 TWh	25,1 TWh	25,1 TWh	25,1 TWh	25,1 TWh
Wind onshore	40,6 TWh	38,6 TWh	37,6 TWh	46,5 TWh *	68,0 TWh	73,0 TWh	73,9 TWh	56,3 TWh	68,0 TWh	73,0 TWh	77,0 TWh	79,4 TWh
Wind offshore	0,0 TWh	0,0 TWh	0,2 TWh		34,3 TWh	63,5 TWh	90,7 TWh	113,0 TWh	26,0 TWh	48,0 TWh	60,0 TWh	68,0 TWh
Biomass*	22,9 TWh	26,0 TWh	29,1 TWh	32,0 TWh *	37,0 TWh	40,0 TWh	41,0 TWh	41,0 TWh	37,0 TWh	40,0 TWh	41,0 TWh	41,0 TWh
PV	4,4 TWh	6,6 TWh	11,7 TWh	19,0 TWh *	31,0 TWh	36,0 TWh	38,0 TWh	39,0 TWh	31,0 TWh	36,0 TWh	38,0 TWh	39,0 TWh
Geothermal	0,0 TWh	0,0 TWh	0,0 TWh	0,0 TWh *	2,0 TWh	3,0 TWh	4,0 TWh	5,0 TWh	2,0 TWh	3,0 TWh	4,0 TWh	5,0 TWh
Waste/other	4,7 TWh	4,4 TWh	4,8 TWh	5,0 TWh *	6,2 TWh	6,2 TWh	6,3 TWh	6,4 TWh	6,2 TWh	6,2 TWh	6,3 TWh	6,4 TWh

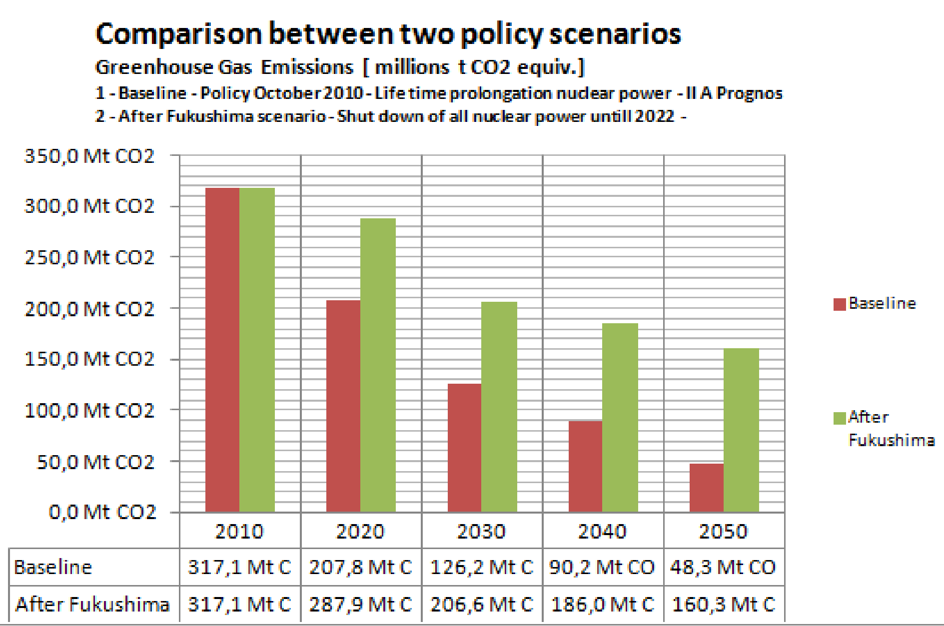
Figure 13 - GHG Emissions — Baseline — "after Fukushima"

	2008	2009	2010	2011	2020	2030	2040	2050	2020	2030	2040	2050
	320.000 kt CO2	296.000 kt CO2	309.000 kt CO2		214.200 kt CO2	166.600 kt CO2	119.000 kt CO2	71.400 kt CO2				
Nuclear	744 kt CO2	675 kt CO2	703 kt CO2	540 kt CO2	743 kt CO2	419 kt CO2	0 kt CO2	0 kt CO2	246 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2
Hard coal	100.129 kt CO2	86.334 kt CO2	94.379 kt CO2	92.131 kt CO2	54.740 kt CO2	43.067 kt CO2	39.472 kt CO2	21.707 kt CO2	94.536 kt CO2	67.743 kt CO2	67.154 kt CO2	43.777 kt CO2
CCS	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	1.263 kt CO2	2.724 kt CO2	4.429 kt CO2	0 kt CO2	0 kt CO2	2.160 kt CO2	3.281 kt CO2
Lignite	171.335 kt CO2	164.930 kt CO2	166.619 kt CO2	174.290 kt CO2	135.730 kt CO2	50.014 kt CO2	18.909 kt CO2	2.056 kt CO2	161.674 kt CO2	82.887 kt CO2	50.388 kt CO2	57.249 kt CO2
CCS	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	314 kt CO2	291 kt CO2	0 kt CO2	0 kt CO2	957 kt CO2	7.259 kt CO2
Natural gas	38.714 kt CO2	35.034 kt CO2	38.906 kt CO2	37.557 kt CO2	6.293 kt CO2	12.306 kt CO2	7.297 kt CO2	0 kt CO2	17.656 kt CO2	34.704 kt CO2	40.010 kt CO2	27.875 kt CO2
Oil	5.343 kt CO2	5.551 kt CO2	4.897 kt CO2	4.070 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2
Pump storrag	3.506 kt CO2	3.536 kt CO2	3.584 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2
Other fuels	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2	0 kt CO2
RE	319.770 kt CO2	296.060 kt CO2	309.087 kt CO2	308.588 kt CO2	197.506 kt CO2	107.069 kt CO2	68.716 kt CO2	28.482 kt CO2	274.112 kt CO2	185.334 kt CO2	160.669 kt CO2	139.441 kt CO2
RE	9.926 kt CO2	10.443 kt CO2	11.569 kt CO2	13.210 kt CO2	16.457 kt CO2	17.373 kt CO2	17.433 kt CO2	16.902 kt CO2	16.384 kt CO2	17.241 kt CO2	17.209 kt CO2	16.773 kt CO2
Hydro	253 kt CO2	228 kt CO2	241 kt CO2	224 kt CO2	281 kt CO2	274 kt CO2	267 kt CO2	254 kt CO2	281 kt CO2	274 kt CO2	267 kt CO2	260 kt CO2
Wind onshore	481 kt CO2	442 kt CO2	414 kt CO2	510 kt CO2	729 kt CO2	763 kt CO2	752 kt CO2	557 kt CO2	729 kt CO2	763 kt CO2	783 kt CO2	786 kt CO2
Wind offshor	0 kt CO2	0 kt CO2	2 kt CO2	0 kt CO2	301 kt CO2	543 kt CO2	755 kt CO2	915 kt CO2	228 kt CO2	410 kt CO2	499 kt CO2	551 kt CO2
Biomass*	6.238 kt CO2	6.844 kt CO2	7.359 kt CO2	8.076 kt CO2	9.127 kt CO2	9.614 kt CO2	9.595 kt CO2	9.336 kt CO2	9.127 kt CO2	9.614 kt CO2	9.595 kt CO2	9.336 kt CO2
PV	496 kt CO2	713 kt CO2	1.215 kt CO2	1.961 kt CO2	2.982 kt CO2	3.182 kt CO2	3.063 kt CO2	2.839 kt CO2	2.982 kt CO2	3.182 kt CO2	3.063 kt CO2	2.839 kt CO2
Geothermal	1 kt CO2	1 kt CO2	1 kt CO2	0 kt CO2	80 kt CO2	117 kt CO2	152 kt CO2	185 kt CO2	80 kt CO2	117 kt CO2	152 kt CO2	185 kt CO2
Waste/other	2.456 kt CO2	2.215 kt CO2	2.338 kt CO2	2.439 kt CO2	2.956 kt CO2	2.880 kt CO2	2.850 kt CO2	2.817 kt CO2	2.956 kt CO2	2.880 kt CO2	2.850 kt CO2	2.817 kt CO2
LC CO2 eq	**329.696 kt CO2**	**306.503 kt CO2**	**320.656 kt CO2**	**321.798 kt CO2**	**213.963 kt CO2**	**124.442 kt CO2**	**86.149 kt CO2**	**45.385 kt CO2**	**290.496 kt CO2**	**202.575 kt CO2**	**177.878 kt CO2**	**156.214 kt CO2**

The life cycle greenhouse gas emissions 2010 -2050 for the two analyzed policy scenarios are presented in **Figure 14**.

Figure 14 – Life cycle impacts

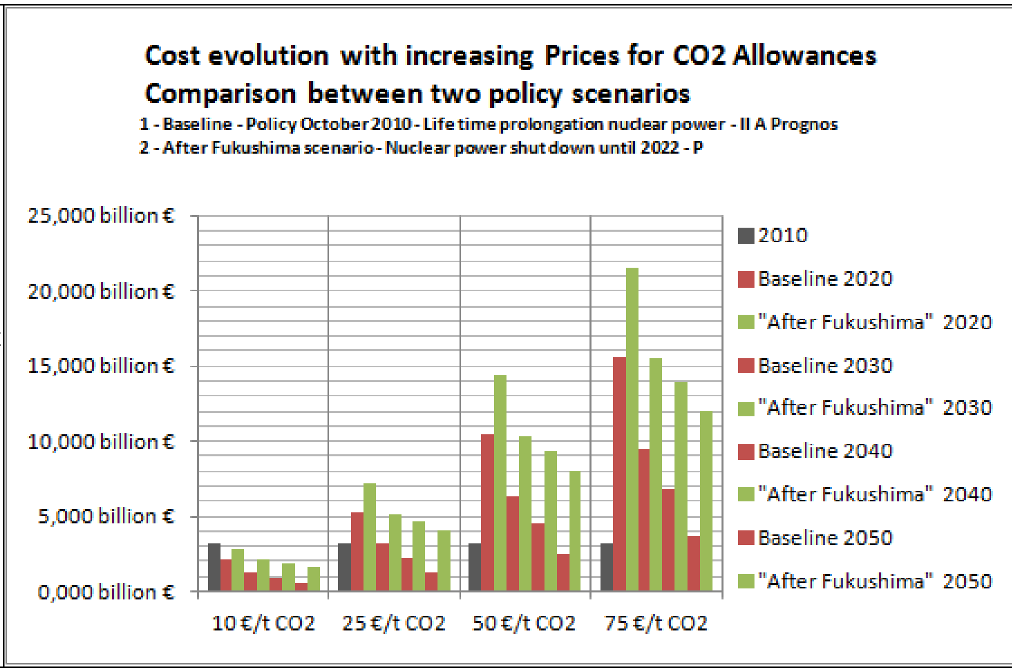
- A prolongation of the life time for Germany's nuclear power plants (Policy October 2010) would lead to lower GHG Emissions
- Germany's ambitioned GHG-Emission goal (Germany's Climate program, Kyoto, EU Burden sharing convention) would be easier to achieve with the baseline scenario
- The change of the political view implies electricity imports and increased electricity prices (electricity production doesn't exceed the electricity demand any more)
- Baseline Scenario has benefits in comparison with the „after Fukushima" one



A comparative cost evolution for the two analyzed policy scenarios with increasing prices for CO2 allowances is represented in **Figure 15.**

Figure 15 – Explanatory notes

- Investment in the electricity transmission infrastructure is required (balancing problems) – not part of this assessment
- Costs for final disposal of used nuclear fuel (it doesn't exist a final disposal solution yet) – not included
- Baseline based on Prognos Scenario AII macro-economic model , which considers the investment for lifetime prolongation



<u>5.1. Consolidated findings</u>

- Both selected scenarios lead to less GHG emissions due to the tremendous increase of renewable energies.
- In the current policy Scenario – "After Fukushima" the electricity production does not cover the demand.
- The lifetime prolongation has, compared with the "after Fukushima scenario" economical benefits (electricity import isn't required).
- In the "After Fukushima" scenario Germany has to replace its low carbon nuclear electricity production (nearly zero in the "use" phase) with other forms of electricity generation, which are either more carbon intensive (fossil based electricity production) or extremely difficult to structure (electricity production based on renewable energies with extreme capacity fluctuations and reduced utilization hours: wind, solar, etc.).
- Therefore, the current policy scenario is more likely to be more expensive than the "Baseline" scenario (leads to higher electricity prices, higher investment)
- This study do not take into consideration the final disposal costs for used nuclear fuel (it doesn't exist a final disposal solution yet), but the Prognos figures are based on a macroeconomic model, which consider the investment for lifetime prolongation (baseline).
- The calculated historical GHG with two different methods are very close the official figures of the Federal Environmental Agency (average deviation 2.3%).

- The analyzed future scenarios correspond to the cited literature [15] and suppose that the efficiency measures implemented will decrease the total energy demand according to Germany's integrated energy and climate policy from 565 TWh in 2008 to 461 TWh in 2040 and 2050, although Germany's historical greenhouse gas emission had until today a moderate decrease rate.
- Although the literature LCA approach leads to plausible data compared with the official figures there is a lot of uncertainty.
- The Concept of Germany's Federal Government includes furthermore about 30 measures for reducing GHG emissions (not all affecting the electricity sector).
- In spite of the fact that a huge quantity of data is available, not all data are sound, complete or presented in a way which allows a clear cost-benefit analysis and a corresponding relationship between the measures and the reduction.
- Extreme effects due to the implementation of the successive Renewable Acts (negative electricity prices, net instability, extreme costs for the energy intensive industries and the German tax payers) are not subject of this study, but are very important in order to analyze these political decisions.

6. Conclusion

The "baseline scenario" (lifetime prolongation for Germany's nuclear power plants) has, compared with the "after Fukushima scenario" economical benefits (lower GHG emissions / electricity import and investment in the net infrastructure are not required).

Considering only the assessed pollutants one should conclude, that Germany's current policy is not likely to deliver a healthy balance between ecology, economy with respect to the entire carbon life cycle of the future electricity mix.

However, due to the quantity of assumptions, the lack transparency for the macro-economic Prognos model, the exclusion of important parameters, the complexity of measures, the required investment (grid stability, storage, CCS & renewable energies), the impossibility to separate properly electricity from heat production and consumption, and to allocate correctly the life-cycle sub-process emissions, and due to the dependency of electricity imports, the system boundary is likely to become incommensurate increasing data uncertainty. Furthermore, the integration of other environmental aspects (human health, final disposal of nuclear waste) in the life cycle assessment could eventually lead to the conclusion that Germany's complex transition towards a "neutral" carbon footprint is not only ambitious but also the most sustainable one.

Despite of the high uncertainty of the presented results, LCA remains a very important tool for assessing different decision making processes, a tool which should be better used on a regular basis before and not after taking important political decisions.

References

[1] Bundesregierung, *Das Energiekonzept der Bundesregierung 2010 und die Energiewende 2011,*

2011/10

[2] Bundestag, *Report of the Enquete Commission of the German Federal Government,* 2002

[3] Bundesregierung, *Energiewende: Am Beginn eines langen Prozesses*, 2012/01/20 http://www.bundesregierung.de/Content/DE/Artikel/2012/01/2012-01-20-energiewende.html

[4] Umweltbundesamt (Federal Environment Agency, Germany),*Energy policy and energy data*, 14th October 2011, http://www.umweltbundesamt.de/energie-e/politik.htm

[5] Umweltbundesamt (Federal Environment Agency, Germany) Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2011, *National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2009,* June 2011

[6] Workgroup Energy Balances - Arbeitsgruppe Energiebilanzen, *Energy balance of the Federal Republic of Germany*

[7] Martin Pehnt, *Dynamic life cycle assessment (LCA) of renewable energy technologies,* SD, Renewable Energy 31 (2006) 55–71

[8] Varun, I.K. Bhat, Ravi Prakash, *LCA of renewable energy for electricity generation systems—A review,* Renewable and Sustainable Energy Reviews 13 (2009) 1067–1073

[9] Ontario

[10] Álvaro Restrepo, Raphael Miyake, Fábio Kleveston, Edson Bazzo, *Exergetic and environmental analysis of a pulverized coal power plant*, Energy 2012

[11] Martin Pehnt, Johaness Henkel, *Life cycle assessment of carbon dioxide capture and storage from lignite power plants, international jurnal of Greenhouse Gas Control Nr. 3, 2009, 49-66*

[12] Margaret K. Mann,Pamela L. Spath, *A comparison of the environmental consequences of power from biomass, coal and natural gas,* NREL 2000

[13] Pamela L. Spath, Margaret K. Mann, *Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System*, NREL

[14] UK Parliamentary Office of Science and Technology, Postnote 268, *Carbon footprint of the electricity production*, 2006

[15] Prognos Study fort he Bundesministerium für Wirtschaft und Technologie, *Energieszenarien für das Energiekonzept der Bundesregierung (Energy Scenarios for the Energy Concept of the Federal Government)*, 2010

[16] Report of the Brundland Commission, Our common future, Oxford University Press, 1987

[17] Dr. Peter Saling, BASF Aktiengesellschaft, GUP, Ökonomische Berechnungen in der Nachhaltigkeitsbewertung, http://www.oc-praktikum.de/de/articles/pdf/EconomicalSustainability_de.pdf

[18] ISO 44040, *Environmental management- Life cycle assessment- Principles and framework,* 2006/07/01

[19] ISO 44044, Environmental management- Life cycle assessment- Requirements and guidelines, 2006/7/1

[20] Kyoto Protocol, 1997

[21] United Nation Framework Convention on Climate Change, *Agreement between the European Community and its member states under the Article 4 of the Kyoto Protocol*, 2002/07