EN

COMMISSION OF THE EUROPEAN COMMUNITIES

Brussels,
UNOFFICIAL VERSION

COMMISSION STAFF WORKING DOCUMENT

accompanying the

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Second Strategic Energy Review

AN EU ENERGY SECURITY AND SOLIDARITY ACTION PLAN

Energy Sources, Production Costs and Performance of Technologies for Power Generation, Heating and Transport

{COM(2008) 744}

TABLE OF CONTENTS

1. INTRODUCTION

Europe needs to act now to deliver sustainable, secure and competitive energy. The inter-related challenges of climate change, security of energy supply and competitiveness are multifaceted and require a profound change in the way Europe produces, delivers and consumes energy. Harnessing technology is vital to achieve the Energy Policy for Europe objectives adopted by the European Council on 9 March 2007[1].

This document provides a comparative analysis of energy sources, production costs and performance of technologies for power generation, heating and transport for use in the Second Strategic EU Energy Review (SEER). It builds upon the work performed for the first Strategic EU Energy Review COM(2007)1, and relies on the capacity of SETIS, the information system of the European Strategic Energy Technology Plan (SET-Plan). The comparative Tables presented in the previous SEER exercise have been updated. The portfolio of technologies considered for the power sector has been also expanded to include carbon capture power plants, a large scale oil fired plant and an additional biomass conversion route. In addition, two fuel price scenarios have been considered to reflect variations in the future price of energy commodities. All reported values in the Tables for electricity generation, heating and transport fuels have been calculated following a consistent methodology, hence they are directly comparable. The calculations rely on up-to-date available data and information on energy conversion technology performance.

This report consists of two parts. Part I includes the three Tables for use in the 2nd SEER. Part II provides a comprehensive description of the implemented methodology and includes the technology-related data used for the calculations, accompanied by a reference list.

2. PART I: MAIN TABLES

[1] European Council conclusions adopted on the basis of the Commission's Energy Package, e.g. the Communications: '*An Energy Policy for Europe*' COM(2007)1, '*Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond*' COM(2007)2 and '*A European strategic energy technology plan (SET-plan) - Towards a low carbon future*' COM(2007)723

Table 2-1: Energy Technologies for Power Generation – Moderate Fuel Price Scenario [a]

Energy source	Power generation technology		Production Cost of Electricity (COE)			Net efficiency 2007	Lifecycle GHG emissions			Fuel price sensitivity
			State-of-the-art 2007	Projection for 2020	Projection for 2030		Direct (stack) emissions	Indirect emissions	Lifecycle emissions	
			€$_{2005}$/MWh	€$_{2005}$/MWh	€$_{2005}$/MWh		kg CO_2/MWh	kg CO_2(eq)/MWh	kg CO_2(eq)/MWh	
Natural gas	Open Cycle Gas Turbine (GT)	-	65 ÷ 75 [b]	90 ÷ 95 [b]	90 ÷ 100 [b]	38%	530	110	640	Very high
	Combined Cycle Gas Turbine (CCGT)	-	50 ÷ 60	65 ÷ 75	70 ÷ 80	58%	350	70	420	Very high
		CCS	n/a	85 ÷ 95	80 ÷ 90	49% [c]	60	85	145	Very high
Oil	Internal Combustion Diesel Engine	-	100 ÷ 125 [b]	140 ÷ 165 [b]	140 ÷ 160 [b]	45%	595	95	690	Very high
	Combined Cycle Oil-fired Turbine (CC)	-	95 ÷ 105 [b]	125 ÷ 135 [b]	125 ÷ 135 [b]	53%	505	80	585	Very high
Coal	Pulverised Coal Combustion (PCC)	-	40 ÷ 50	65 ÷ 80	65 ÷ 80	47%	725	95	820	Medium
		CCS	n/a	80 ÷ 105	75 ÷ 100	35% [c]	145	125	270	Medium
	Circulating Fluidised Bed Combustion (CFBC)	-	45 ÷ 55	75 ÷ 85	75 ÷ 85	40%	850	110	960	Medium
	Integrated Gasification Combined Cycle (IGCC)	-	45 ÷ 55	70 ÷ 80	70 ÷ 80	45%	755	100	855	Medium
		CCS	n/a	75 ÷ 90	65 ÷ 85	35% [c]	145	125	270	Medium
Nuclear	Nuclear fission	-	50 ÷ 85	45 ÷ 80	45 ÷ 80	35%	0	15	15	Low
Biomass	Solid biomass	-	80 ÷ 195	85 ÷ 200	85 ÷ 205	24% ÷ 29%	6	15 ÷ 36	21 ÷ 42	Medium
	Biogas	-	55 ÷ 215	50 ÷ 200	50 ÷ 190	31% ÷ 34%	5	1 ÷ 240	6 ÷ 245	Medium
Wind	On-shore farm	-	75 ÷ 110	55 ÷ 90	50 ÷ 85	-	0	11	11	nil
	Off-shore farm	-	85 ÷ 140	65 ÷ 115	50 ÷ 95	-	0	14	14	
Hydro	Large	-	35 ÷ 145	30 ÷ 140	30 ÷ 130	-	0	6	6	nil
	Small	-	60 ÷ 185	55 ÷ 160	50 ÷ 145	-	0	6	6	
Solar	Photovoltaic	-	520 ÷ 880	270 ÷ 460	170 ÷ 300	-	0	45	45	nil
	Concentrating Solar Power (CSP)	-	170 ÷ 250 [d]	110 ÷ 160 [d]	100 ÷ 140 [d]	-	120 [d]	15	135 [d]	Low

[a] *Assuming fuel prices as in 'European Energy and Transport: Trends to 2030 - Update 2007' (barrel of oil 54.5$$_{2005}$ in 2007, 61$$_{2005}$ in 2020 and 63$$_{2005}$ in 2030)*

[b] *Calculated assuming base load operation*

[c] *Reported efficiencies for carbon capture plants refer to first-of-a-kind demonstration installations that start operating in 2015*

[d] *Assuming the use of natural gas for backup heat production*

Table 2-2: Energy Technologies for Power Generation – High Fuel Price Scenario [a]

Energy source	Power generation technology		Production Cost of Electricity (COE): State-of-the-art 2007	Production Cost of Electricity (COE): Projection for 2020	Production Cost of Electricity (COE): Projection for 2030	Net efficiency 2007	Lifecycle GHG emissions: Direct (stack) emissions	Lifecycle GHG emissions: Indirect emissions	Lifecycle GHG emissions: Lifecycle emissions	Fuel price sensitivity
			€$_{2005}$/MWh	€$_{2005}$/MWh	€$_{2005}$/MWh		kg CO_2/MWh	kg CO_2(eq)/MWh	kg CO_2(eq)/MWh	
Natural gas	Open Cycle Gas Turbine (GT)	-	80 ÷ 90 [b]	145 ÷ 155 [b]	160 ÷ 165 [b]	38%	530	110	640	Very high
	Combined Cycle Gas Turbine (CCGT)	-	60 ÷ 70	105 ÷ 115	115 ÷ 125	58%	350	70	420	Very high
		CCS	n/a	130 ÷ 140	140 ÷ 150	49% [c]	60	85	145	Very high
Oil	Internal Combustion Diesel Engine	-	125 ÷ 145 [b]	200 ÷ 220 [b]	230 ÷ 250 [b]	45%	595	95	690	Very high
	Combined Cycle Oil-fired Turbine (CC)	-	115 ÷ 125 [b]	175 ÷ 185 [b]	200 ÷ 205 [b]	53%	505	80	585	Very high
Coal	Pulverised Coal Combustion (PCC)	-	40 ÷ 55	80 ÷ 95	85 ÷ 100	47%	725	95	820	High
		CCS	n/a	100 ÷ 125	100 ÷ 120	35% [c]	145	125	270	Medium
	Circulating Fluidised Bed Combustion (CFBC)	-	50 ÷ 60	95 ÷ 105	95 ÷ 105	40%	850	110	960	High
	Integrated Gasification Combined Cycle (IGCC)	-	50 ÷ 60	85 ÷ 95	85 ÷ 95	45%	755	100	855	High
		CCS	n/a	95 ÷ 110	90 ÷ 105	35% [c]	145	125	270	Medium
Nuclear	Nuclear fission	-	55 ÷ 90	55 ÷ 90	55 ÷ 85	35%	0	15	15	Low
Biomass	Solid biomass	-	80 ÷ 195	90 ÷ 215	95 ÷ 220	24% ÷ 29%	6	15 ÷ 36	21 ÷ 42	Medium
	Biogas	-	55 ÷ 215	50 ÷ 200	50 ÷ 190	31% ÷ 34%	5	1 ÷ 240	6 ÷ 245	Medium
Wind	On-shore farm	-	75 ÷ 110	55 ÷ 90	50 ÷ 85	-	0	11	11	nil
	Off-shore farm	-	85 ÷ 140	65 ÷ 115	50 ÷ 95	-	0	14	14	
Hydro	Large	-	35 ÷ 145	30 ÷ 140	30 ÷ 130	-	0	6	6	nil
	Small	-	60 ÷ 185	55 ÷ 160	50 ÷ 145	-	0	6	6	
Solar	Photovoltaic	-	520 ÷ 880	270 ÷ 460	170 ÷ 300	-	0	45	45	nil
	Concentrating Solar Power (CSP)	-	170 ÷ 250 [d]	130 ÷ 180 [d]	120 ÷ 160 [d]	-	120 [d]	15	135 [d]	Low

[a] *Assuming fuel prices as in DG TREN 'Scenarios on high oil and gas prices' (barrel of oil 54.5\$$_{2005}$ in 2007, 100\$$_{2005}$ in 2020 and 119\$$_{2005}$ in 2030)*

[b] *Calculated assuming base load operation*

[c] *Reported efficiencies for carbon capture plants refer to first-of-a-kind demonstration installations that start operating in 2015*

[d] *Assuming the use of natural gas for backup heat production*

Table 2-3: Energy Sources for Heating – Moderate Fuel Price Scenario [(a)]

Energy source		EU-27 market share by energy source (residential sector) [(b)]	Fuel retail price (inc. taxes)	Production Cost of Heat (inc. taxes)		Lifecycle GHG emissions		
				Running cost	Total cost	Direct (stack) emissions	Indirect emissions	Lifecycle emissions
			€$_{2005}$/toe	€$_{2005}$/toe	€$_{2005}$/toe	t CO_2 /toe	t CO_2(eq)/toe	t CO_2(eq)/toe
Fossil fuels	**Natural gas**	45.4%	625	750 ÷ 950	1050 ÷ 1300	2.5	0.7	3.2
	Heating oil	20.0%	640	800 ÷ 1100	1325 ÷ 2025	3.5	0.6	4.1
	Coal	3.1%	375	675 ÷ 750	1500 ÷ 1825	5.4	0.7	6.1
Biomass, solar and other	**Wood chips**	11.6%	390	700 ÷ 900	1550 ÷ 2650	0.0	0.3	0.3
	Pellets		580	900 ÷ 1300	1675 ÷ 4125	0.0	0.7	0.7
	Solar		-	275 ÷ 300	1350 ÷ 9125	0.0	0.3	0.3
	Geothermal		-	525 ÷ 900	1025 ÷ 3625	0.0	0.2 ÷ 5.9	0.2 ÷ 5.9
Electricity		12.3%	1470	1500 ÷ 1575	1600 ÷ 2475	0.0	0.7 ÷ 15.2	0.7 ÷ 15.2

[(a)] *Assuming fuel prices as in 'European Energy and Transport: Trends to 2030 - Update 2007' (barrel of oil 54.5\$$_{2005}$)*

[(b)] *District heating has an additional share of 7.6% of the market*

Table 2-4: Energy Sources for Heating – High Fuel Price Scenario [(a)]

Energy source		EU-27 market share by energy source (residential sector) [(b)]	Fuel retail price (inc. taxes)	Production Cost of Heat (inc. taxes)		Lifecycle GHG emissions		
				Running cost	Total cost	Direct (stack) emissions	Indirect emissions	Lifecycle emissions
			€$_{2005}$/toe	€$_{2005}$/toe	€$_{2005}$/toe	t CO_2 /toe	t CO_2(eq)/toe	t CO_2(eq)/toe
Fossil fuels	Natural gas	45.4%	1010	1125 ÷ 1400	1425 ÷ 1750	2.5	0.7	3.2
	Heating oil	20.0%	1030	1200 ÷ 1600	1775 ÷ 2525	3.5	0.6	4.1
	Coal	3.1%	590	975 ÷ 1025	1775 ÷ 2100	5.4	0.7	6.1
Biomass, solar and other	Wood chips	11.6%	410	725 ÷ 925	1575 ÷ 2675	0.0	0.3	0.3
	Pellets		610	925 ÷ 1350	1700 ÷ 4175	0.0	0.7	0.7
	Solar		-	275 ÷ 300	1350 ÷ 9125	0.0	0.3	0.3
	Geothermal		-	650 ÷ 1100	1150 ÷ 3775	0.0	0.2 ÷ 5.9	0.2 ÷ 5.9
Electricity		12.3%	1875	1925 ÷ 1975	2025 ÷ 2900	0.0	0.7 ÷ 15.2	0.7 ÷ 15.2

[(a)] Assuming high fuel prices as in DG TREN 'Scenarios on high oil and gas prices' (barrel of oil 100\$$_{2005}$)

[(b)] District heating has an additional share of 7.6% of the market

Table 2-5: Energy Sources for Road Transport – Moderate and High Fuel Price Scenario

Energy source for road transport	**Cost of Fuels to the EU**		**Lifecycle GHG emissions [c]**
	Moderate Fuel Price Scenario [a] $€_{2005}$**/toe**	**High Fuel Price Scenario [b]** $€_{2005}$**/toe**	**t CO_2(eq)/toe**
Petrol and diesel	470	675	3.6 ÷ 3.7
Natural gas (CNG) [d]	500	630	3.0
Domestic biofuel [e]	725 ÷ 910	805 ÷ 935	1.9 ÷ 2.4
Tropical bio-ethanol	700 [f]	790 [f]	0.4
Second-generation biofuel [e]	1095 ÷ 1245	1100 ÷ 1300	0.3 ÷ 0.9

[a] *Values are given for 2015, assuming oil price of 57.9$*$_{2005}$*/barrel as in 'European Energy and Transport: Trends to 2030 - Update 2007'*

[b] *Values are given for 2015, assuming oil price of 83.3$*$_{2005}$*/barrel as in DG TREN 'Scenarios on high oil and gas prices'*

[c] *Data subject to revision pending on an agreement on an appropriate methodology for calculating indirect land use change*

[d] *Requires a specially adapted vehicle, which is not accounted for in the reported values*

[e] *Ranges is between cheapest wheat-ethanol and biodiesel*

[f] *Values are based on an assumed competitive market price of biofuels imported in the EU*

3. PART II: METHODOLOGY AND DATA

3.1. Energy Technologies for Power Generation

This section describes the methodology and data used for the comparison Table of energy technologies for power generation. Table 3-1, Table 3-2 and Table 3-3 summarise the techno-economic characteristics of the selected state-of-the-art power generation technologies.

3.1.1. Technologies

The technologies addressed are:

1. Natural gas fuelled
   – Open cycle gas turbine
   – Combined cycle gas turbine
   – Combined cycle gas turbine with carbon capture and storage (CCS)
2. Oil fuelled
   – Diesel internal combustion engine
   – Oil fired combined cycle
3. Coal fuelled
   – Pulverised fuel
   – Pulverised fuel with carbon capture and storage
   – Circulating fluidised bed
   – Integrated gasification combined cycle
   – Integrated gasification combined cycle with carbon capture and storage
4. Nuclear fission
   – Water cooled reactor
5. Biomass fuelled
   – Biomass fired combustion steam cycle: large (>10MW_e) and small scale (≤10MW_e)
   – Biogas from co-digestion and landfill gas
6. Wind
   – On-shore wind
   – Off-shore wind
7. Hydropower
   – Large scale (>10MW_e)
   – Small scale (≤10MW_e)
8. Solar power
   – Photovoltaics
   – Concentrating solar thermal power

It is noted that cogeneration of heat and power is not considered in this analysis.

3.1.2. Indicators

For each technology the following indicators are reported:

(I) Production cost of electricity (current and projected to 2020 and 2030): The levelized production cost of electricity, expressed in constant €(2005)/MWh of net power generated, is used to compare the economic competitiveness among power generation technologies during their life time. The reported values for the production cost of electricity for each technology refer to a state-of-the-art facility, assumed to start operating in the indicated year (2007, 2020 or 2030), as described in Table 3-1. The reported range reflects variations in capital costs which depend on specific technology choices, plant location, etc. The reported range does not, however, reflect the variability in the fuel retail prices between the Member States[2].

The reported production cost values have been calculated using the following formula:

$$COE = \frac{SCI \cdot (1 + IDC) \cdot CRF}{8760 \cdot LF} + \frac{FOM}{8760 \cdot LF} + VOM + FC + CC + CTS$$

Where:

COE …is the levelized production cost of electricity, in $€_{2005}$/MWh,

SCI …is the specific overnight capital investment of the power generation facility, in $€_{2005}$/MW,

IDC …is the interest during construction,

CRF …is the capital recovery factor,

LF …is the annual load factor of the facility,

FOM …refers to the annualized fixed operating costs during the facility life time, in $€_{2005}$/MW,

VOM …refers to the annualized variable operating costs during the facility life time, in $€_{2005}$/MWh,

FC …refers to annualized fuel costs during the facility life time, in $€_{2005}$/MWh,

CC …refers to annualized carbon costs during the facility life time, in $€_{2005}$/MWh

CTS …refers to annualized expenditures for transport and storage of captured CO_2 during the facility life time, in $€_{2005}$/MWh (only applicable to plants with CCS).

All values are reported in net power capacity (MW) or generated electricity (MWh).

In more detail, values for *SCI* were collected from the most recent available literature. The reported ranges reflect market variations in investment costs for a given technology within the EU and within a same power class. Values reported in the literature in currency other than euros were converted to euros based on the Eurostat exchange rates for the reference year of the data given in the publication and were converted to 2005 euros ($€_{2005}$) using the annual average inflation rates for the Euro area as reported by Eurostat. Finally, to include the recent price increases these values were adjusted to January 2007 using the *chemical engineering*

2 An average European fuel price has been considered as discussed below.

plant cost index[3]. The *SCI* values are shown in Table 3-2. Values for future *SCI*s were calculated on the assumption that current prices will decrease due to learning effects. Hence, based on the technology learning theory, the future specific cost of a technology, SCI_F, was calculated using the global installed capacity as a proxy, based on the formula:

$$SCI_F = SCI_P \left(\frac{C_F}{C_P} \right)^{\frac{\ln(1-LR)}{\ln 2}}$$

Where:

SCI_P …is the current specific capital investment cost,

C_P …is the current global installed capacity,

C_F …is the installed capacity of the technology in a future time, e.g. in 2020,

LR …is the learning rate of the technology.

Values for C_P, C_F and LR were collected from the literature and are also shown in Table 3-3. Especially, for fossil fuel power plants with CCS, it was assumed that the first-of-the-kind installations will start operating in 2015. Furthermore, the global installed capacity of each technology is kept constant for the two fossil fuel price scenarios.

The *IDC* was calculated considering the construction time for each plant (see Table 3-3) and a capital expenditure profile during construction:

$$IDC = \sum_{k=1}^{CT} W_k (1+r)^{CT-(k-1)} - 1$$

Where:

CT …is the construction time,

W_k …is the fraction of total capital used in year k,

r …is the interest rate.

For all technologies an interest rate of 10% was assumed for the calculation of IDC.

The capital recovery factor (*CRF*) was calculated from the formula:

$$CRF = \frac{d \cdot (1+d)^n}{(1+d)^n - 1}$$

Where *d* is the real discount rate and *n* is the facility life time.

For all technologies a real discount rate of 10% was assumed. Moreover, it was assumed that the economic life time of facility is equal to the technical life time (see Table 3-3).

It was further assumed that all facilities operate in a base-load mode with a *LF* of 85%, including open cycle gas turbines and diesel reciprocating engines that are used also to meet peak load. The following exceptions were made:

– Photovoltaics: 11%

---

[3] For more information see: *Updating the CE Plant Cost Index,* Chemical Engineering, January 2002, p. 62.

– Concentrating solar thermal power: 41%[4]

– Wind: on-shore 23% and off-shore 39%

– Landfill: 75%

– Hydropower: Large scale 50% and Small scale 57%

FOM costs account for maintenance, which was calculated as a fraction of the total investment costs (calculated using the net capacity and SCI values from Table 3-1 and Table 3-2 respectively) based on standard sectoral costing methodologies; salaries (assuming an annual average salary of €55,000 and estimating the number of people employed in each facility); and overheads (30% of salaries). The evolution of *FOM* costs during the life time of a facility (due to learning effects, etc.) was considered through an annualizing process, where the annual *FOM* values were discounted to the net present value and then multiplied by the *CRF*. *VOM* costs account for the cost of consumables, chemicals, auxiliary power, etc. Values were obtained from the literature. Table 3-2 shows the total operational and maintenance costs (OM)[5] normalised to the installed net capacity.

Fuel costs (*FC*) were calculated for two scenarios, moderate and high. The fuel prices for the moderate scenario are derived from the DG TREN publication 'European Energy and Transport: Trends to 2030 - Update 2007'[6], while fuel prices for the high scenario are based on DG TREN 'Scenarios on high oil and gas prices'[7]. Moreover, prices for biomass were calculated based on values reported in EUBIONET II[8] and adjusted to reflect the biomass price trends considered in the previously mentioned DG TREN scenarios. These values reflect the fuel price at the plant gate. Table 3-2 shows the fuel prices assumed for the years 2007, 2020 and 2030. The evolution of *FC* during the life time of a facility, due to changes in fuel prices, was also considered through an annualizing process, as described above for FOM. In the case of nuclear energy, the fuel price encompasses the whole fuel cycle including provisions for waste management. For concentrating solar thermal power, FC were calculated assuming a constant consumption of natural gas of 385 TJ per year for backup heat production.

Carbon costs (*CC*) were considered only for the projected costs of electricity in 2020 and 2030. It was assumed that each tonne of CO_2 directly emitted from the facility was charged with €41/tCO_2 and €47/tCO_2 in 2020 and 2030 respectively. *CC* were also annualized similarly to FOM. The annual CO_2 emissions during plant operation were derived from the IPCC Guidelines for National Greenhouse Gas Inventories[9], as explained below. It was assumed that concentrating solar thermal power does not carry carbon costs.

In the case of power plants with carbon capture technology, the cost of CO_2 transport and storage costs was also taken into account for the calculation of the production cost of electricity and was treated as an additional operational cost element. A value of €20 per tonne of CO_2 captured was assumed to account for the cost of transport and storage of captured CO_2.

Dismantling costs were not considered except in the case of nuclear plants, where the cost of decommissioning was included both in SCI and FOM.

---

4 Including thermal storage and natural gas backup. Load factor is assumed constant over time.

5 This accounts for FOM and VOM, and excludes fuel and carbon costs

6 See reference [80]

7 To be published

8 See reference [56]

9 See reference [127]

(II) Net efficiency: The reported values refer to the current state-of-the-art power generating facility with the exception of the CCS plants. For the latter, the reported values refer to first-of-a-kind demonstration installations, assumed to start operating in 2015 (for references see Table 3-1). These net efficiency values were used for calculating fuel and carbon costs, and hence the production cost of electricity. The net efficiency values used for calculating the projected cost of electricity in 2030 are also shown in Table 3-1.

(III) Life-cycle greenhouse gas emissions: Values for the life-cycle greenhouse gas (GHG) emissions for current state-of-the-art facilities were obtained from the pertinent literature and/or calculated by the JRC based on in-house life cycle assessment data.

The lifecycle GHG emissions for fossil fuel technologies comprise the direct (stack) emissions from the combustion/gasification process and the indirect emissions originating among others from the fuel supply chain and plant construction. Direct emissions were calculated according to IPCC Guidelines. In the case of carbon capture, the direct emissions are the difference between the produced and captured CO_2 amounts. Conservative capture rates have been assumed (85% for all CCS technologies), which is the minimum capture efficiency proposed by the IPCC Guidelines. The indirect emissions of plants were based on an average value provided by the Ecoinvent Life Cycle Inventory[10] for the supply of each type of fuel in Europe. Indirect emissions from other stages of the life cycle (e.g. construction) were obtained based on available data for relevant facilities. Finally, the calculated lifecycle emissions were harmonized with the life cycle GHG emission values of similar technologies available in the Ecoinvent database and other relevant literature[11].

For the non-fossil fuel technologies, lifecycle GHG emissions were obtained directly from available references listed in Table 3-3.

It is noted that the pathways for the supply of fuel and raw materials, and the location of power generation facilities have a significant influence on lifecycle emissions. Table 3-3 shows the range of values calculated by the JRC or reported in the literature with the corresponding references.

(IV) Fuel price sensitivity: This refers to the sensitivity of the production cost of electricity to changes in fuel prices, which can be estimated by the fraction of fuel costs to the total production cost of electricity. In the context of this analysis, the following scale was assumed:

Sensitivity	Fraction of fuel cost to COE - Δ(FC)
Very high	$\Delta(FC) > 60\%$
High	$60\% \geq \Delta(FC) > 40\%$
Medium	$40\% \geq \Delta(FC) > 20\%$
Low	$\Delta(FC) \leq 20\%$

[10] See reference [95]
[11] See reference [103] and [104]

Table 3-1: Technology description, installation size, and current and future conversion efficiency

Technology	Description	Net capacity		Net efficiency			
				2007 (2015 for CCS)		2030	
		[MW]	*References*	[%]	*References*	[%]	*References*
Open Cycle Gas Turbine (GT)	Industrial gas turbine	250	[1]	38%	[1]	45%	[89]
Combined Cycle Gas Turbine (CCGT)	Plant with state-of-art heavy duty industrial turbines, optimised heat recovery steam generator and anti-NOx equipment	650	[1],[5],[24],[91]	58%	[1]	65%	[89]
Combined Cycle Gas Turbine with CCS	As above, equipped with post-combustion capture based on MEA scrubbing	550	[7],[5],[97-98]	49%	[5]	55%	JRC
Internal Combustion Diesel Engine	Heavy duty reciprocating engine	50	[24]	45%	[99]	48%	JRC
Combined Cycle Oil-fired Turbine	Plant with state-of-the-art oil-fired industrial turbines	175	[100]	53%	JRC	59%	JRC
Pulverised Coal Combustion (PCC)	Supercritical power plant, steam at 600ºC, FGD and SCR	800	[1],[5],[24],[91]	47%	[91],[101]	54%	JRC
Pulverised Coal Combustion with CCS	As above, equipped with post-combustion capture based on MEA scrubbing	500	[7],[5],[97]	35%	[5]	42%	JRC
Circulating Fluidised Bed Combustion (CFBC)	Circulating fluidised bed plant	300	[1],][24]	40%	[101]	50%	[101]
Integrated Gasification Combined Cycle (IGCC)	Plant with a dry-fed entrained flow gasifier and state-of-the-art syngas turbines	675	[1],[97],[101],[102],[88],[91]	45%	[101],[102]	57%	[101]
Integrated Gasification Combined Cycle with CCS	Mean performance of dry- and slurry-fed IGCC plants with pre-combustion capture using the Selexol process	600	[7],[97],[102]	35%	[102]	47%	JRC
Nuclear fission	Generation III water cooled reactor designs (mainly considering evolutionary light water reactor designs as EPR and ABWR)	1600	[19],[15],[33-38]	35%	[19],[15],[33-38]	36%	JRC
Biomass combustion steam cycle – small scale	Combustion boiler with a steam turbine	5	[54],[55]	24%	[42], [54], [55]	25%	JRC
Biomass combustion steam cycle – large scale	Fluidized bed combustion boiler with a steam turbine	30	[54]	29%	[42], [54]	30%	JRC
Biogas plant	Farm-scale co-digestion biogas plant	0.3	[41],[42],[113]	31%	[41], [43]	32%	JRC
Landfill Gas	Landfill with a gas engine	4.4	[41]	34%	[41], [42]	36%	JRC
On-shore Wind	On-shore wind turbine in a farm configuration	2	[1],[24],[41],[64-65],[119]	-	-	-	-
Off-shore Wind	Off-shore wind turbine in a farm configuration, located in shallow waters (up to 30m)	3.6	[1],[24],[41],[77-78],[119]	-	-	-	-
Hydropower – large scale	Hydropower plant above 10 MWe, considering different configurations from the building of a new facility, the extension of an existing facility and the powering an existing hydro scheme	20	[41],[63]	-	-	-	-
		75	[41],[63]	-	-	-	-
		250	[41],[63]	-	-	-	-
Hydropower – small scale	Hydropower plant below 10 MWe considering different configurations from the building of a new facility, the extension of an existing facility and the powering an existing hydro scheme	2	[41],[63]	-	-	-	-
		10	[41],[63]	-	-	-	-
Photovoltaics	System based on crystalline silicon panels	1	JRC	-	-	-	-
Concentrating Solar Power (CSP)	Parabolic trough collector with storage and natural gas backup power plant	50	[146]	-	-	-	-

Table 3-2: Overnight specific capital investment and O&M costs of power generation technologies, and assumed fuel prices

Technology	SCI_P (state-of-the-art, 2007) [€$_{2005}$/kW] REF	Range	*References*	Annualized O&M costs (VOM+FOM) [€$_{2005}$/kW] REF	Range	*References*	Fuel prices (Moderate / High) [€$_{2005}$/toe] 2007	2020	2030
Open Cycle Gas Turbine (GT)	310	200 ÷ 400	[2-3]	10	6 ÷ 13	JRC,[5]	250	L: 300 H: 510	L: 320 H: 595
Combined Cycle Gas Turbine (CCGT)	635	480 ÷ 730	[1],[5],[24],[91]	25	19 ÷ 26				
Combined Cycle Gas Turbine with CCS	1200	1000 ÷ 1300	[7],[5],[97-98]	40	37 ÷ 44				
Internal Combustion Diesel Engine	800	550 ÷ 1350	[3],[24]	40	29 ÷ 63	JRC	440	L: 550 H: 745	L: 540 H: 920
Combined Cycle Oil-fired Turbine	1000	900 ÷ 1100	[100]	50	48 ÷ 55				
Pulverised Coal Combustion (PCC)	1265	1000 ÷ 1440	[1],[5],[24],[91]	60	50 ÷ 67	JRC,[5],[94],[102]	90	L: 95 H: 155	L: 105 H: 190
Pulverised Coal Combustion with CCS	2250	1700 ÷ 2700	[92],[94],[97]	90	76 ÷ 101				
Circulating Fluidised Bed Combustion (CFBC)	1400	1250 ÷ 1500	[1,24]	70	62 ÷ 71				
Integrated Gasification Combined Cycle (IGCC)	1550	1400 ÷ 1650	[1],[97],[101],[102],[88],[91]	65	61 ÷ 69				
Integrated Gasification Combined Cycle with CCS	2100	1700 ÷ 2400	[7],[97],[102]	85	74 ÷ 95				
Nuclear fission	2680	1970 ÷ 3380	[8-32],[1]	90	74 ÷ 107	[1],[22-25],[27],[31],[38-39]	33	L: 35 H: 53	L: 37 H: 63
Biomass combustion steam cycle – small scale	3800	2900 ÷ 5080	[42],[54],[55],[85],[147]	260	235 ÷ 292	[42],[54],[55],[120],[125]	160	L: 215 H: 235	L: 235 H: 275
Biomass combustion steam cycle – large scale	2450	2020 ÷ 3220	[54],[42],[55]	135	124 ÷ 161	[54],[55],[120],[125]	90	L: 120 H: 135	L: 135 H: 160
Biogas plant	3140	2960 ÷ 5790	[41],[42],[43],[45],[108],[113]	245	237 ÷ 334	[113]	270	270	270
Landfill Gas	1530	1400 ÷ 2000	[41],[48],[49]	200	199 ÷ 211	[42],[132]	0	0	0
On-shore Wind	1140	1000 ÷ 1370	[1],[6],[19],[24],[40-42],[64-70]	35	33 ÷ 42	[1],[6],[19],[24],[41-42],[64-65],[68-70]		-	
Off-shore Wind	2000	1750 ÷ 2750	[1],[6],[19],[24],[40-41],[66],[68],[70],[119]	80	71 ÷ 105	[1],[6],[24],[41-42],[64-65],[68],[70]		-	
Hydropower – large scale	2510	1750 ÷ 4500	[6],[41],[60],[63],[126]	75	-	[24],[41],[119],[132-134]		-	
	1800	1230 ÷ 3650		55	-	[24],[41],[119],[121],[132-134]		-	
	1350	900 ÷ 3100		40	-	[24],[41],[119],[132-134]		-	
Hydropower – small scale	4500	2500 ÷ 6600	[6],[41],[60],[63],[126],[147]	130	-	[24],[41],[119],[132-134]		-	
	2900	2000 ÷ 4800		85	-			-	
Photovoltaics	4700	4100 ÷ 6900	[136],[24],[90],[94]	80	72 ÷ 114	JRC,[92]		-	
Concentrating Solar Power	5000	4000÷6000	[146],[6],[19],[24],[137-143]	115	111÷121	[146],[24],[137],[139-143]	250 [(a)]	L: 300 H: 510 [(a)]	L: 320 H: 595 [(a)]

[(a)] *Natural gas consumed for backup heat production.*

Table 3-3: Construction time and life time of facility, current and future global installed capacity, learning rate and lifecycle GHG emissions

Technology	Construct. time [year]	Life-time [year]	Global installed capacity C_P [GW]	C_{2030} [GW]	Learning rate, LR [%]	*References*	Lifecycle GHG emission t_{CO2}/GWh	*References*
Open Cycle Gas Turbine (GT)	1	25	225	1110	5.0%	[6],[7],[87]	520 ÷ 600	[95],[104]
Combined Cycle Gas Turbine (CCGT)	3	25	350	790	5.0%	[6],[7],[96]	365 ÷ 495	[95],[103-104]
Combined Cycle Gas Turbine with CCS	4	25	1	61	2.2%	[7],[6]	80 ÷ 235	[95],[103-104]
Internal Combustion Diesel Engine	1	25	200	930	3.0%	[87]	670 ÷ 690	[95],[104]
Combined Cycle Oil-fired Turbine	3	25	350	790	3.0%	[6],[7],[96]	570 ÷ 590	[95],[104]
Pulverised Coal Combustion (PCC)	3	40	300	790	6.0%	[6],[7],[96]	800 ÷ 860	[95],[103-104]
Pulverised Coal Combustion with CCS	4	40	10	235	2.1%	[7],[6]	240 ÷ 290	[95],[103-104]
Circulating Fluidised Bed Combustion (CFBC)	3	40	70	230	6.0%	[101],[101]	950 ÷ 980	[95],[103-104]
Integrated Gasification Combined Cycle (IGCC)	3	40	1	3	11.0%	[7]	830 ÷ 860	[95],[103-104]
Integrated Gasification Combined Cycle with CCS	4	40	10	235	5.0%	[6],[7]	240 ÷ 290	[95],[103-104]
Nuclear fission	6	40	3 [(a)]	100 [(a)]	3.0%	[26],[40],[6]	3 ÷ 40	[95],[129-131],[103-104]
Biomass combustion steam cycle – small scale	2	30	62	125	12.5%	[6],[41]	42	[119]
Biomass combustion steam cycle – large scale	2	30			12.5%	[6],[41]	21	[119]
Biogas plant	1	25	4	11	12.5%	[6],[41],[46],[47]	245	[119]
Landfill Gas	1	25			11.0%	[6],[41],[46],[47]	6	[119]
On-shore Wind	1	20	95	960	8.0%	[6],[64],[68],[73-76]	7 ÷ 30	[95],[40],[103-104]
Off-shore Wind	2	20	12	210	8.0%	[6],[64],[68],[73-76]	9 ÷ 22	[95],[40],[103-104]
Hydropower – large scale	4	50	770	n/a	-0.5% per year	[6],[41],[73]	3.5 ÷ 40	[95],[119]
	4	50						
	4	50						
Hydropower – small scale	3	50	75	n/a	-1.2% per year	[41],[73]	3.5 ÷ 10	[59],[119],[95]
	3	50					3.5 ÷ 32	[59],[119],[95]
Photovoltaics	0	25	8	150	23.0%	[94],[93],[6],[93]	40 ÷ 110	[40],[95],[103]
Concentrating Solar Power	2	40	0.4	60	10.0%	[6],[138],[144-146]	135 [(b)]	[40]

[(a)] *Values represent the global installed capacity of Generation III (and 3+) nuclear reactors only, and not the total installed nuclear capacity operating worldwide (370 GW in 2007).*

[(b)] *This includes 15 t_{CO2}/GWh of indirect emissions and the direct combustion emissions from natural gas use.*

3.2. Energy Sources for Heating

This section describes the methodology and data used for the comparison Table of energy sources for heating. Table 3-4 summarises the techno-economic characteristics of selected current state-of-the-art heat generation technologies.

3.2.1. Technologies

This analysis focuses on central heating systems for households with heat generation capacities between 15 kW_{th} and 100 kW_{th}. The technologies addressed are:

1. Natural gas fuelled boiler
2. Heating oil fuelled boiler
3. Coal fuelled boiler
4. Biomass fuelled boiler:
   - Wood chips
   - Pellets
5. Solar thermal system
6. Geothermal with heat pump
7. Electricity boiler and heater

District heating and cogeneration of heat and power (CHP) are not addressed in this analysis.

3.2.2. Indicators

The methodology used for calculating the cost of heat generation is similar to the one used for the calculation of the production cost of electricity. In this section, only the main differences are described.

(I) Market share: The market shares reported in the updated Table refer to the residential sector only. The reported values have been adopted from the publication 'European Energy and Transport: Trends to 2030 - Update 2007'[12]. It is noted that district heating, which has a share of 7.6% of the market, has not been considered in the analysis.

(II) Fuel retail price: This refers to fuel prices for households, including taxes. Fuel costs for the moderate fuel price scenario are derived from the DG TREN publication 'European Energy and Transport: Trends to 2030 - Update 2007'[13], while fuel costs for the high fuel price scenario are based on the DG TREN 'Scenarios on high oil and gas prices'[14]. Moreover, prices for biomass were calculated based on values reported in EUBIONET II[15] and adjusted to reflect the biomass price trends considered in the previously mentioned DG TREN scenarios.

(III) Production cost of heat: The production cost of heat, expressed in constant €(2005)/toe in useful heat produced, is used to compare the economic competitiveness among different energy sources for heating. The reported values represent a snapshot of costs in 2007. Running costs refer to the annual cost to produce heat without considering the initial capital costs. Total costs refer to the production cost that includes the recovery of capital. The

---

12 See reference [80]
13 See reference [80]
14 To be published
15 See reference [56]

reported values for each energy source refer to a state-of-the-art heating facility, as described in Table 3-4. The reported range reflects different technologies and variations in capital costs but does not reflect the variability in the fuel retail prices between the Member States.

The reported running production cost values have been calculated using the following formula:

$$RCH = \frac{FOM}{8760 \cdot LF} + VOM + FC$$

The reported total production cost values have been calculated using the following formula:

$$COH = \frac{SCI \cdot CRF}{8760 \cdot LF} + RCH$$

Where:

RCH …is the running cost of heat production, in $€_{2005}$/toe,

COH …is the total production cost of heat, in $€_{2005}$/toe,

LF …is the annual load factor of the heating system,

FOM …refers to the annual fixed operating costs, in $€_{2005}$/toe,

VOM …refers to the variable operating costs, in $€_{2005}$/toe,

FC …refers to fuel costs, in $€_{2005}$/toe,

SCI …is the specific overnight capital investment, in $€_{2005}$/toe,

CRF …is the capital recovery factor.

All values are reported in useful heat produced

An annual load factor of 10% was used for the calculations for all technologies except for solar where a value of 8% was used to reflect resource constraints. The former load factor refers to an average of the annual operating time of the heat production facility at nominal capacity to meet the heat demand of a typical European house of about 110 m^2 and of a small residential building of about 550 m^2, based on an average annual outdoor temperature of 8.8°C and an indoor temperature of 20/19/22°C[16].

FOM costs account for the service, maintenance and repair of the heating facility, while *VOM* costs account for the cost of other consumables, mainly auxiliary power. Table 3-4 shows the total operational and maintenance costs (OM) normalised to the installed net capacity.

The fuel costs were calculated based on the fuel retail prices as noted above for the two scenarios.

The overnight specific capital investment (*SCI*) for each heating facility refers to the price of the heating unit and its installation, excluding the cost of additional infrastructure.

A real discount rate of 15% was assumed for all technologies for the calculation of the capital recovery factor (*CRF*).

No carbon costs were considered in the calculation of the cost of heat generation.

16 See reference [117]

(IV) Life-cycle greenhouse gas emissions: Life cycle emissions were calculated following the same methodology and databases as for power generation technologies.

Table 3-4: Technology description, installation size, current conversion efficiency, overnight specific capital investment, life-time and O&M costs of heat generation technologies

Technology	Description	Capacity	Efficiency		Capital costs, 2007 [€$_{2005}$/kW], VAT excl.			Annual O&M costs (VOM+FOM) [€$_{2005}$/kW], VAT excl.			Life-time	Lifecycle GHG emissions	
		[kW]	[%]	*References*	REF	Range	*References*	REF	Range	*References*	[year]	t_{CO2}/toe	*References*
Natural gas boiler	Natural gas fuelled boiler, large size, combi, floorstanding	75	89%	[112], [117], [116]	110	95 ÷ 135	[112], [118]	9	9 ÷ 10	[112], [118]	17	3.3	[95]
	Natural gas fuelled boiler, medium/small size, combi, wall-hung	20	86%	[112], [117], [116]	125	100 ÷ 130	[112]	13	11 ÷ 14	[112]	17	3.4	[95]
	Natural gas fuelled condensing boiler, medium size, combi, wall-hung	20	104%	[112], [117], [116]	145	115 ÷ 155	[112]	11	10 ÷ 12	[112]	17	2.9	[95]
Heating oil boiler	Heating oil fuelled boiler, large size, combi, floor standing, with oil reservoir	75	86%	[112], [117], [116]	190	160 ÷ 240	[112], [110], [118]	12	11 ÷ 14	[112], [118]	17	4.2	[95]
	Heating oil fuelled boiler, medium/small size, combi, floorstanding, with oil reservoir	20	80%	[112], [117], [116]	325	265 ÷ 355	[112]	18	15 ÷ 19	[112]	17	4.5	[95]
	Heating oil fuelled condensing boiler, medium size, combi, floorstanding, with oil reservoir	20	99%	[112], [117], [116]	390	310 ÷ 425	[112]	13	11 ÷ 14	[112]	17	3.6	[95]
Coal boiler	Solid fuel fuelled boiler, large size, with heat buffer	50	75%	JRC	340	310 ÷ 410	JRC	13	12 ÷ 15	JRC	17	6.1	[95],[103]
Wood chips boiler	Wood chips fired boiler, large size, with hot water reservoir and heat buffer	50	79%	[110]	385	325 ÷ 440	[109], [110], [111]	16	14 ÷ 18	[110]	17	0.3	[59], [95]
	Wood chips fired boiler, medium size, with hot water reservoir and heat buffer	35	79%	[110]	575	490 ÷ 665	[109], [110], [111]	22	20 ÷ 25	[110]	17	0.3	[59], [95]
Pellets boiler	Pellets fired boiler, large size, with hot water reservoir and heat buffer, inc. pellets silo	50	84%	[110]	355	300 ÷ 410	[109], [110], [111]	15	13 ÷ 17	[110]	17	0.7	[95]
	Pellets fired boiler, medium size, with hot water reservoir and heat buffer, inc. pellets silo	35	84%	[110]	505	430 ÷ 585	[109], [110], [111]	19	17 ÷ 22	[110]	17	0.7	[95]
	Pellets fired boiler, small size, with hot water reservoir and heat buffer, inc. pellets silo	15	84%	[110]	940	800 ÷ 1080	[109], [110], [111]	34	29 ÷ 38	[110]	17	0.8	[95]
Solar heat	Water heating system	3.5	98%	[135]	980	340 ÷ 2800	[92]	16	-	[92]	20	0.3	[95]
Geothermal heat pump	Large size electrical operated heat pump with geothermal heat source	100	100%	[116]	500	200 ÷ 1150	[92]	39	34 ÷ 60	[92]	25	0.2 ÷ 3.7	[95]
	Medium size electrical operated heat pump with horizontal or water ground heat source	15	100%	[116]	640	550 ÷ 720	[115]	55	54 ÷ 69	[112]	17	0.3 ÷ 5.9	[95]
Electrical heating	Electric combi heating/water boiler, medium/small size, wall-hung	20	100%	JRC	75	65 ÷ 90	JRC	5	-	JRC	17	0.7÷14.8	[95]
	Resistance heaters with fan assisted air circulation	2	97%	[123]	140	30 ÷ 300	JRC	n/a	-	[123]	10	0.7÷15.2	[95]

3.3. Energy Sources for Transport Fuels

The techno-economic characteristics of the selected transport fuels reported have been calculated by the JRC based on the methodology developed in the Well to Wheel JRC–EUCAR-CONCAWE study[17], but using the fuel prices used in this analysis. The time horizon considered is 2015.

Domestic biofuel production encompass ethanol produced from wheat grain with by-product credits for animal feed and heat supply from natural gas fired CCGT, and RME biodiesel with credits for animal feed. The second generation biofuel pathways are based on ethanol from straw and BTL using short rotation forestry as a feedstock.

[17] See reference [4]

4. REFERENCES

[1] Royal academy of engineering: *The Cost of Generating Electricity*. March 2004

[2] Nye Thermodynamics Corporation: *Prices*. Available at www.gas-turbines.com/trader/outprice.htm

[3] IEA GHG: *CO_2 capture from medium scale combustion installations*. Report 2007/7, 2007

[4] JRC, EUCAR, CONCAWE: *Well-To-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context - update 2007*. March 2007

[5] IEA GHG: *Improvement in power generation with post-combustion capture*. Report PH4/33, 2004.

[6] IEA: *Energy Technology Perspectives 2008 – Scenarios and Strategies to 2050*. 2008

[7] E. Rubin et al: *Use of experience curves to estimate the future cost of power plants with CO_2 capture*. International Journal of GHG control, 1 (2007) 188-197, 2007

[8] Areva: *Finnish EPR Olkiluoto 3 – The world's first third-generation reactor now under construction*. May 2007

[9] *Finland's EPR milestone*. Issue 9, 2007. Available at www.energy-focus.com,

[10] *Finnish plant demonstrates nuclear power industry's perennial problems*. Bloomberg News, International Herald Tribune, 6.9.2007. Available at www.iht.com

[11] Florida Power & Light Company: *Project "Turkey Point - Units 5&6" of the Florida Power & Light Company*. Direct Testimony of Steven D. Scroggs, Florida Public Service Commission (doc.no. 09467-07), October 2007. Available at www.psc.state.fl.us

[12] *NRG forms new nuclear unit with Toshiba*. Reuters, 25.03.2008. Available at www.reuters.com

[13] *NRG picks Toshiba for South Texas reactor project*. Reuters, 10.08.2007. Available at www.reuters.com

[14] TVA (Tennessee Valley Authority): *New Nuclear Power Plant Licensing Demonstration Project - ABWR Cost/Schedule/COL Project at TVA's Bellefonte Site*. DOE Programme NP2010, August 2005

[15] GE Nuclear Energy: A*BWR - Advanced Boiling Water Reactor Plant General Description. General Electric*, June 2000

[16] Makhijani, A.: *Assessing Nuclear Plant Capital Costs for the Two Proposed NRG Reactors at the South Texas Project Site*. Institute for Energy and Environmental Research, March 2008

[17] *How Much?*. Nuclear Engineering International, 29.11.2007.

[18] *Standard & Poor Estimation*. Nuclear Engineering International, May 2007, Available at www.neimagazine.com

[19] Eurelectric: *The Role of Electricity - A New Path to Secure, Competitive Energy in a Carbon-Constrained World*. June 2007

[20] The Keystone Centre: *Nuclear Power Joint Fact-Finding*. June 2007

[21] Energy Information Administration: *Assumptions to the Annual Energy Outlook 2007*. Report #:DOE/EIA-0554(2007), April 2007

[22] World Energy Council: *The Future Role of Nuclear Power in Europe*. January 2007

[23] Department of Trade and Industry: *The Future of Nuclear Power - The Role of Nuclear Power in a Low Carbon UK Economy*. Consultation Document, DTI/Pub 8519/4k/05/07/NP, May 2006

[24] IEA/NEA: *Projected Costs of Generating Electricity - 2005 Update*. 2005

[25] Direction Génerale de l'Energie et des Matières Premières: *Reference cost of power generation*. March 2004

[26] World Nuclear Association: *The New Economics of Nuclear Power*. WNA Report, 2005

[27] The University of Chicago: *The Economic Future of Nuclear Power*. US DOE Program NP2010, August 2004

[28] Canadian Energy Research Institute: *Levelised Unit Electricity Cost Comparison of Alternate Technologies for Baseload Generation in Ontario*. August 2004

[29] Massachusetts Institute of Technology: *The Future of Nuclear Power.* 2003

[30] US Department of Energy - Office of Nuclear Energy, Science and Technology: *A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010.* October 2001

[31] Roques et all: *Nuclear Power: a Hedge against Uncertain Gas and Carbon Prices?* The Energy Journal, International Association for Energy Economics, Vol.27 No.4. October 2006

[32] J.Harding, *Economics of New Nuclear Power and Proliferation Risks in a Carbon Constrained World*. Nonproliferation Policy Education Centre, June 2007

[33] Areva: *EPR*. Framatome ANP, March 2005

[34] Areva: *N4 - The most advanced reactor in operation.* Framatome ANP, February 2004

[35] Westinghouse Electric Co.: *The Westinghouse AP1000 Advanced Nuclear Plant - Plant Description*. 2003

[36] *Technology Fact Sheet - Westinghouse – AP1000*. Available at www.energetics.com/pdfs/nuclear/ap1000.pdf

[37] *Technology Fact Sheet - General Electric – ESBWR*. Available at www.energetics.com/pdfs/nuclear/esbwr.pdf

[38] IEA: *Energy Technology Essentials - Nuclear Power*, March 2007

[39] Beuter,D.: *Westminster Energy Forum : EPR Background and its Role in Continental Europe*. AREVA Corporate Strategy Department, June 2005

[40] European Commission: *A European Strategic Energy Technology Plan (SET-Plan) - Technology Map*. SEC(2007) 1510, November 2007

[41] Ragwitz M., Resch G.: *Economic analysis of reaching a 20% share of renewable energy sources in 2020 - Annex 1 to the final report: Methodological aspects & database for the scenarios of RES deployment*. Fraunhofer / Energy Economics Group / ECOFYS, August 2006

[42] Van Tilburg, X., et al: *Technisch-economische parameters van duurzame elektriciteitsopties in 2008-2009 - Eindadvies basisbedragen voor de SDE-regeling*. ECN / KEMA, January 2008

[43] Braun R.: *Energy Efficiency in Energy Crop Digestion - Based on an Evaluation of 41 Austrian Full Scale Biogas Plants*. IEA Task 37 Energy from Biogas - Biomass Conference Berlin 2007. Available at www.iea-biogas.net

[44] Chesshire, M.: *Anaerobic Digestion & Biogas technology within UK Agriculture*. Greenfinch / Cropgen, 2006. Available at www.cropgen.soton.ac.uk

[45] IEA Task 37: *Biogas- basic data on biogas - Sweden 2007*. June 2007

[46] IEA: *Renewables Information*. IEA Statistics 2007

[47] IEA: *Electricity Information*. IEA Statistics 2007

[48] US Environmental Protection Agency: *Turning a liability into an Asset: A Landfill Gas-to-Energy Project Development Handbook*. September 1996

[49] Banks, C.: *Status of biogas production and application*. University of Southampton. May 2007. Available at www.iea-biogas.net/Dokumente/berlin/banks_contribution_berlin07.pdf

[50] ECN: *Kosten Duurzame Elektriciteit – Vergistingsopties*. Report ECN-C-03-074/F, August 2003

[51] Hogg, D.: *Costs for Municipal Waste Management in the EU, Final Report to DG Environment, European Commission*. Eunomia Research and Consulting, 2002

[52] DANCEE/OECD: *The FEASIBLE Model, Version 2 - User Manual and Documentation, Appendix 4*. Prepared by COWI, May 2003

[53] Murphy J.D.: *Technical, economic and environmental analysis of energy production from municipal waste*. Renewable Energy 29 (2004) 1043–1056, 2004

[54] Caputo A.C. et al: *Economics of biomass energy utilization in combustion and gasification plants: effects of logistics variables*. Biomass and Bioenergy (2005) 35-51, 2005

[55] Bridgwater A.V. et al: *A technico-economic comparison of power production by biomass fast pyrolysis with gasification and combustion*. Renewable and Sustainable Energy Reviews 6 (2002) 181-248, 2002

[56] VTT Technical Research Centre of Finland: *Biomass fuel Trade in Europe*, - Summary Report VTT-R-03508-07. EUBIONET II, March 2007

[57] IFEU, IER: *New Energy Externalities Developments for Sustainability - Final report on technical data, costs and life cycle inventories of biomass CHP plants*. NEEDS Project, Deliverable n° 13.2 - RS 1a, April 2008

[58] DGEMP-DIDEME: *Coûts de référence de la production électrique - Deuxième partie – Moyens de production décentralisés*. 2004

[59] Pehnt M.: *Dynamic life cycle assessment (LCA) of renewable energy technologies*. Renewable Energy 31 (2006) 55–71, 2006

[60] DSI: *Ilisu Dam and HEPP Environmental Impact Assessment Report*. 2006

[61] Lawrence, S.: *Presentation on Hydropower*. University of Colorado, Available at leeds-faculty.colorado.edu/lawrence/syst6820/Lectures/Hydropower.ppt

[62] U.S. Army Corps of Engineers: *Engineering and Design Hydropower, Engineering Manual*. No. 1110-2-1701, Department of the Army, 1985

[63] Hall, D., Hunt R., Reeves K., Carroll G.: *Estimation of Economic Parameters of U.S. Hydropower Resources*. Idaho National Engineering and Environmental Laboratory, June 2003

[64] Global Wind Energy Council / Greenpeace: *Global Wind Energy Outlook 2006*. September 2006

[65] EWEA: *Wind Energy - The Facts*. 2004

[66] Junginger, F., et al: *Cost Reduction Prospects for Offshore Wind Farms*. Wind Energy Vol. 28, No. 1, 2004

[67] National Renewable Energy Laboratory: *Power Technologies Energy Data Book - Fourth Edition*. NREL/TP-620-39728, U.S. Department of Energy - Office of Energy Efficiency and Renewable Energy, August 2006

[68] Norland, D., Jenkin, T.: *Projected Benefits of Federal Energy Efficiency and Renewable Energy Programs: FY 2006 Budget Request*. National Renewable Energy Laboratory, NREL/TP-620-37931, May 2005

[69] US Department of Energy: *Annual Report on US Wind Power Installation, Cost and Performance Trends: 2006*. May 2007

[70] Van Tilburg, X., et al: *Technisch-economische parameters van duurzame elektriciteitsopties in 2008 - Conceptadvies onrendabele topberekeningen*. ECN / KEMA, September 2006

[71] Wien,F.: *Power Quality and Utilisation Guide: Distributed Generation and Renewables - 8.3.2. Wind Power*. KEMA, November 2006

[72] Gorban, A., Gorlov, A, Silantyev, V.: *Limits of the Turbine Efficiency for Free Fluid Flow*. Journal of Energy Resources Technology, Vol. 123, ASME, December 2001

[73] REN21 (Renewable Energy Policy Network for the 21st Century): *Renewables 2007 - Global Status Report*. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 2008

[74] Global Wind Energy Council: *Gobal Wind Report 2007*. 2008

[75] McDonald, A., Schrattenholzer, L.: *Learning Rates for Energy Technologies*. Energy Policy 29, 2001

[76] Junginger, M., et al: *Global Experience Curves for Wind Farms*. Energy Policy 33, 2005

[77] EWEA: *Delivering Offshore Wind Power in Europe*. December 2007

[78] IEA: *Offshore wind experiences*. June 2005

[79] Eurostat: *Energy, transport and environment indicators - 2007 edition*. February 2008

[80] DG TREN: *European Energy and Transport: Trends to 2030 - Update 2007*. April 2008

[81] Federal Institute for Geosciences and Natural Resources: *Reserves, Resources and Availability of Energy Resources 2006: status 31.12. 2006, Federal Institute for Geosciences and Natural Resources*. December 2007

[82] Walla C.: *The optimal size for biogas plants*, Biomass and Bioenergy, Article in Press 2007

[83] Jenkins B.M.: *A comment on the optimal sizing of a biomass utilization facility under constant and variable cost scaling*. Biomass and Bioenergy 13, 1997

[84] Goldstein R. et al: *The Impact of landfill Gas to Energy Projects on Jobs and Revenue*, 8th Annual LMOP Conference Baltimore, MD, January 2005

[85] Danish Energy Authority: *Technology Data for Electricity and Heat Generating Plants*. March 2005

[86] *IEA Implementing Agreement IEA Hydropower*. Available at www.ieahydro.org/faq.htm#a2

[87] McNeely, M.: *Diesel & Gas Turbine Worldwide*, Power Generation Order Survey, October 2007

[88] *Cost comparison IGCC and Advanced Coal*. EPRI Presentation, 2004, Available at www.climatevision.gov/pdfs/coal_roundtable/dalton.pdf

[89] *A Power Generation Strategy for Europe*. CAME-GT, 2004. Available at www.came-gt.com

[90] Solarbuzz: *Solar module price highlights - April 2008*. Available at www.solarbuzz.com/ModulePrices.htm

[91] IEA: *Fossil-fuelled power generation*. 2007

[92] IEA: *Renewables for heating and cooling*. 2007

[93] G. Nemet: *Learning curves for photovoltaics*. Presentation to IEA, 2007. Available at www.iea.org/Textbase/work/2007/learning/Nemet_PV.pdf

[94] IEA: *Trends in photovoltaics applications*. Report IEA-PVPS T1-16, 2007

[95] Ecoinvent Centre: *Ecoinvent data v2.0.* Swiss Centre for Life Cycle Inventories, Dübendorf, 2007 (CD-ROM)

[96] IEA: *World Energy Outlook 2007*. 2007

[97] IPCC: *Special report on carbon capture and storage*. 2005

[98] IEA GHG: *Retrofit of CO_2 capture to natural gas combined cycle power plants*, Report 2005/1, 2005

[99] Boyce, M.P.: *Handbook for Cogeneration and Combined Cycle Power Plants*. ASME Press, 2002

[100] *Endesa announcements for Son Reus and Cas Tresover power plants*. Available at www.endesa.es/Portal/en/default.htm

[101] PowerClean: *Fossil fuel power generation: State-of-the-art*. 2004.

[102] IEA GHG: *Potential for improvement in gasification combined cycle power generation with CO_2 capture*. Report 4/19, 2003

[103] World Energy Council: *Comparison of Energy Systems Using Life Cycle Assessment*. July 2004

[104] Weisser, D.: *A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies*. Energy 32 (2007) 1534-1559, ScienceDirect, 2007

[105] ESTTP presentation to SET-Plan Hearings, 2007. Available at ec.europa.eu/energy/res/setplan/index_en.htm

[106] Khan, I.: *A Generator's View of Future Fuels*. Institute of Physics – Combustion Physics Group, Cardiff University, April 2005

[107] *Biomass Power Plants in Europe*. Available at www.industcards.com/biomass-europe.htm

[108] Department of Trade and Industry: *UK Biomass Strategy 2007; Working Paper 1 – Economic analysis of biomass energy*. May 2007

[109] Hansen H.: *Marktübersicht Pellet-Zentralheizungen und Pelletöfen*. Fachagentur Nachwachsende Rohstoffe e.V. (FNR), April 2005

[110] Hartman H et al: *Handbuch Bioenergy-Kleinanlagen*. Fachagentur Nachwachsende Rohstoffe e.V. (FNR), March 2007

[111] Frei, T.: *Nutzung von Getreidekorn als Brennstoff*. Fakultät II Studiengang Agrarwirtschaft (Diplom) Diplomarbeit, January 2007

[112] VHK: *Eco-design of Boilers - Preparatory Study, Task 1÷7*. Prepared for European Commission, DG TREN, September 2007

[113] Institut fur Energetik und Umwelt Gmbh: *Handreichung - Biogasgewinnung und – nutzung*. Fachagentur Nachwachsende Rohstoffe e.V. (FNR), 2005

[114] IEA Implementing Agreement for Cooperation in Geothermal Research & Technology: *IEA Geothermal Energy Annual Report 2006*. January 2008

[115] Sustainable Energy Ireland (SEI): *Renewable Heat Pumps - A guide for the technically minded*. Available at www.sei.ie

[116] Ecoheatcool Project: *Recommendations and project reports*. Ecoheatcool and Euroheat&Power, 2006

[117] VHK: *Ecoboiler Integrated Model– Draft V.5b. (20 June 2007)*. Available at www.ecoboiler.org

[118] BIOHEAT: *Promoting Biomass heating in large buildings and blocks*. Energieverwertungsagentur – the Austrian Energy Agency (E.V.A.), January 2003

[119] Staiß F. et al: *Vorbereitung und Begleitung der Erstellung des Erfahrungsberichtes 2007 gemäß § 20 EEG*. Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), im Auftrag des Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit, November 2007

[120] Müller-Langer F. et al: *Monitoring zur Wirkung der Biomassenverordnung*. Publikationen des Umweltbundesamtes, February 2006

[121] Reichmuth M. et al: *Auswirkungen der Änderungen des Erneuerbare-Energien-Gesetzes hinsichtlich des Gesamtvolumens der Förderung, der Belastung der Stromverbraucher sowie der Lenkungswirkung der Fördersätze für die einzelnen Energiearten*. Institute for Energy and Environment, November 2006

[122] Eurostat: *Gas prices for EU households and industrial consumers on 1 January 2007*. Statistics in focus 78/2007, 2007

[123] Gustavsson, L., Joelsson, A.: *Energy conservation and conversion of electrical heating systems in detached houses*. Energy and Buildings 39, 2007

[124] DG TREN with Eurostat: *EU Energy and Transport in Figures 2007*. December 2007

[125] Nitsch J.: *Ökologisch optimierter Ausbau der Nutzung erneuerbarer Energien in Deutschland*. DLR/IFEU/WI, March 2004

[126] Fichtner: *Gutachten zur Berücksichtigung großer Laufwasserkraftwerke im EEG*. July 2003

[127] Eggleston, H.S. at al: *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. IPCC 2006, prepared by the National Greenhouse Gas Inventories Programme, IGES, 2006

[128] Borjesson, P.: *Environmental systems analysis of biogas systems—Part I:Fuel-cycle emissions*. Biomass and Bioenergy 30, 2006

[129] IAEA: *Nuclear Power and Sustainable Development*. April 2006

[130] Sustainable Development Commission: *The Role of Nuclear Power in a Low Carbon Economy*. Position Paper, March, 2006

[131] World Nuclear Association: *Energy Balances and CO_2 Implications*. March 2006

[132] OXERA: *Results of Renewables Market Modelling*. DTI, 2004

[133] EPRI: *California Renewable Technology Market and Benefits Assessment.* Final Report, California Energy Commission, November 2001

[134] California Energy Commission: *Comparative Cost of California Central Station Electricity Generation Technologies*. Final Staff Report, June 2003

[135] IEA SHC: *Solar heat worldwide - Edition 2007*. 2007

[136] IEA: *Trends in Photovoltaic Applications - Survey report of selected IEA countries between 1992 and 2007*. IEA Photovoltaic Power Systems Programme, August 2008

[137] Sargent & Lundy: *Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts* (prepared for Department of Energy and National Renewable Energy Laboratory). May 2003

[138] Greenpeace with ESTIA and IEA SolarPACES Implementing Agreement: *Concentrated Solar Thermal Power - Now*. September 2005

[139] Leitner, A.: *Fuel from the Sky: Solar Power's Potential Western Energy Supply*. RDI Consulting, prepared for National Renewable Energy Laboratory, USA, July 2002

[140] DLR: *MED-CSP: Concentrating Solar Power for the Mediterranean Region*. April 2005

[141] Zhang, Y., Smith, S.J.: *Long-Term Modeling of Solar Energy: Analysis of Concentrating Solar Power (CSP) and PV Technologies*. Pacific Northwest National Laboratory, prepared for US DOE, August 2008

[142] IEA SolarPACES Implementing Agreement: *Parabolic Trough Systems*. Available at www.solarpaces.org/CSP_Technology/csp_technology.htm

[143] Pitz-Paal, R. at al: *ECOSTAR - European Concentrated Solar Thermal Road-Mapping - Roadmap Document*. Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), February 2005

[144] Eichhammer, W at al: *Assessment of the World Bank / GEF Strategy for the Market Development of Concentrating Solar Thermal Power*. Fraunhofer / CSIRO / CSIR, May, 2005

[145] Kearney, D.W, Tester, J.W: *Key Factors Affecting the Future of Concentrating Solar Thermal Power Plants*. International Executive Conference on Expanding the Market for Concentrating Solar Power: Launching the 5000 MW CSP Global Market Initiative, October, 2003. Available at http://www.energylan.sandia.gov/sunlab/

[146] Direct communication to the European Commission from European Solar Thermal Electricity Association (ESTELA), October 28, 2008

[147] Ministère de l 'Ecologie, de l'Energie, du Développement durable et de l'Aménagement du territoire: *Synthèse publique de l'étude des couts de référence de la production électrique*. 2008