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Climate change: The opportunity cost of Medupi and Kusile power stations

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Abstract
Eskom has embarked on the construction of two coal-fired power stations (Medupi and Kusile) that use a new dry-cooling process with flue gas desulphurisation (FGD). While the introduction of these new technologies does have meaningful environmental benefits beyond the conventional coal-fired power stations, they still emit greenhouse gasses. The question at stake here is what is the opportunity cost, viewed from a climate change perspective, of these two new power stations? This question is answered by considering the carbon footprint of the two power stations and a range of unit values for CO_2*. From this analysis, it is evident that the most likely range of the opportunity cost is between R6.3 billion and R10.7 billion per year. This converts to a damage cost of between R0.10 and R0.17/kWh when assuming a net combined generation capacity of 8 677 MW and a load factor of 85%.*

Keywords: climate change, Medupi, Kusile, opportunity cost

1. Introduction

Eskom has embarked on a process of developing two very large coal-fired power stations, namely Medupi and Kusile. Given the on-going global debate regarding climate change, the question that could, and should, rightfully be asked is what is the social (including environmental/climate change) damage cost of embarking on this route, and hence the opportunity cost of doing so? This question is addressed here.

In order to address this question, some background information as to the value of a ton of carbon will first be considered. Thereafter, Eskom's carbon footprint and its contribution to a global social damage cost will be considered. Lastly, the opportunity cost, from a climate change damage cost perspective, of the two new power plants will be considered. It should be noted that this analysis excludes the contribution to externalities of other parts of the coal chain, such as plant construction, water, health and the coal mining operation itself, these are captured elsewhere in this publication (Riekert & Koch 2012; Inglesi-Lotz & Blignaut 2012; Nkambule & Blignaut 2012). This paper will include a discussion on the amount of renewable electricity generation technologies that can be 'bought' by the social damage cost of the two new coal-fired power plants, and how many years it will take to establish the same power generation capacity when converting the damage cost into renewable electricity.

2. Background: the value of a ton of carbon

Climate change is one of the most researched yet ill-understood phenomena of the current era. Climate change studies cover a wide range of issues, such as agriculture (Blignaut *et al.,* 2009; Thornton et al., 2009; Kurukulasuriya *et al.,* 2006), health (Hutton 2011, Markandya & Chiabai 2009, Tol 2008), invasive alien plant species (Masters & Norgrove 2010), and corporate adjustments programmes linked to climate change (Tyler & Chivaka, 2011; Reyers *et al.,* 2011), to mention but a few.

While it is possible to do a sectoral analysis to determine the economy-wide impact of climate change, such as a bottom-up approach, is fraught with difficulty. Most attempts are therefore based on the national or global impacts of climate change and its related damage costs, also called the social damage cost of carbon.

Estimating the social damage cost of climate change has gripped many authors and has led to a wide range of studies (Rafey & Sovacool, 2011; Stage, 2010; Tol, 2009; Kuik *et al.,* 2009; Stern, 2007; Tol, 2005; IPCC, 2000; IPCC, 1999). However, the subject has also become the topic of a heated debate pertaining to the use of discount rates, or more accurately, the appropriate pure rate of time preference (PRTP). PRTP is defined as 'the marginal rate of substitution between present and future consumption under the condition that consumption levels in both periods are equal' (Anthoff et al., 2009:2) or, stated differently, the equalising rate whereby the value of current and future consumption would be the same. The choice of PRTP is important as it drives, to a very large extent, the estimate of the likely impact of climate change on national economies (Anthoff *et al.,* 2009; Tol & Yohe, 2009; Stern, 2008; Stern, 2007; Dasgupta, 2007; Nordhaus 2007).[1] It is not only the choice of discount rate that influences the estimates, but also the time period, country focus, income levels of countries and distribution of income both within and among countries. It is, therefore, not surprising that there are very wide discrepancies in the results among studies, as can be seen from the summary of the studies reviewed by Tol (2009) (see Annexure 1). What is evident from Annexure 1, however, is that these studies agree that the region likely to be most adversely impacted upon is Africa (to the effect of between -2% and -5% of GDP).

While Africa's contribution to climate change through anthropogenic induced emissions of CO_2 is small, South Africa is considered a main global player in this respect (Blignaut *et al.,* 2005) being the 13[th] highest CO_2 emitter among nations (according to annual emissions in 2008) (UNSD, 2011). This is largely as a result of its coal-fired power stations, the production of liquid petroleum from coal, and an electricity-intensive mining and base metals industry. There have been a number of studies attempting to quantify the external cost of the combustion of coal in South Africa, most notably with respect to electricity power generation (see Table 1). Spalding-Fecher and Matibe (2003) estimate the climate change impact of greenhouse gas emissions related to power generation to be about R7billion/y. PDG (2003), considering all the negative impacts related to coal-fired power generation, estimates the impact to be between R75billion/y and R120billion/y. Blignaut and King (2002) estimate the climate change related social damage cost of power generation to be R7.3billion/y, or approximately 24.6% of Eskom's 2002 sales revenue. Van Zyl *et al.* (1999) consider only the methane emissions from coal mines specifically and estimate the damage cost at approximately R1billion/y. Given the historic evidence both discussed here and summarised in Table 1, the contribution of coal-fired power stations in South Africa to climate change related damage cost is meaningful, and requires regular attention and subsequent policy intervention to mitigate the impacts, adapt to the reality of climate change and reduce the country's future carbon intensity.

Determining coal-fired power stations' contribution to climate change induced damage cost hinges on two factors. The emission factor of a power station (tCO_2/MWh) and the unit value of carbon dioxide. While Eskom's emission factors are published, the social damage cost of carbon (SCC) is not observed and is the subject of much debate. Blignaut and King (2002), for example, base their estimates on Sandor (2001) who indicated the damage cost of CO_2 as between \$5 and \$10/tCO_2 (\$18.3–\$36.6/tC). Subsequently, however, many studies have been published considering the unit value of carbon dioxide.

The study that gained the most attention was that of Sir Nicholas Stern. Stern (2007, 2008), however, was criticised heavily by some for the use of a very low PRTP (0.1%), a choice based largely on philosophical rather than empirical considerations. The outcome of using such a low PRTP is a very high social cost of carbon (\$314/tC, or \$85/tCO_2). This has become a bone of serious contention because the chosen unit value has a major impact on the total damage cost when multiplying it with total emissions. This, however, explains Stern's predictions that climate change could cost the global economy anything between 5% and 20% of GDP, a number much higher than most other studies (such as those listed in Annexure 1).

So, what are the alternative views with respect to the unit value of a ton of carbon? Tol (2005), after reviewing 28 studies regarding the damage cost of climate change under varying PRTPs, found that the 'mode is \$2/tC, the median \$14/tC, the mean \$93/tC, and the 95[th] percentile \$350/tC'. He concluded that 'the marginal damage costs of carbon dioxide emissions are unlikely to exceed \$50/tC, and probably much smaller' (Tol, 2005:2064). He also stated that '[i]f we use a pure rate of time preference of 3% — corresponding to a social rate of discount of 4 – 5%, close to what most western governments use for most long term investments — the combined mean estimate is \$16/tC, not exceeding \$62/tC with a probability of 95%' (Tol, 2005:2073).

Table 1: Summary of studies conducted on the cost of coal-fired power generation in South Africa

Authors	*Year*	*Areas considered*	*Estimate*
Spalding-Fecher & Matibe	2003	Climate change cost of coal-fired power stations	R7billion/y
PDG	2003	All the negative impacts related to coal-fired power generation	R75–R120billion/y
Blignaut & King	2002	Climate change cost of coal-fired power stations	R7.3billion/y
Van Zyl *et al.*	1999	Methane emissions from coal mines	R1billion/y

Therefore, Tol preferred a pure rate of time preference, which is solely consumption-based as defined earlier, rather than a wider human preference or social discount rate, and estimated a relatively low range for the carbon values. In 2009 he conducted another review, this time of more than 200 studies (see Annexure 2), in which he concluded that 'for a standard discount rate, the expected value is \$50/tC, which is much lower than the price of carbon in the European Union but much higher than the price of carbon elsewhere' (Tol, 2009:29) (it should be noted that these values are for 1995US\$; Refer to Table 4 for the conversion to 2010 values). In a conclusion on the debate, Anthoff *et al.* (2009) state that the most likely social cost of carbon is approximately \$41/tC (\$11.18/tCO_2), if one ignores uncertainty and equity. If uncertainty and global income differentials among countries are taken into consideration through a variation of country parameters, the value lies somewhere between \$61.6/tC (\$16.8/tCO_2) and \$206/tC (\$56.18/tCO_2). While this is higher than Sandor's estimate, it is still much lower than Stern's. The range of estimates from a number of studies is summarised in Table 2.

The values depicted in Table 2 are well within the range of acceptability. This is emphasised by Bell and Callan (2011:1, 3) who state that:

> In 2009 an interagency team of U.S. government specialists, tasked to estimate the SCC, reported a range of values from \$5 to \$65 per tonne of carbon dioxide. The choice of a final figure (or range of figures) is, in itself, a major policy decision, since it sets a likely ceiling for the cost per tonne that any federal regulation could impose on the economy to curb CO_2. At \$5 a tonne, government could do very little to regulate CO_2; at \$65, it could do significantly more. Higher SCC numbers, such as the United Kingdom's range of \$41–\$124 per tonne of CO_2 with a central value of \$83, would justify, from an economics perspective, even more rigorous regulation.
>
> Using modelling developed by economists and other analyses and tools described in detail in the following sections, the IWG panel report recommended a range of SCC values — \$5, \$21, \$35, and \$65 (in 2007 dollars) — per tonne of carbon dioxide with the intent that these values be used in individual rulemakings across government involving the regulation of CO_2. \$21 is the 'central number' and carries the most weight in analysis.

Ackerman and Stanton (2011), however, challenge this range of values. They estimate the social cost of carbon between \$28/tCO_2 and \$893/tCO_2. Their study, however, has not been reviewed and proven yet. It does seem odd, though, that the authors assumed a fixed consumption discount rate of 1.5% per year, while also assuming a higher per capita growth rate for the first century. This implies negative pure discounting.[2] It is obviously a matter of concern, but it would explain the high damage cost values. Given the concern, these numbers are not used in this study.

3. Eskom's carbon profile and contribution to climate change related global damage cost

Eskom is South Africa's main power producing utility and it mainly uses coal (see Table 3). It is therefore no surprise that Eskom's carbon footprint is, by own admission, quite severe. Eskom (2011: 51–52), through the Letter of the Chairman, states the following:

> Due to the coal-centric nature of our generation mix, we are not satisfied with our current performance in this regard. Eskom's CO_2 emissions for the period were 230.3Mt, an increase of 2.5% on the previous year's 224.7Mt. We remain committed to reducing our emissions as conveyed in our climate change strategy. Our commitment is to see a reduction by 2030. Subject to the support from the shareholder and the allocation of nuclear and renewables to

Table 2: The social cost of carbon: 1995\$/Ct[a, d]

	Mode	*Mean*	*Median*	*Min*	*Max*	*Used*	*No uncertainty with equity*	*Uncertainty, no equity*	*Uncertainty and equity*
Tol (2005: 1% PRTP[b])	4.7	51	33		165				
Tol (2005: 3% PRTP)	**1.5**	16	7		**62**				
Stern (2007 & 2008)						314[c]			
Tol (2009: 1% PRTP)	49	120	91		410				
Tol (2009: 3% PRTP)	25	50	**36**		205				
Anthoff et al. (2009)				0	121k		14	61	**206**

a) It should be noted that these values are in \$/tC; to convert the numbers to \$/tCO_2, divide the values by 3.6667.
b) PRTP = pure rate of time preference.
c) 2000 value.
d) The values in bold are used later on in this study.

Eskom, this reduction follows what we anticipate to be our peak at 283Mt in 2022 to 235Mt by 2030. This will see our relative CO_2 emissions at 0.68t/MWh compared to the current 0.99t/MWh. No company takes pride in the negative impacts of its business, and Eskom is no different. One of Eskom's objectives is to become a greener energy company.

Eskom's power generation and carbon dioxide emissions profile is provided in Table 3.

Using this Table 3 information, in conjunction with the global assessment of the social damage cost of carbon (Table 2), it is possible to estimate Eskom's contribution to such. This is depicted in Table 4 and Figure 1 using a range of damage cost estimates starting at $2/tC ($0.55/tCO_2$) up to Stern's estimate of $314/tC ($85.63/tCO_2$). Most of these values are for 1995US$; and are therefore first converted into $/tCO_2$, and then adjusted to 2010 values using the inflation rate of the USA. The range becomes $0.8/tCO_2$ to $112/tCO_2$. As an additional benchmark, an average market rate of $15/CO_2$ has been added. This average market rate was derived from considering carbon prices within the EU emission trading scheme (ETS) programme, certifiable emission reduction (CER) certificate prices and prices in the voluntary carbon market.

Applying these values to the published emissions profile of Eskom converts to an estimated contribution to global damage cost. Eskom's contribution to global damage cost related to climate change is estimated to be between $183million (R1.3billion) and $28.8billion (R188billion) in 2010/11. Arguably the most likely range, using the median, market and high rates (which are the rates flanking the market rate), is between $3.5billion (R25.3billion) and $5.5billion (R41billion) – or between 28% and 45% of Eskom's 2010/11 turnover. Using the high rate of $24.29/tCO_2$ (or

Table 3: Eskom's carbon emissions profile[a]
Source: Eskom (2011)

	Unit	2006/7	2007/8	2008/9	2009/10	2010/11
Power generated	GWh	243 928	250 619	241 133	246 566	252 876
Power generated by coal (net)	GWh	215 211	222 908	211 941	215 940	220 219
Coal combusted	t (mil)	119.1	125.3	121.2	122.7	124.7
Total CO_2-emissions (as published)[b]	t (mil)	208.9	223.6	221.7	224.7	230.3

a) Power plants only, i.e. excludes emissions related to coal mining and the transport of coal, etc.

b) Calculated figures are based on coal characteristics and the power station design parameters. CO_2-emissions are based on coal analysis and tonnages of coal burnt in 2010/11. From 2009 it includes Camden, Grootvlei and the gas turbine power stations as well as oil consumed during power station start-ups. From 2010, total CO_2 includes the additional contribution from the Underground Coal Gasification pilot project (flaring) and Komati power station.

Table 4: Eskom's contribution to global damage cost through its CO_2-emissions

	Emission load: mil tCO_2		*Very low*	*Median*	*Market*	*High*	*Very high*	*Stern*
		1995$/tC	2	36	-	61	206	314*
		1995$/$tCO_2$	0.55	9.82	-	16.64	56.18	85.64*
		2010$/$tCO_2$	0.80	14.33	15.00	24.29	82.02	112.01
2006/7	208.9	$/mil1	166	2 994	3 134	5 074	17 135	23 399
2007/8	223.6	$/mil1	178	3 205	3 354	5 430	18 338	25 042
2008/9	221.7	$/mil1	177	3 178	3 326	5 385	18 185	24 833
2009/10	224.7	$/mil1	179	3 221	3 371	5 458	18 431	25 169
2010/11	230.3	$/mil1	183	3 301	3 455	5 594	18 890	25 796
2010/11	Damage cost: Rmillion		1 342	25 287	24 165	40 946	138 277	188 826
2010/11	Eskom's turnover: Rmillion		90 485	90 485	90 485	90 485	90 485	90 485
2010/11	Global damage cost as % of turnover		1.5%	27.9%	26.7%	45.3%	152.8%	208.7%

* Year 2000 value

Note: The values to the right have been estimated as follows: the 2010$/$tCO_2$ unit value of carbon has been multiplied by the annual emission load (mil tCO_2)

about R170/tCO_2) translates into an accrued damage over the time period concerned (2006/07–2010/11) of R197 billion in 2010 values. This value could be as high as R907 billion if Stern's estimate is accepted.

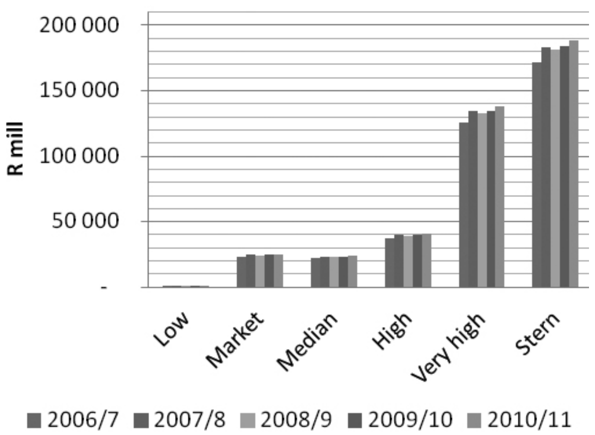

Figure 1: Eskom's contribution to global damage cost related to climate change based on various estimates of the unit value of a ton of carbon and its own estimates of its CO_2 emissions

4. The opportunity cost of two power plants: a climate change damage cost perspective

Eskom has reached the supply limit of its current power generation facilities and had to commit to an infrastructure expansion programme. This programme includes the addition of two large coal-fired power stations, Medupi and Kusile, each with a gross capacity of 4 800 MW. It is anticipated that these stations will each consume about 17million ton of coal annually and contribute to an additional CO_2 load of 30 million ton per station (AfDB 2009, Synergistics 2011).[3] The combined CO_2-emissions of these two new power stations are, therefore, approximately 60 million tons, or 26% of the 2010/11 emission load of Eskom (230.3million tons). Eskom's contribution to the global damage cost as a result of these two power stations, using the unit values as previously described, is shown in Table 5. While the estimated damage cost range is between R350 million and R49 billion, the most likely range (i.e. the median, market and high range) is between R6.3 billion and R10.7 billion per year. (The market rate as a gauge and the values around it are used, and hence the very low and the very high values, such as that of Stern, which are heavily contested are excluded.)

Assuming a net generation capacity of 8 677 MW and a load factor of 85%, this translates to a damage cost of between R0.10 and R0.17/kWh, or R0.56/kWh when using the very high estimate or R0.76/kWh when using the Stern values, and should be compared to an average electricity price for South Africa of about R0.41/kWh (RSA, 2011).

Given the anticipated damage cost of the two new coal-fired power stations, the question that can rightfully be asked is what the opportunity cost thereof is. In other words, how much power – using renewable power generation technologies – does either R6.3billion or R10.7billion a year, buy? To answer this question, the power generation unit costs, as published in the 2011 IRP of South Africa (given in Table 6) for a range of different technologies, are used. It should be noted that the capital costs of these technologies will probably decline

Table 5: Eskom's additional annual contribution to global damage cost as a result of Medupi and Kusile: Rmillion (in ZAR2010 terms)

	CO_2-emissions	*Low*	*Median*	*Market*	*High*	*Very high*	*Stern*
Medupi	30 million t	174.88	3 147.84	3 294.00	5 333.84	18 012.63	24 597.40
Kusile	30 million t	174.88	3 147.84	3 294.00	5 333.84	18 012.63	24 597.40
Both	60 million t	349.76	6 295.68	6 588.00	10 667.67	36 025.25	49 194.79

Table 6: Unit cost of a range of different power generation technologies in South Africa: 2010
Source: RSA (2011)

	Load factor	*Present value of capital cost*	*Fixed operating and maintenance cost*	*Variable operating and maintenance cost*
	%	*Rmil/MW*	*R/MW/yr*	*R/MWh/yr*
Wind	29	14.445	266 000	0.0
Concentrated PV	26.8	37.225	502 000	0.0
PV (crystalline silicon)	19.4	20.805	208 000	0.0
Forest residue biomass	85	33.270	972 000	31.1
Municipal solid waste	85	66.900	2 579 000	38.2
Concentrated solar power, parabolic trough with 9 hours storage	43.7	50.910	635 000	0.0

over time, some estimate this to be as much as between 25% and 60%, as developments within the renewable electricity generation sector advances (Teske, 2011). This will, in all likelihood, improve matters all-round.

Taking the respective load factors into account as well as the capital cost, and the fixed and variable cost for the different technologies as provided in Table 6, it is possible to determine the annual required cost of operating these technologies. The power generation capacity (MW) and power generation output (MWh) that either R6.3billion or R10.7billion a year can 'buy' is presented in Table 7.

The global damage cost due to climate change of Medupi and Kusile could 'buy' between 388 MW (municipal solid waste) and 3 381 MW (wind) every year, on a capacity basis assuming that the capital can be paid over 5 years, which is a very short and hence an overly conservative assumption. Alternatively, the opportunity cost is an additional generation output, after considering load factors, of between 1.9TWh (concentrated PV) and almost 10.1TWh (biomass). This implies that after between 7 (biomass) and 38 years (concentrated PV) the combined damage cost of Medupi and Kusile would have bought an equivalent generation capacity using renewable power generation technologies. This does not suggest that only one technology should be used; a technology bundle is probably more beneficial and/or realistic – also considering resource restrictions, such as biomass availability. This analysis does indicate that the environmental pay-back period of all the alternative technologies considered here, when internalising externalities, are well within the life-span of Medupi and Kusile, which is estimated to be 50 years (Action Sera club n.d.). The lower the cost of the technologies become, the shorter the environmental pay-back periods are likely to be.

5. Conclusion

Eskom, South Africa's primary power utility, has embarked on a capital expansion programme that, at its core, implies the development of two large-scale coal-fired power plants, Medupi and Kusile. This is despite concerns and international pressure not to do so in the wake of the on-going debate and active effort to mitigate and offset carbon dioxide emissions. The question therefore is, at what (climate change damage) cost are these two power plants being built?

It is anticipated that the two power plants will emit about 60 million tons of CO_2 annually (excluding CO_2 emissions from construction, transports and coal mining). When considering a range of global damage costs of between \$0.8/tCO_2 and \$112/tCO_2, the estimated damage cost is between R350 million and R49 billion per year. The most likely range is between R6.3 billion and R10.7 billion per year. This converts to a damage cost of between R0.10 and R0.17/kWh when assuming a net combined generation capacity of 8 677 MW and a load factor of 85%.

After considering the cost of renewable electricity generation technologies as per the IRP (RSA 2011:54), it was estimated that, for the most part, it would be possible to develop the same amount of

Table 7: Opportunity cost, due to climate change, of Medupi and Kusile[a,b,c,d]

	MW capacity and MWh generated that would equal a total annual cost of: R6 296mil		*Time it would take to equal Medupi and Kusile's output*	*MW capacity and MWh generated that would equal a total annual cost of: R10 667mil*		*Time it would take to equal Medupi and Kusile's output*
	MW	*MWh*	*# years*	*MW*	*MWh*	*# years*
Wind	1 995	5 069 266	14	3 381	8 589 589	8
Concentrated PV	792	1 859 850	38	1 342	3 151 413	23
PV (crystalline silicon)	1 441	2 448 872	29	2 442	4 149 478	17
Forest residue biomass	801	5 965 915	12	1 358	10 108 911	7
Municipal solid waste	388	2 885 941	25	657	4 890 066	15
Concentrated solar power, parabolic trough with 9 hours storage	582	2 228 030	32	986	3 775 273	19

Notes:

a) Assuming that the capital costs are repaid in 5 years and that there are no resource and/or technological constraints.

b) While it is unlikely that, in reality, the focus will be exclusively on one technology, i.e. investing either R6.3 billion or R10.7 billion in one technology only, we do this here (as opposed to a bundle of technologies) for demonstration purposes.

c) Given the on-going R&D in RE technologies, the unit costs are likely to come down, reducing the time it will take to reach the capacity of Medupi and Kusile.

d) While it might be argued that it is currently unlikely that there are sufficient resources to invest in 1 300 MW of biomass based technology, or 660 MW of municipal solid waste (MSW) technologies annually on an on-going basis, with R&D and mprovements in efficiencies, this might become plausible soon. Also, in reality, a bundled approach is arguably the best way going forward, i.e. using a suite of technologies.

installed capacity as the two power plants, using the damage cost only, in under 20 years. That implies that over the 50-year life-span of Medupi and Kusile the alternative installed capacity of renewable energy technologies could have been more than doubled. From this, it is self-evident that the climate change related opportunity cost of Medupi and Kusile is equal to 21 700 MW of renewable electricity alternatives (8 677MW * 50years/20years). This is just more than half South Africa's current installed capacity and it exceeds the 17.8 GW capacity for renewables discussed in the IRP (RSA 2011:6). While benchmarking this opportunity cost is difficult, it seems extraordinary high. The question therefore is: Can the country afford forgoing the opportunity to invest in 21 700MW of renewable alternatives?

Notes

1. A discount rate refers to the time preference value of money. In other words at what rate does society value the worth of tomorrow's money with respect to today's money. The higher the rate is, the lower society considers the value of tomorrow's money. The pure rate of time preference (PRTP) is a specific form of discounting namely that it is the discount rate at which the consumption rate of both the current and future generations are held constant, i.e. no reduction or increase in welfare over time. In other words the time value of money and economic growth per capita are constant.
2. This point was highlighted by Professor Reyer Gerlagh, Tilburg School of Economics and Management in The Netherlands, personal communication. Negative discounting implies a net appreciation in the value of money over time.
3. It should be noted that the power plants will introduce flue gas desulphurisation (FGD) technology. This increases the demand for both coal and water as what otherwise would have been the case, but to the benefit of reduced sulphur emissions. CO_2 emissions are therefore higher due to the increase in coal consumption, but with the added benefit of reduced sulphur emissions.

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Annexure 1:
Estimates of the welfare impact of climate change (expressed as an equivalent income gain or loss in per cent GDP)*

Source: Tol (2009)

Study	*Warming °C*	*Impact % of GDP*	*Worst-off region % of GDP*	*Worst-off region Name*	*Best-off region % of GDP*	*Best-off region Name*
Nordhaus (1994a)	3.0	-1.3				
Nordhaus (1994b)	3.0	-4.8				
		(-30.0 to 0.0)				
Fankhauser (1995)	2.5	-1.4	-4.7	China	-0.7	E. Europe and former USSR
Tol (1995)	2.5	-1.9	-8.7	Africa	-0.3	E. Europe and former USSR
Nordhaus and Yang (1996)[a]	2.5	-1.7	-2.1	Developing countries	0.9	Former USSR
Plambeck & Hope (1996)[a]	2.5	2.5	-8.6	Asia (w/o China)	0.0	E. Europe and former USSR
		(-0.5 to -11.4)	(-0.6 to -39.5)		(-0.2 to 1.5)	
Mendelsohn, Schlesinger, & Williams (2000)[a, b, c]	2.5	0.0b	-3.6b	Africa	4.0b	E. Europe and formerUSSR

Study	Warming °C	Impact % of GDP	Worst-off region % of GDP	Worst-off region Name	Best-off region % of GDP	Best-off region Name
		0.1b	-0.5b		1.7b	
Nordhaus & Boyer (2000)	2.5	-1.5	-3.9	Africa	0.7	Russia
Tol (2002)	1.0	2.3	-4.1	Africa	3.7	W. Europe
		(1.0)	(2.2)		(2.2)	
Maddison (2003)[a, d, e]	2.5	-0.1	-14.6	South America	2.5	W. Europe
Rehdanz & Maddison (2005)[a, c]	1.0	-0.4	-23.5	Sub-Saharan Africa	12.9	South Asia
Hope (2006)a, f	2.5	0.9	-2.6	Asia (w/o China)	0.3	E. Europe and former USSR
		(-0.2 to 2.7)	(-0.4 to 10.0)		(-2.5 to 0.5)	
Nordhaus (2006)	2.5	-0.9 to 0.1				

Notes:

* Where available, estimates of the uncertainty are given in parentheses, either as standard deviations or as 95 per cent confidence intervals.

a) The global results were aggregated by the current author.

b) The top estimate is for the 'experimental' model, the bottom estimate for the 'cross-sectional' model.

c) Mendelsohn et al. only include market impacts.

d) The national results were aggregated to regions by the current author for reasons of compatibility.

e) Maddison only considers market impacts on households.

f) The numbers used by Hope (2006) are averages of previous estimates by Fankhauser and Tol; Stern et al. (2006) adopt the work of Hope (2006).

Annexure 2: The social cost of carbon (measured in $/tC)

Source: Tol (2009)

	Sample (unweighted)				Fitted distribution (weighted)			
		Pure rate of time preference				*Pure rate of time preference*		
	All	*0%*	*1%*	*3%*	*All*	*0%*	*1%*	*3%*
Mean	105	232	85	18	151	147	120	50
Standard deviation	243	434	142	20	271	155	148	61
Mode	13	-	-	-	41	81	49	25
33rd percentile	16	58	24	8	38	67	45	20
Median	29	85	46	14	87	116	91	36
67th percentile	67	170	69	21	148	173	142	55
90th percentile	243	500	145	40	345	339	272	112
95th percentile	360	590	268	45	536	487	410	205
99th percentile	1500	-	-	-	1687	667	675	270
N	232	38	50	66	-	-	-	

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