THE COST OF ELECTRICITY GENERATION[1]

A consistent methodology is outlined for calculating the cost of 26 electricity generation technologies globally.

1 Author: Stephen Stretton <stephen@stephenstretton.org.uk> Last Updated: 10th March 2010

Overview

Summary

This document describes the estimation of the parameter values of the Energy Technology subModel (ETM), in particular the matrix "Technical Characteristics of Energy Technologies" (TCET). The cost and other technological characteristics of 28 electricity generation and other technologies were estimated.

Functions indexing and adjusting the cost of generating electricity by region and time, and calculating the levelised cost of generating electricity are defined and implemented in an Excel spreadsheet *TCET-New.xl*s.

This paper updates and expands on the work of Anderson & Winne (2003; 2004) and Barker (2007).

Report Topic

This report concerns the parameter values of the *Technical Characteristics of Energy Technologies* (TCET) matrix, used in the *Energy Technology subModel* (ETM) of the sectoral model E3MG. This report will focus on the *capital (investment)* costs, *operation and maintenance, fuel* costs and *learning rates*.

Report Audience

This report is intended, in the first instance, to be internal to members of 4CMR and Cambridge Econometrics (CE).

Report Purpose

This report will describe the data collection process in estimating the TCET matrix, the data sources used, and the final results of that process. This report has been put together specifically because the TCET matrix is being updated in the other models, namely E3ME and MDM. To avoid duplication of effort and inconsistency, this report present the data collection work already completed.

Report Type

This is a technical report providing background on the data used, estimation methodology and the justification for the values adopted. This material is a working paper and is not intended in the first instance for journal publication.

What Technologies are covered in the ETM?

There are 26 different energy technologies covered[2]. ETM is primarily a model of *electricity generation technologies*. Each technology is defined in technological terms (rather than by fuel). These technologies do in general have a single input fuel; however, this could vary by region.

In addition to pure electricity generation technologies, there are various technologies which have a component of electricity generation, but also another function or are associated with electricity generation in some way. These are as follows:

- It also considers low grade *heat* associated with thermal electricity generation (as could be used in CHP, industry or desalination) and *distributed fuel cells* but not domestic gas boilers and heat-pumps (these are considered in the domestic sub-model).
- It includes electricity *storage* (electric flow batteries, pumped storage) and hydrogen production but not *transport*. Electric cars, including plug-in hybrids, are dealt with in the transport sub-model.
- It includes Carbon Capture and Storage, including *negative carbon* technologies such as Biomass with CCS (BECS), which produces electricity and Air Capture, which does not.
- It deals with *transmission*.

Use of Technical Characteristics of Energy Technologies in The Model

There are two major matrices which define the cost of technology within ETM. Firstly, the two dimensional matrix Technical Characteristics of Energy Technologies (mTCET): this matrix includes the median estimates of each parameter value in our model. Secondly, the TCET matrix is transformed into a three dimensional array, BEWK, which includes variations across regions.[3]

2 These are outlined in detail in appendix 1.

3 The matrices have the following specification:

```
!TCET NTCxNET:technicalcharacteristics(region-independent),variousunits,
!BEWK NETxNWRxNTC:ETcharacteristics,variousunits,yearandyear-end
```

Where the dimensions of the matrices are:

```
!NTC:numberoftechnicalcharacteristics(TC)fornewenergytechnologies(ET)
!NET:numberofenergytechnologies(ET)
!NWR:numberofworldregions
```

Data Sources & Methodology

There are 23 primary technical characteristics in the new TCET matrix. An additional 17 characteristics (making 40 in total) have been also been estimated for clarification and further information; these are not used directly in E3MG.[4]

Methodology By Technical Characteristic

The methodology adopted for estimating each of the parameter values differs according to the data availability.

Parameter	Data Availability	Methodology
Capital Cost	Excellent	Simple Average Across Studies[5 6]; Adjusted for Time and Country
O&M	Moderate	Expert Estimate based on comparing a small number of studies
Learning Rate	Good	Expert Estimate of capital cost curve based on comparing a small number of studies and integration of time and capacity information
Efficiencies	Moderate	Expert Estimate based on comparing a small number of studies
CO2 Emissions	Excellent	Implicit from the carbon content of fuels (elsewhere specified) and the efficiencies of the energy technologies
Non-CO2 Emissions (SOx, NOx etc)	Poor	Old data used
Full Lifecycle Greenhouse Gas Emissions	Good	Parliamentary Office of Science and Technology (POST)

Data

There are four main classes of information sources.

1. Survey data from the International Energy Agency document "The Cost of Electricity Generation" (IEA 2005) (base year 1st July 2003).
2. Data from Energy Technology Perspectives (IEA 2006), from the US NEMS model (EIA 2007b; EIA 2007a)and from a recent EU (Strategic Energy Technology Plan) study (EU 2007).
3. Other recently published peer-reviewed articles.
4. Estimates used in the Markal model.
5. The studies that were used as input to the UK Markal team.

4 For details of these characteristics, please see Appendix 3.

5 We assume the logarithm of the costs are drawn from a normal distribution with unknown variance. Under common Bayesian assumptions, the posterior distribution of log(costs) is a t-distribution with n-1 degrees of freedom, where n is the sample size. The mid points quoted are the anti-log of the mean of this distribution (ie e^{μ} where μ is the mean of the posterior distribution of Ln(Capital Cost)).

6 For a discussion of how uncertainty from all sources is implemented in the model please see appendix 1.

All the data was compiled into a master database, with information on the costs of all the generating technologies. Each of the studies was treated as one datapoint, except the IEA (2005) data, where each of the input estimates is treated as a single data point.

Primary Data Sources (IEA 2005; IEA 2006; IEA 2008; EU 2007; EIA 2007a; EIA 2007b)

Source	Reviewed	Data used	Summa rized	Document title	Autho r	Date of publica tion
IEA (2005)	Yes	Yes	Yes	Projected Costs of Generating Electricity, a 2005 update	IEA	2005
IEA (2006)	Yes	Yes	Yes	Energy technology perspectives (2006)	IEA	2006
IEA (2008)	Yes	Yes	Yes	Energy technology perspectives (2008)	IEA	2008
EU (2007)	Yes	Yes	Yes	A European strategic energy technology plan	EU	2007
EIA	Yes	Yes	Yes	NEMS Model Documentation - Presentation from IEA/DBerr CCS Workshop	EIA	2007

Minor Studies (El-Kordy et al. 2002; Harding 2007; Winters 2007; Gibbins & Chalmers; Sims et al. 2003)

Source	Reviewed	Data used	Summa rized	Document title	Autho r	Date of publica tion
DBerr/IEA CCS Workshop	Yes	Yes	Yes	Feedback from CCS workshop held late 2007	Various	2007
Harding	Yes	Yes	Yes	Economics of nuclear power and proliferation risks in a carbon-constrained world	Harding	2007
El-Kordy et al	Yes	Yes	Yes	Economical evaluation of electricity generation considering externalities.	El-Kordy et al.	2002
Winters	Yes	Yes	Yes	Electric Supply Options in a World Driven by CO2 Emission Policies	Winters	2007
Gibbins and Chalmers	Yes	Yes	Yes	Carbon capture and storage, Foresight Document	Gibbins and Chalm	2004

Source	Reviewed	Data used	Summarized	Document title	Author	Date of publication
					ers	
Andersol	Yes	Yes	Yes	Concentrated Solar Power Data for the Andersol 1 Plant	Andersol	2006
Sims	Yes	Yes	Yes	Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation	Sims	2002

UK (Markal Team) Data Sources ***(full reference provided in Markal team documentation)***

Primary sources	**Reviewed**	**Data used**	**Summarized**	**Document title**	**Author**	**Date of publication**
RAE	Yes	Yes	Yes	The Costs of Generating Electricity: A study carried out for the Royal Academy of Engineering	PB Power (for RAE)	2004
WNA	Yes	Yes	Yes	The New Economics of Nuclear Power	World Nuclear Association	2005
OXERA	Yes	Yes	No	Results of Renewables Market Modelling	OXERA	2004
ECN	Yes	Yes	No	Characterisation of Power Generation Options for the 21st century	ECN Policy Studies (Lako and Seebregts)	1998
ICEPT	Yes	No	Yes	Alternative fuels for transport and low carbon electricity generation: A technical note	Robert Gross and Ausilio Bauen	2005
SDC	Yes	Yes	Yes	Economics of Nuclear Power: A report to the Sustainable Development Commission	University of Sussex and NERA	2005
WADE	Yes	Yes	Yes	Decentralising UK energy: Cleaner, cheaper, more secure energy for the 21st century: application of the WADE economic	World Alliance for Decentralized Energy (on behalf of Greenpeace)	2006

				model to the UK economy.		
Carbon Trust	Yes	Yes	Yes	Future Marine Energy: Results of the Marine Energy challenge: cost competitiveness and growth of wave and tidal stream energy	Carbon Trust	2006
RCEP	Yes	No	No	Biomass as a renewable energy source	Royal Commission on Environmental Pollution	2004
Enviros	Yes	No	Yes	The costs of supplying renewable energy	Enviros Consulting Ltd (for DTI)	2005
IEA	Yes	No	No	National Survey report of PV power applications in the United Kingdom	International Energy Agency	2004
UKERC	Yes	No	No	The Costs and Impacts of Intermittency	UK Energy Research Centre	2006
AEA	Yes	Yes	No	Options for a Low carbon future: appendix E (energy white paper modelling)	AEA Technology	
PSIRU	Yes	No	Yes	The Economics of Nuclear Power: analysis of recent studies	Steve Thomas (PSIRU)	2005
Secondary sources *	** Secondary sources are those referred to in primary sources.*					
Chicago		Yes	Yes	The Economic Future of Nuclear Power	University of Chicago	2004
MIT		Yes		The Future of Nuclear Power: an interdisciplinary MIT study	Massachusetts Institute of Technology	2003
DGEMP		Yes		Energy Baseline Scenario for France to 2030	General Directorate for Energy & Raw Materials (France)	2004
T&R		Yes			Tarjanne and Rissanen	
T&L		Yes		Research report: Competitiveness	Tarjanne and Luostarinen (in	2003

				comparisons of electricity production alternatives	Finnish)	
CERI		Yes			Canadian Energy Research Institute	2004
Scully		Yes		Business case for new nuclear power plants: bringing public and private resources together for nuclear power	Scully Capital (for the US Department of Energy)	2002
Areva		Yes		EPR Background and its role in Continental Europe	AREVA	2005

Basis

In order for the parameters to be fully defined, we need to choose a convenient monetary, time, geographical and energy basis.

Nominal/Currency Base

The initial calculation estimates costs and other financial quantities in US Dollars of 1st Jan 2000.

Reference Cost Year

The cost of capital equipment varies over time, depending on supply and demand for raw materials and labour, and technological learning. Our costs are estimated to be correct for a reference year of 1st Jan 2000.

Reference Capacities

Future costs of an energy technology are a function of the cumulative investment in that technology. The initial cost C at our base year t_{base} is a function of the cumulative investment in energy capacity at our base year: $C = C(I_{t_{base}})$.

Energy Basis

All energy is measured according to the Net Calorific Value, NCV (Also known as: Lower Heating Value (LHV)), consistently with the energy data (Enerdata) used in the model.

The net calorific value energy content of a given mass of fuel will be numerically less than its gross calorific value equivalent.

NCV electrical efficiencies will be correspondingly higher than GCV efficiencies. For example, a supercritical coal plant might have a Lower Heating Value (LHV) efficiency of 45%; an equivalent gross heating value efficiency would be 40%.

Time and Geographical Indexation

Time Indexation Methodology

The IEA study presents information approximately consistent with capital costs in 1st Jan 2000, in 1st Jan 2000US$. Cost estimates are indexed to the present using the Chemical Engineering Plant Cost Index (CEPCI) (CECPI 2007; Chemical-Engineering 2007a) (Consistent with the Marshall and Swift Index for used equipment (Chemical-Engineering 2007b)). More recent electricity cost data (Sims et al. 2003) was also used. (*Reference dates for compared studies vary).

By indexing with the CEPCI and US CPI, the spreadsheet also has the functionality to refer to any Nominal Currency year and any Cost Year.

Regional Effects

In order to adjust for relative costs, relative cost information and exchange rates were used. This information was recovered from the World Bank (World-Bank 2005).
The relative cost numbers used were an average of the cost for capital goods and those of construction goods. A weighting of 50% for equipment and 50% for construction was estimated for . Further work would integrate this with the exchange rates

Implementation in the TCET Spreadsheet

The front page allows one to choose the characteristics for any currency and any country and any year 2000-2008.

Net Present Value & Levelised Cost Calculation

This section goes beyond what is required for the ETM. It describes an analytical method for calculating the levelised cost of electricity production.

Cost Components

We assume that there are the following sources of costs:

- I: Unit Investment Costs
- I*: Infrastructure or Back-end or Other System Costs
- O_F: Non-fuel Operation and Maintenance (Fixed)
- O_V: Non-fuel Operation and Maintenance (Variable)
- F: Fuel Costs
- CT: Costs of Carbon internalised by an additional tax or cost of permits

There is a single source of revenue

- R: Revenue from Output Electricity

Discount Rates

Discount Rates are given exogenously in the model. We replicate the model assumption in the spreadsheet.
For example, the UKERC runs use a real discount rate of 10%, (Pathways to a low carbon economy, p18).

However, it is sometimes useful to assume an exogenous value of discount rates. For example the international Energy Agency uses a real discount rate of 5% or 10%. (IEA 2005).

Real or Nominal?

Cost calculations are carried out in constant money (ie. real terms). Our initial calculations consider the elements to be constant in real terms.

We use a real interest rate r in the calculation below.

Net Present Value

The net present value is calculated as the discounted sum of cash flows (CF) i.e. revenue minus costs, where revenue accrues from the sale of electricity and costs include: investment, operation and maintenance, fuel and other costs. Time t is measured in years:

$$\Rightarrow NPV = \sum CF_t \, e^{-r.t}$$

$$\Rightarrow NPV = \sum_t (R_t - I_t - I^*_t - O_{Ft} - O_{Vt} - F_t - CT_t) \, e^{-r.t}$$

Continuous Time Approximation

For any cashflow CF_t we approximate the sum:

$$NPV = \sum_t CF_t \, e^{-r.t}$$

by the integral

$$NPV = \int_{T_0}^{T} CF_t \, e^{-r.t} \, dt$$

If the cash flow CF_t is constant in real terms, $CF_t = CF$, then we can integrate trivially:

$$NPV = \int_{T_0}^{T} CF \, e^{-r.t} \, dt = CF \, \frac{e^{-rT_0} - e^{-rT}}{r}$$

In the case of a constant real escalation s

$$NPV = \int_{T_0}^{T} CF \, e^{s.t} \, e^{-r.t} \, dt = \frac{e^{-(r-s)T_0} - e^{-(r-s)T}}{r-s}$$

$$\text{So: } NPV = CF \, \frac{e^{-(r-s)T_0} - e^{-(r-s)T}}{r-s}$$

Levelised Cost

The Levelised Cost of Electricity (LCE) is calculated as the discounted sum of costs (C) divided by the discounted electricity produced (EP) . EP = LF*365*24 where LF is the load factor. It is the electricity price required to give a net present value of zero for a required rate of return equal to the discount rate.

$$LCE = \sum_t (I_t + I^*_t + O_{Ft} + O_{Vt} + F_t + CT_t) \, e^{-r.t}$$

In general we calculate the levelised cost of each component i as follows:

$$LCE^i = EP_t \, e^{-rt}$$

Employing the continuous time approximation we have

$$LCE^i = \frac{NPVi(C^i, r-s^i, T_0^{\,i}, T^i)}{NPVi(EP, r, T_0^{\,e}, T^e)}$$

(note the denominator is not a NPV calculation, but uses the same function giving

Where

$$NPV^i = \frac{C_i * [e^{-(r-s)T_0^{\,i}} - e^{-(r-s)Ti}]}{r - s}$$

NPV can be interpreted as the net present value of cash flow CF at interest rate r-s obtained between $T_0^{\,i}$ and T^i.

The following page gives a summary of the parameters needed for this relation:

Summary of Parameters

Item	Cost/year	Start	End	Real Cost Esc	Uncertainty
i	C^i	T_0^i	T^i	s^i	σ^i
Investment	I/T_{con}	0	T_{con}	0	σ_I
Infrastructure	I*	0	0	0	0
O & M Fix	O_F	T_{con}	$T_{con} + T_{life}$	0	0
O & M Var	O_V*EP	T_{con}	$T_{con} + T_{life}$	0	0
Fuel Cost	FC_f.[EP/(η)]	T_{con}	$T_{con} + T_{life}$	s^f	σ_f*[EP/(η)]
Carbon Cost	CT.CC_f.[EP/(η)]	T_{con}	$T_{con} + T_{life}$	s^{ct}	σ_{CT}*CC_f*[EP/(η)]

- I: Overnight Investment Costs per kW
- I*: Infrastructure or Back-end or Other System Costs cost per kW
- O_F: Non-fuel Operation and Maintenance (Fixed) cost per kW
- O_V: Non-fuel Operation and Maintenance (Variable) cost per kWh
- FC_f: Fuel Costs per kWh_{th}
- CT: Costs of Carbon internalised by an additional tax etc
- T_{con}: Construction Time
- T_{life}: Design Life
- EP: Electricity produced per year; EP = 365*24*LF
- LF: Expected Load Factor
- η: Electrical Efficiency %(LHV)
- s^f: Real escalation in Fuel cost
- s^{ct}: Real escalation in Carbon Price
- CC_f: Carbon Content of Fuel [$(tCO_2)/(kWh_{th})$]
- CT: Carbon Price $\$/tCO_2$
- σ_I: Prior uncertainty in Construction Cost
- σ_f: Uncertainty in Fuel Cost
- σ_{ct}: Uncertainty in Carbon Price

Results - Capital Cost

Technology	*Median of Published Studies*	*Variability*	*Data points*	*Old Estimates*	*US Data*	*EU Data*	*Markal*	*Capital Cost Mid-Range*	*High (1sd)*	*Low (1sd)*	*Modelled Uncertainty*	*Lear ning Rate*
Coal - IGCC	1496	0.29	32	1200	1491		1431	**1431**	1844	1111	0.4	0.1
Coal - PC	1198	0.21	15	1000	1290		1257	**1257**	1620	1037	0.45	0.1
Oil	895	0.39	3	1340	594		800	**800**	1031	574	0.46	0.1
Gas	591	0.31	36	450	420		540	**540**	696	413	0.4	0.1
Gas CHP	1095	0.31	23	2200			1094	**1094**	1410	838	0.37	0.1
Fuel Cell	4465	0.17	8	4500	4520		4520	**4520**	5824	3855	0.51	0.16
Nuclear LWR	2001	0.36	23	2200	2081	2175	2080	**2080**	2680	1532	0.83	0.1
Nuclear Adv	3216						3216	**3216**	4144	1757	0.83	0.12
Hydro	2587	0.66	14	1500	1500	3263	2586	**2586**	3332	1553	0.57	0.06
Biomass	2278	0.16	11	1800	1869		2300	**2300**	2964	1976	0.44	0.12
Biomass CHP	2962	0.6	4				2385	**2385**	3073	1489	0.44	0.12
Onshore Wind	1179	0.38	55	1200	1208	1595	1378	**1378**	1776	999	0.4	0.14
Offshore Wind	2042	0.28	11			2465	2200	**2200**	2835	1717	0.26	0.14
PV Flat	5695	0.49	27	4160	4751	5075	6000	**6000**	7731	4018	0.51	0.16
CPV							5000	**5000**	6443	3788	0.32	0.16
CSP	4259	0.37	6		3149	4785	3500	**3500**	4510	2550	0.4	0.14
Tidal							2951	**2951**	3803	2236	0.32	0.14
Wave	3413	0.77	11	2800		14460	4927	**4927**	6349	2783	0.32	0.14
Geothermal							2000	**2000**	2577	1515	0.32	0.14
CCS Retrofit	770	0.3	3				1000	**1000**	1289	771	1.53	0.12
Biomass CCS	1997	0.09	4	2000	1880	2175	2500	**2500**	3221	2300	0.77	0.12
Gas CCS	1101	0.43	7	800	1185	1885	1100	**1101**	1418	770	0.83	0.12
Coal CCS	2246	0.12	11	2000	2134	2465	2246	**2246**	2895	2006	0.83	0.12
H2	2962		1				6120	**6120**	7886	3511	0.74	0.12
Air Capture				800			3500	**3500**	4510	2652	0.32	0.1
Pumped Storage							2905	**2905**	3743	2201	0.32	0.12
Batteries							3000	**3000**	3866	1882	0.59	0.1
Transmission							500	**500**	644	379	0.32	0.1

Results – All Parameters

The following tables show the final assumptions adopted by technology group. The first 23 characteristics are 'core'; the others are included for purposes of completeness.

Fossil Fuels

New data for new TC, new ET	1 Coal - IGCC	2 Coal - PC	3 Oil - Peaking	4 Gas - CCGT	5 Gas -CHP DH	6 Gas - Fuel Cell Dist
1 Invest cost USD/kWe	1431	1257	800	540	1094	4520
2 OM Var costs USc/kWh	0.33	0.30	0.19	0.36	0.67	4.51
3 OM Fix costs USD/kWe	39	25	12	11	15	5
4 Elec Eff kwhe/kwh	0.45	0.40	0.25	0.55	0.40	0.48
5 Exp Load factor %	80	80	50	80	50	50
6 Heat produced %	0.0	0.0	0.0	0.0	0.4	0.0
7 CO2 Captured % of fuel	0.0	0.0	0.0	0.0	0.0	0.0
8 NOx emissions: g/kWh	0.9	9.0	0.1	0.1	0.1	0.1
9 SO2 emissions g/kWh	0.5	10.0	0.0	0.0	0.0	0.0
10 PM10 emissions g/kWh	0.2	16.0	0.0	0.0	0.0	0.0
11 Lifetime of plant, yr	30	30	30	25	25	25
12 Investment lag, yrs	4.00	3.50	3.00	2.00	2.50	2.00
13 Development lag, yrs	1.00	1.00	1.00	1.00	10.00	15.00
14 Energy Density (W/m2)	1000	1000	1000	1000	1000	1000
15 Subn parameter ‘a’	10	10	10	10	6	3
16 Learning Parameter b	0.15	0.15	0.15	0.15	0.15	0.25
17 Min. cost: US$/kWhe	3.00	2.70	5.00	3.00	2.50	4.00
18 Rel tech limit % elec	1.00	1.00	1.00	1.00	1.00	0.10
19 Initial mkt sh. S0, %	24	20	1	18	0	0
20 Infrastr. cost US$/kW	0	0	0	0	500	0
21 Resource endow (var.)	0.00	0.00	0.00	0.00	0.00	0.00
22 Waste used % input	0.00	0.00	0.00	0.00	0.30	0.00
23 Average Cost (c/kWh) incl fuel	4.64	4.17	18.69	5.09	10.52	8.12
24 Availability Factor	*0.8333*	*0.8333*	*0.412*	*0.8333*	*0.6871*	*0.5*
25 Flexibility (y/n)	*Yes*	*Yes*	*Yes*	*Yes*	*No*	*Yes*
26 Intermittency (y/n)	*No*	*No*	*No*	*No*	*No*	*No*
27 Contr to peak load	*0.90*	*0.90*	*0.90*	*0.90*	*0.50*	*0.90*
28 Decomm Cost ($/kWe)	*0*	*0*	*0*	*0*	*0*	*0*
29 Waste Cost (c/kWhe)	*0*	*0*	*0*	*0*	*0*	*0*
30 Real Esc rate: Invest	*0*	*0*	*0*	*0*	*0*	*0*
31 Real Ec rate: OM	*0*	*0*	*0*	*0*	*0*	*0*
32 Real Esc rate: Decom	*0*	*0*	*0*	*0*	*0*	*0*
33 Abs tech pot Gwe	*0*	*0*	*0*	*0*	*0*	*0*
34 Base Year	*2000*	*2000*	*2000*	*2000*	*2000*	*2000*
35 Global Capacity Base						
36 Unit Size (MW)	*500*	*500*	*500*	*500*	*100*	*0.01*
37 Learning Rate R	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.16*
38 LCA CO2 (g/kWh)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
39 Other GHG gCO2e/kWh						
40 NonGHG External Cost	*0*	*0*	*0*	*0*	*0*	*0*

Nuclear, Hydro & Biomass

New data for new TC, new ET	7 Nuclear LWR	8 Nuclear - advanced	9 Hydro Large	10 Biomass	11 Biomass/Coal CHP
1 Invest cost USD/kWe	2080	3216	2586	2300	2385
2 OM Var costs USc/kWh	0.04	0.25	0.33	0.20	0.58
3 OM Fix costs USD/kWe	63	63	13	59	13
4 Elec Eff kwhe/kwh	0.30	0.35	1.00	0.34	0.30
5 Exp Load factor %	90	90	34	80	70
6 Heat produced %	0.0	0.0	0.0	0.5	0.4
7 CO2 Captured % of fuel	0.0	0.0	0.0	0.0	0.0
8 NOx emissions: g/kWh	0.0	0.0	0.0	0.9	0.9
9 SO2 emissions g/kWh	0.0	0.0	0.0	0.5	0.5
10 PM10 emissions g/kWh	0.0	0.0	0.0	0.2	0.2
11 Lifetime of plant, yr	60	50	60	25	25
12 Investment lag, yrs	7.00	10.00	6.00	4.00	4.00
13 Development lag, yrs	1.00	20.00	1.00	1.00	1.00
14 Energy Density (W/m2)	1000	1000	0	0	0
15 Subn parameter ‘a’	10	10	4	6	6
16 Learning Parameter b	0.25	0.25	0.09	0.18	0.18
17 Min. cost: US$/kWhe	3.50	3.50	3.50	3.50	1.80
18 Rel tech limit % elec	0.80	0.80	0.10	0.10	0.10
19 Initial mkt sh. S0, %	17	0	17	1	0
20 Infrastr. cost US$/kW	0	0	0	0	0
21 Resource endow (var.)	0.00	0.00	0.00	0.00	0.00
22 Waste used % input	0.00	0.00	0.00	0.00	0.40
23 Average Cost (c/kWh) incl fuel	5.9	8.4	12.70	9.85	11.00
24 Availability Factor	*0.8333*	*0.8333*	*0.372*	*0.8333*	*0.5469*
25 Flexibility (y/n)	*No*	*No*	*Yes*	*Yes*	*Yes*
26 Intermittency (y/n)	*No*	*No*	*No*	*No*	*No*
27 Contr to peak load	*0.90*	*0.90*	*0.70*	*0.90*	*0.00*
28 Decomm Cost ($/kWe)	*1000*	*0*	*0*	*0*	*0*
29 Waste Cost (c/kWhe)	*0.15*	*0.15*	*0*	*0*	*0*
30 Real Esc rate: Invest	*0*	*0*	*0*	*0*	*0*
31 Real Ec rate: OM	*0.00*	*0*	*0*	*0*	*0*
32 Real Esc rate: Decom	*0.02*	*0.02*	*0*	*0*	*0*
33 Abs tech pot Gwe	*0*	*0*	*0*	*0*	*0*
34 Base Year	*2000*	*2000*	*2000*	*2000*	*2000*
35 Global Capacity Base					
36 Unit Size (MW)	*1000*	*100*	*1000*	*50*	*50*
37 Learning Rate R	*0.16*	*0.16*	*0.06*	*0.12*	*0.12*
38 LCA CO2 (g/kWh)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
39 Other GHG gCO2e/kWh					
40 NonGHG External Cost	*0*	*0*	*0*	*0*	*0*

Wind and Photovoltaic

New data for new TC, new ET	12 Wind onshore	13 Wind offshore	14 Solar PV Flat Panel	15 Solar Conc PV
1 Invest cost USD/kWe	1378	2200	6000	5000
2 OM Var costs USc/kWh	0.00	0.00	0.00	0.00
3 OM Fix costs USD/kWe	40	63	50	50
4 Elec Eff kwhe/kwh	1.00	1.00	1.00	1.00
5 Exp Load factor %	26	30	20	20
6 Heat produced %	0.0	0.0	0.0	0.0
7 CO2 Captured % of fuel	0.0	0.0	0.0	0.0
8 NOx emissions: g/kWh	0.0	0.0	0.0	0.0
9 SO2 emissions g/kWh	0.0	0.0	0.0	0.0
10 PM10 emissions g/kWh	0.0	0.0	0.0	0.0
11 Lifetime of plant, yr	25	20	30	30
12 Investment lag, yrs	2.00	3.00	2.00	2.00
13 Development lag, yrs	1.00	1.00	1.00	1.00
14 Energy Density (W/m2)	2	3	12	12
15 Subn parameter ‘a’	6	6	3	3
16 Learning Parameter b	0.22	0.22	0.25	0.25
17 Min. cost: US$/kWhe	2.50	2.50	4.00	4.00
18 Rel tech limit % elec	0.20	0.20	0.20	0.20
19 Initial mkt sh. S0, %	1	0	0	0
20 Infrastr. cost US$/kW	100	200	0	0
21 Resource endow (var.)	0.00	0.00	0.00	0.00
22 Waste used % input	0.00	0.00	0.00	0.00
23 Average Cost (c/kWh) incl fuel	9.58	14.7	42.75	36.10
24 Availability Factor	*0.2675*	*0.3*	*0*	*0*
25 Flexibility (y/n)	*No*	*No*	*No*	*No*
26 Intermittency (y/n)	*Yes*	*Yes*	*Yes*	*Yes*
27 Contr to peak load	*0.43*	*0.43*	*0.00*	*0.00*
28 Decomm Cost ($/kWe)	*0*	*0*	*0*	*0*
29 Waste Cost (c/kWhe)	*0*	*0*	*0*	*0*
30 Real Esc rate: Invest	*0*	*0*	*0*	*0*
31 Real Ec rate: OM	*0*	*0*	*0*	*0*
32 Real Esc rate: Decom	*0*	*0*	*0*	*0*
33 Abs tech pot Gwe	*0*	*0*	*0*	*0*
34 Base Year	*2000*	*2000*	*2000*	*2000*
35 Global Capacity Base				
36 Unit Size (MW)	*3*	*3*	*0.01*	*1*
37 Learning Rate R	*0.14*	*0.14*	*0.16*	*0.16*
38 LCA CO2 (g/kWh)	*0.0*	*0.0*	*0.0*	*0.0*
39 Other GHG gCO2e/kWh				
40 NonGHG External Cost	*0*	*0*	*0*	*0*

Solar, Marine and Geothermal

New data for new TC, new ET	16 Conc Sol Thermal CSP	17 Tidal	18 Wave	19 Geothermal
1 Invest cost USD/kWe	3500	2951	4927	2000
2 OM Var costs USc/kWh	0.00	0.00	0.00	0.00
3 OM Fix costs USD/kWe	53	77	300	155
4 Elec Eff kwhe/kwh	0.33	1.00	1.00	0.09
5 Exp Load factor %	20	39	35	80
6 Heat produced %	0.0	0.0	0.0	0.0
7 CO2 Captured % of fuel	0.0	0.0	0.0	0.0
8 NOx emissions: g/kWh	0.0	0.0	0.0	0.0
9 SO2 emissions g/kWh	0.0	0.0	0.0	0.0
10 PM10 emissions g/kWh	0.0	0.0	0.0	0.0
11 Lifetime of plant, yr	30	50	25	30
12 Investment lag, yrs	3.00	8.00	3.00	3.00
13 Development lag, yrs	3.00	2.00	10.00	1.00
14 Energy Density (W/m2)	12	3	6	1000
15 Subn parameter ‘a’	6	6	6	3
16 Learning Parameter b	0.22	0.22	0.22	0.22
17 Min. cost: US$/kWhe	3.50	4.00	4.00	2.50
18 Rel tech limit % elec	0.10	0.50	0.40	0.10
19 Initial mkt sh. S0, %	0	0	0	0
20 Infrastr. cost US$/kW	0	0	0	0
21 Resource endow (var.)	0.00	0.00	0.00	0.00
22 Waste used % input	0.00	0.00	0.00	0.00
23 Average Cost (c/kWh) incl fuel	27.57	15.59	30.20	5.71
24 Availability Factor	*0*	*0.23*	*0*	*0.635*
25 Flexibility (y/n)	*No*	*No*	*No*	*No*
26 Intermittency (y/n)	*Yes*	*Yes*	*Yes*	*Yes*
27 Contr to peak load	*0.00*	*0.09*	*0.18*	*0.63*
28 Decomm Cost ($/kWe)	*0*	*0*	*0*	*0*
29 Waste Cost (c/kWhe)	*0*	*0*	*0*	*0*
30 Real Esc rate: Invest	*0*	*0*	*0*	*0*
31 Real Ec rate: OM	*0*	*0*	*0*	*0*
32 Real Esc rate: Decom	*0*	*0*	*0*	*0*
33 Abs tech pot Gwe	*0*	*0*	*0*	*0*
34 Base Year	*2000*	*2000*	*2000*	*2000*
35 Global Capacity Base				
36 Unit Size (MW)	*100*	*1*	*0.1*	*1*
37 Learning Rate R	*0.14*	*0.14*	*0.14*	*0.14*
38 LCA CO2 (g/kWh)	*0.0*	*0.0*	*0.0*	*0.0*
39 Other GHG gCO2e/kWh				
40 NonGHG External Cost	*0*	*0*	*0*	*0*

Carbon Capture and Sequestration

New data for new TC, new ET	20 Coal CCS Retrofit	21 Biomass/Coal with CCS	22 Gas with CCS (Post)	23 Coal with CCS (Pre)
1 Invest cost USD/kWe	1000	2500	1101	2246
2 OM Var costs USc/kWh	0.45	0.45	0.30	0.45
3 OM Fix costs USD/kWe	47	47	20	47
4 Elec Eff kwhe/kwh	0.40	0.26	0.35	0.35
5 Exp Load factor %	50	50	80	80
6 Heat produced %	0.0	0.0	0.0	0.0
7 CO2 Captured % of fuel	0.9	0.9	0.9	0.9
8 NOx emissions: g/kWh	0.0	0.0	0.1	0.9
9 SO2 emissions g/kWh	0.0	0.0	0.0	0.5
10 PM10 emissions g/kWh	0.0	0.0	0.0	0.2
11 Lifetime of plant, yr	30	30	30	30
12 Investment lag, yrs	3.00	3.00	4.00	5.00
13 Development lag, yrs	10.00	15.00	10.00	10.00
14 Energy Density (W/m2)	1000	0	1000	1000
15 Subn parameter ‘a’	6	6	6	6
16 Learning Parameter b	0.18	0.18	0.18	0.18
17 Min. cost: US$/kWhe	4.50	4.50	3.50	4.50
18 Rel tech limit % elec	1.00	1.00	1.00	1.00
19 Initial mkt sh. S0, %	0	0	0	0
20 Infrastr. cost US$/kW	0	0	0	0
21 Resource endow (var.)	0.00	0.00	0.00	0.00
22 Waste used % input	0.00	0.00	0.00	0.00
23 Average Cost (c/kWh) incl fuel	5.57	14.29	8.33	6.92
24 Availability Factor	*0*	*0*	*0.8333*	*0.8333*
25 Flexibility (y/n)	*Yes*	*Yes*	*Yes*	*Yes*
26 Intermittency (y/n)	*No*	*No*	*No*	*No*
27 Contr to peak load	*0.00*	*0.00*	*0.90*	*0.90*
28 Decomm Cost ($/kWe)	*0*	*0*	*0*	*0*
29 Waste Cost (c/kWhe)	*0*	*0*	*0*	*0*
30 Real Esc rate: Invest	*0*	*0*	*0*	*0*
31 Real Ec rate: OM	*0*	*0*	*0*	*0*
32 Real Esc rate: Decom	*0*	*0*	*0*	*0*
33 Abs tech pot Gwe	*0*	*0*	*0*	*0*
34 Base Year	*2000*	*2000*	*2000*	*2000*
35 Global Capacity Base				
36 Unit Size (MW)	*500*	*500*	*500*	*500*
37 Learning Rate R	*0.12*	*0.12*	*0.12*	*0.12*
38 LCA CO2 (g/kWh)	*0.9*	*0.9*	*0.9*	*0.9*
39 Other GHG gCO2e/kWh				
40 NonGHG External Cost	*0*	*0*	*0*	*0*

Related Non-Electricity-Generating Technologies

New data for new TC, new ET	24-Hydrogen	25 Air Capt kw~kgCO2/h	26 Pumped Storage	27 Battery storage	28-Transmission
1 Invest cost USD/kWe	6120	3500	2905	3000	500
2 OM Var costs USc/kWh	6.48	4.00	0.43	0.50	0.00
3 OM Fix costs USD/kWe	265	50	2	100	0
4 Elec Eff kwhe/kwh	0.63	0.25	0.77	0.70	0.99
5 Exp Load factor %	80	100	20	50	50
6 Heat produced %	0.0	0.0	0.0	0.0	0.0
7 CO2 Captured % of fuel	0.0	1.0	0.0	0.0	0.0
8 NOx emissions: g/kWh	0.0	0.0	0.0	0.0	0.0
9 SO2 emissions g/kWh	0.0	0.0	0.0	0.0	0.0
10 PM10 emissions g/kWh	0.0	0.0	0.0	0.0	0.0
11 Lifetime of plant, yr	30	20	50	10	50
12 Investment lag, yrs	5.00	5.00	7.00	2.00	5.00
13 Development lag, yrs	10.00	30.00	3.00	10.00	1.00
14 Energy Density (W/m2)	0	0	100	0	0
15 Subn parameter 'a'	6	0	3	3	0
16 Learning Parameter b	0.18	0.15	0.18	0.15	0.15
17 Min. cost: US$/kWhe	4.50	0.00	4.00	4.00	0.00
18 Rel tech limit % elec	1.00	0.00	1.00	1.00	1.00
19 Initial mkt sh. S0, %	0	0	0	0	0
20 Infrastr. cost US$/kW	0	0	0	0	0
21 Resource endow (var.)	0.00	0.00	0.00	0.00	0.00
22 Waste used % input	0.00	0.00	0.00	0.00	0.00
23 Average Cost (c/kWh) incl fuel	25.35	18.57	35.13	26.21	9.57
24 Availability Factor	*0*	*0*	*0.65*	*0*	*0*
25 Flexibility (y/n)	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
26 Intermittency (y/n)	*No*	*No*	*No*	*No*	*No*
27 Contr to peak load	*0.00*	*0.00*	*0.95*	*0.00*	*0.00*
28 Decomm Cost ($/kWe)	*0*	*0*	*0*	*0*	*0*
29 Waste Cost (c/kWhe)	*0*	*0*	*0*	*0*	*0*
30 Real Esc rate: Invest	*0*	*0*	*0*	*0*	*0*
31 Real Ec rate: OM	*0*	*0*	*0*	*0*	*0*
32 Real Esc rate: Decom	*0*	*0*	*0*	*0*	*0*
33 Abs tech pot Gwe	*0*	*0*	*0*	*0*	*0*
34 Base Year	*2000*	*2000*	*2000*	*2000*	*2000*
35 Global Capacity Base					
36 Unit Size (MW)	*200*	*100*	*1000*	*1*	*1*
37 Learning Rate R	*0.12*	*0.1*	*0.12*	*0.1*	*0.1*
38 LCA CO2 (g/kWh)	*0.0*	*1.0*	*0.0*	*0.0*	*0.0*
39 Other GHG gCO2e/kWh					
40 NonGHG External Cost	*0*	*0*	*0*	*0*	*0*

Cost of Generating Electricity - Summary

The following table shows the cost of generating electricity in 2008.

Levelised Costs (c/kWh)	Coal (IGCC)	Coal (PC)	Gas	Nuclear	Onshore Wind	Offshore Wind	Coal CCS
Investment Costs	3.7	3.1	1.3	5.3	4.1	6.5	6.1
O&M Costs	1.1	0.8	0.7	1.2	2.2	3	1.4
Fuel Cost	1.5	1.7	7	0.9	-	-	2
Carbon Cost	-	-	-	-	-	-	-
Total Cost	6.3	5.7	9	7.3	6.3	9.5	9.5

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