What is the carbon emission factor for the South African electricity grid?

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Abstract
One of the most important parameters for developing Clean Development Mechanism (CDM) project proposals in the electricity sector (both supply and efficiency) is the standard electricity 'grid emission factor', which represents the carbon dioxide related to a megawatt hour of electricity supplied or saved on the grid. While there are detailed guidelines from the CDM Executive Board on how to calculate this emission factor, the values used in registered CDM projects in South Africa vary widely, both due to changes in the rules over time and also to misapplication of the rules. This paper shows how the application of the latest guidelines gives a 'combined margin emission factor' for South Africa of 0.957 tCO_2/MWh in 2009/2010. The variation in emission factors in the literature, as well as the importance of reducing the transaction costs for South African project developers, points to the need for an official published grid emission factor from the CDM host country authority in South Africa, the Designated National Authority (DNA), within the Department of Energy.

Keywords: Clean Development Mechanism, electricity, grid emission factor, carbon emissions, mitigation

1. Introduction

The last decade has seen the global carbon market grow from a few million dollars per year to over $144 billion in 2009. Transactions for project-based carbon offsetting projects in developing countries under the Clean Development Mechanism (CDM) have reached 2 to 3 billion dollars per year (Kossoy and Ambrosi, 2010). Electricity supply (e.g. renewable power, gas fired power) and electricity efficiency projects are some of the most important components of this market. South Africa was a late comer to the CDM market, and even today has only 17 registered projects, compared to 179 for Brazil, 547 for India and 1003 for China (Fenhann, 2010).

One of the most important strategies for promoting access to the CDM in under-represented countries and sectors is the development of 'standardised baselines', which provide default factors and assumptions that can be used to more easily and objectively calculate emissions reductions, as well as determine project eligibility (Broekhoff, 2007; Hayashi et al., 2010; Lazarus, Kartha, and Bernow, 2000; Ellis, Corfee-Morlot, and Winkler, 2007). This is particularly important in the power sector, where the key standardised parameter is a 'grid emission factor' for a national or regional electricity grid (Kartha, Lazarus, and Bosi, 2004; Sathaye et al., 2004). This emission factor, expressed as tonnes carbon dioxide per MWh, can be used for all electricity supply and efficiency projects to relate measured power production or savings to carbon emissions. Of the 2403 registered CDM projects across all sectors in October 2010, more than 1800 refer to some type of grid emission factor(IGES, 2010) . The CDM Executive Board (CDM EB) has published a detailed guideline entitled 'Tool to calculate the emission factor for an electricity system' (UNFCCC, 2011) , that specifies the procedures of selecting the relevant plants on the grid and calculating the emission factor of the grid. This tool applies only to supply projects, not demand side projects, and so does not consider transmission and distribution losses between generation and the end -user.

Despite these guidelines, however, the grid emission factor used in registered CDM projects in South Africa varies significantly (see Table 1), and currently project developers must research and analyse this emission factor on their own. The objective of this paper is to present a transparent and objective calculation of the relevant grid emission factors for South Africa, which can be referenced by the Designated National Authority (DNA) (the host country authority for the CDM in South Africa, situated in the Department of Energy) and/or individual project developers.

2. Operating build and combined margin

Most large scale projects (under the definitions of the CDM, i.e. >15MW capacity or >60 GWh/yr savings) in the electricity sector must apply the 'Tool to calculate the emission factor for an electricity system' to calculate an appropriate grid emission factor. The Tool explains how to calculate the 'combined margin emission factor' for an integrated electricity transmission grid. The combined margin refers to the weighted average of the 'operating margin' and the 'build margin' (Biewald, 2005; Sharma and Shrestha, 2006; Bosi and Laurence, 2002). These two concepts represent two possible impacts of a new electricity sector CDM project. The operating margin estimates how a new project may affect the operation of existing power plants: in other words, which plant's production is likely to be displaced. The build margin estimates how a new project will affect the construction of new plants. The methodologies for these two are presented in this paper. In addition, small scale projects are also allowed to use a simple weighted average emission factor covering all of the plants on the grid.

As with all baseline methodologies, these approaches only provide a hypothetical 'counterfactual' analysis of the sector, because once the CDM project is implemented it is not possible to know with complete certainty what would have happened if the project had *not* been implemented. In the following sections, the methodologies for the operating, build, and combined margins are explained, and the data presented for these calculations, along with an assessment of the calculations in previous PDDs.

3. Operating margin

The registered CDM projects in South Africa report operating margin emission factors between 0.908 and 1.195 tCO_2/MWh, which is more than a 30% variation. In some cases, this is because projects registered earlier used different version of the tool, or even previous versions of a methodology. In other cases, however, it may be a different choice of plants or fuel-related parameters. This section explains the approach and plants that should be used for this calculation, as well as the data sources.

3.1 Selection of approach

The 'Tool to calculate the emission factor for an electricity system' (hereafter called 'the Tool') provides four possible approaches for calculating the operating margin. One of the approaches, 'dispatch data analysis' is not relevant for South Africa, because the hourly dispatch data this requires is not available to CDM project developers. The 'simple operating margin' is the generation weighted average emission factor (tCO_2/MWh) of existing plants excluding 'low cost/must run' plants. The principle here is that plants that either have virtually no variable cost (e.g. hydropower) or that must run in order to use an available resource (e.g. wind power), will not be displaced by any new plant. In addition, baseline nuclear plants may be excluded from the calculation. The 'simple adjusted operating margin' approach is for cases where low cost/must run plants make up more than 50% of

Table 1: South African Registered CDM projects using an electricity grid emission factor
Source: IGES (2010)

No.	*Name of CDM project activity*	*Project participants*	*Project type*	*Scale*	*Method -ology*	*Operating margin (tCO_2 / MWh)*	*Build margin (tCO_2 /MWh)*	*Combined margin (tCO_2 / MWh)*	*Weighted av. (tCO_2 /MWh)*
3677	Ekurhuleni Landfill Gas Recovery Project	Ekurhuleni Metropolitan Municipality	Landfill gas recovery & utilization	large	ACM0001	0.99	1.05	1.02	0
2549	Alton Landfill Gas to Energy Project	ENER·G Systems uMhlathuze (Pty) Ltd	Landfill gas recovery & utilization	small	AMS-I.D. AMS-III.G.	0.908	0.951	0.93	0
2692	Bethlehem Hydroelectric project	Bethlehem Hydro (Pty) Ltd	Run of river hydro	small	AMS-I.D.	0.99	1.05	1.02	0
1665	Kanhym Farm manure to energy project	BioTherm SPV 1 (Pty) Ltd	Animal waste	small	AMS-I.D. AMS-III.D.	0.99	1.05	1.021	0
1027	Transalloys Manganese Alloy Smelter Energy Efficiency Project	Highveld Steel & Vanadium Corp. Ltd	Factory energy efficiency	large	ACM0002 AM0038	1.195	1.248	1.2215	0
1921	Durban Landfill-Gas Bisasar Road	eThekwini Municip.	Landfill gas recovery & utilization	large	AM0010	0	0	0	0.958
0966	Mondi Richards Bay Biomass Project	Mondi Business Paper SA Richards Bay Mill	Others	large	AM0036	0	0	0	0.978
0545	Durban Landfill-gas-to-elec. project – Mariannhill & La Mercy	Durban Solid Waste	Landfill gas flaring	large	AM0010	0	0	0	0.895
0446	PetroSA Biogas to Energy Project	MethCap SPV 1 (Pty) Ltd	Wastewater treatment	small	AMS-I.D.	0	0	0	0.963

Note: Ekurheleni Landfill Gas Recovery Project has received a request for review prior to registration, so it is not yet registered.

generation, which is not the case in South Africa, so this is not discussed further here. Finally, the fourth option is a generation weighted average emissions for all plants, which will generally lead to a lower baseline emissions factor and so it rarely used (see discussion in section). For South Africa, therefore, the appropriate approach is the 'simple operating margin'. This is what is has been used by all of the registered projects applying the Tool.

3.2 Selection of plants

Up until 2005, the National Energy Regulator of South Africa (NERSA) published generation statistics for the entire power sector, including the national utility, Eskom, municipalities and major private generators (e.g. sugar mulls, pulp mills, synthetic fuel plants) (NERSA, 2005). At that time, municipal generation was 0.6% of national total, while private generation was 3.3% of generation (of which 97% was coal). Given that no updated information is available for these plants, and that their inclusion is unlikely to have a material impact on the emission factor, I recommend only using Eskom plants for the calculations.[1]

The question, then, is this which Eskom plants are 'must run/low cost'. Eskom has coal, kerosene/diesel, hydropower, nuclear and pumped storage power stations (Eskom, 2010b). Pumped storage facilities have storage dams, and use primarily coal fired electricity to pump water into the reservoir during off peak hours. This means that these facilities are not actually 'power plants' in the sense of converting a primary energy source into electricity. They should not be included in any of the emission factor calculations because they are net consumers of electricity, not generators. Eskom's hydropower and nuclear plants would be excluded from the simple operation margin, leaving just Eskom's coal and kerosene/gas-fired plants.

3.3 Vintage of data

The Tool requires that, if the operating margin is calculated *ex-ante*, the data should be from the most recent three years available. Eskom reports generation and fuel consumption on their website up to the 2009/2010 financial year (Eskom 2010a), which is much more recent data than what was used by any of the registered CDM projects, particularly the ones registered in 2007 and 2008.

3.4 Data sources

For generation and fuel consumption, the data provided by Eskom should be used for the 2007/2008 to 2009/2010 (see Table 2). The two other critical inputs are net calorific value and carbon emission factor of the fuels. While the Tool does not explicitly say that utility or national values for these parameters must be used in preference to IPCC default factors, the 'best practice' in the CDM is to prefer reliable local data over IPCC default values. Eskom's official reported average Net Calorific Value (NCV) of coal for all power plants was 19.22, 19.10 and 18.51 GJ/tonne in 2010, 2009 and 2008, respectively (Eskom, 2010b). The default IPCC 2006 Guidelines value is 25.8 GJ/tonne (IPCC, 2006). The Tool, however, specifies that the lower bound of the 95% confidence level should be used, which in the IPCC guideline is 19.9 GJ/tonne for 'other bituminous coal', or close to the Eskom value. Note that some earlier PDDs referred to South Africa specific values in the IPCC 1996 Guidelines, but the Tool refers specifically to the IPCC 2006 Guidelines. For carbon emission factor, Eskom does not report a value for this, so the IPCC 2006 Guidelines default value should be used (at the lower limit of 95% confidence), which is 0.0895 tCO_2/GJ (IPCC 2006). While Gourikwa operates on gas and Acacia, Port Rex and Ankerlig operate on diesel/kerosene, Eskom does not report annual generation for each of these plants. To be conservative, all generation from 'gas turbine' plants use the natural gas IPCC emission factor i.e. 0.0543 tCO_2/GJ). Because fuel consumption data for these plants is also not available from Eskom, the default efficiency of 37.5% from the CDM 'Tool to calculate the emissions factor of an electricity system' (version 2.2.1) (UNFCCC,, 2011) was used to calculate the emissions factor for gas turbine stations.

Because Eskom's corporate carbon emission calculations use the IPCC median carbon emission factor, in line with the GHG Protocol Corporate Accounting and Reporting Standard (GHG Protocol 2004), they are roughly 6% higher than carbon emissions calculated for CDM projects. In other words, Eskom's 122.7 million tonnes of coal burnt in 2009/10 with an NCV of 19.22 GJ/tonne would be produce 211 $mtCO_2$ emissions using the lower 95% confidence level but 223 $mtCO_2$ using the median value, which is roughly Eskom's reported CO_2 emissions.

4. Build margin

The registered CDM projects in South Africa report build margin emission factors between 0.951 and 1.248 tCO_2/MWh, which is more than a 30% variation. As with the operating margin, in some cases projects registered earlier used different versions of the Tool, or even previous versions of a methodology. The choice of plants, however, is particularly important. This section explains the approach and plants that should be used to this calculation, as well as the data sources.

4.1 Selection of plants

The Tool says that the build margin should include, '(a) The set of five power units that have been built most recently; or (b) The set of power capacity additions in the electricity system that comprise

Table 3: Eskom grid plant data

Sources: Eskom (2010b, 2010a)

Name	*Net capacity (MW)*	*Commission date*	*Fuel consumption (k tonnes)*			*Electricity generation (GWh)*		
			2007/8	*2008/9*	*2009/10*	*2007/8*	*2008/9*	*2009/10*
Coal								
Arnot	1980	1971	6,211	6,396	6,794	11,905	11,987	13,228
Camden	1600	1966	3,219	3,876	4,732	5,171	6,509	7,472
Duvha	3450	1980	12,426	11,394	11,745	23,623	21,769	22,581
Grootvlei	1200	1969	131	675	1,637	237	1,250	2,656
Hendrina	1895	1970	7,794	7,123	6,906	13,756	12,297	12,143
Kendal	3840	1988	15,986	15,357	13,867	26,517	23,841	23,307
Komati	1000	1969	0	0	664	0	0	1,016
Kriel	2850	1976	9,060	9,421	8,505	17,762	18,157	15,907
Lethabo	3558	1985	18,315	16,715	18,170	25,702	23,580	25,523
Matimba	3843	1996	12,853	13,991	14,637	23,681	26,256	27,964
Majuba	3690	1987	14,862	12,554	12,262	29,022	22,677	22,340
Matla	3450	1979	13,795	12,689	12,438	24,550	21,863	21,955
Tutuka	3510	1985	10,628	11,232	10,603	20,980	21,504	19,848
Gas/liquid fuel								
Acacia	171	1976	N/A	N/A	N/A	Total gas/liquid fuel		
Port Rex	171	1976						
Ankerlig	1327	2007				1,153	143	49
Gourikwa	740	2007						
Nuclear								
Koeberg	1800	1984	N/A	N/A	N/A	11,317	13,004	12,806
Hydropower								
Colley Wobbles*		42	1900	0	0	0	Total hydroelectric	
First Falls*	6	1900	0	0	0			
Gariep	360	1971	0	0	0			
Ncora*	2	1900	0	0	0	751	1,082	1,274
Second Falls*	11	1900	0	0	0			
Van Der Kloof	240	1977	0	0	0			
Pumped storage								
Drakensberg	1000	1981	N/A	N/A	N/A	Total pumped storage		
Palmiet	400	1988	N/A	N/A	N/A	2,979	2,772	2,272
Wind								
Klipheuwel*	3	0	N/A	N/A	N/A	1	2	1

20% of the system generation (in MWh) and that have been built most recently.' In addition, the most recent version of the tool says that, where plants in this group are more than 10 years old, CDM projects should also be included.[2] This would mean that the any of the projects in Table 1 that supplied dispatchable power to the national grid would be included. This is not possible, however, because there is no publically available data on these plants. Eskom only reported production from Eskom-owned plants. The National Energy Regulator, which is tasked with reporting electricity sector data, has not published any electricity sector statistics since 2006 (NERSA 2006), and there are no signs of this changing. Even Bethlehem Hydroelectric, which – unlike many of the landfill gas projects that supply power to municipalities only or the captive power supply projects such as PetroSA – supplies exclusively to the national grid, does not publish their annual production data publically. Given that Bethlehem Hydroelectric's 7MW of installed capacity is less than 0.02% of the total build margin capacity proposed in this paper, excluding this CDM project has no impact on the results.

Some of the registered CDM projects included the Palmiet pumped storage scheme in the build margin. As explained, however, these facilities are for storage, and are not true power generation plants (and would have a high emission factor because they store primarily coal fired power at an efficiency of much less than 100%). The most recent power stations constructed are Ankerlig and Gourikwa, both completed in 2007, although these have a low load factor because they are using for peak and emergency power(Eskom, 2010b) . The next three oldest plants are dispatched for normal grid service are therefore Majuba, Kendal, and Matimba These five build margin plants accounted for 32% of generation in 2009/10.

4.2 Data

The most recent year available for these plants is for 2009/2010. Generation, fuel consumption and coal calorific value are available from Eskom (Eskom 2010a), while all carbon emissions factors are taken form IPCC 2006 Guidelines (IPCC, 2006). Note that Eskom does not report fuel use and production individually for liquid fuel plants, so data for this entire class has been used for Ankerlig and Gourikwa. This is a reasonable assumption, because the older Acacia and Port Rex plants are rarely used, so all liquid fuel-based generation can be attributed to these two plants.[3]

5. Combined margin

The default weighting of the operating and build margins is 50% each, unless the project participants can justify otherwise. In practice, more than 75% of registered projects using a combined margin emission factor use the 50/50 weighting . (IGES, 2010) The results of the calculations are shown in Table 3, along with a simple generation-weighted average emission factor for all of Eskom generation, using the NCV and carbon emission factor assumptions described in this paper.[4] This also shows why, given the choice, most small scale projects would choose to use the Tool rather than simple use a weighted average emission factor for the entire grid. The combined margin of 0.957 tCO_2/MWh is between 3% and 21% lower than the combined margin values used for the registered CDM projects in South Africa.

Table 3: Marginal emissions factors for South African grid (tCO_2/MWh)

	2007/8	*2008/9*	*2009/10*
Operating margin	0.929	0.980	0.979
Build margin			0.953
Combined margin			0.957
Generation-weighted average	0.874	0.905	0.909

6. Regional issues

In addition to the power produced within South Africa, Eskom also distributes imported power, primarily from Cahora Bassa in Mozambique, and also exports power as well.[5] Purchased electricity was 6% of the total electricity for the Eskom system in 2010 (Eskom, 2010b). The Tool specifies that imported electricity may be given an emission factor of 0 tCO_2/MWh, or the operating margin of the exporting grid may be used. Given that this power is primarily hydropower, the emissions factor of zero is appropriate. Although Cahora Bassa was built in the mid-1970s, it was re-commissioned in 1984 following the destruction of the HVDC lines during the Mozambique civil war. Nevertheless, this imported hydropower would not form part of either the operating or the build margin for South Africa. From Mozambique's point of view, however, the interaction of Eskom's grid with Mozambique electricity supply could be very significant for the CDM, because Mozambique's domestic power production is almost entirely hydropower (meaning that electricity supply and conservation projects do not save carbon emissions) (Econ Pöyry, 2008).

7. Conclusions

The variation in approaches and results in calculating the combined margin emission factor for CDM projects in South Africa not only undermines the environmental integrity of the CDM, but adds transaction costs and uncertainty for potential project developers. This paper has shown that the application of the latest guidelines to South Africa, and the resulting grid emission factor are significantly different than in some registered CDM projects, due to changes in the rules over time, misapplication of the guidelines, and the use of incorrect default factors. An alternative to each project developer calculating the grid emission factor would be for the South African DNA to publish an official grid emission factor that may be used by all project developers. This is already allowed in the CDM rules, and the CDM Executive Board is currently discussing on how to improve the quality and transparency of these published emission factors. At a minimum, the DNA should work with NERSA to develop a system to annually report all of the generation and fuel consumption statistics for the entire electricity industry, to supplement the useful information provided by Eskom, and show the calculation of the grid emission factor on an annual basis. By reducing the time and effort required to develop CDM project proposals, this action would facilitate the implementation of more electricity sector CDM projects within South Africa.

Notes

1. A sensitivity analysis conducted by the author using 2005 data for private and municipal generator shows that the inclusion of these plants would have less than a 0.2% impact on the operating margin.
2. The previous version of the Tool was ambiguous about whether plants older than 10 years should all be excluded if there were CDM projects registered in the country. The current version makes clear that as many older plants as necessary to reach 20% of total generation should be included.
3. The Eskom CDM webpage does report the fuel use split between these four plants in 2009/10 only. This shows that Ankerlig and Gourika were 90% of total liquid fuel use.
4. The Eskom weighted average was calculated from Eskom's total reported fuel consumption, because plant-specific fuel consumption was not available for smaller plants.
5. The Tool states that exports are not considered separately, because the generation for them is already taken into consideration in the calculations.

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