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Power generation scenarios for Nigeria: An environmental and cost assessment

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ABSTRACT

Exploratory scenarios for the power sector in Nigeria are analysed in this paper using possible pathways within the Nigerian context and then compared against the Government's power expansion plan in the short to medium term. They include two fossil-fuel (FF and CCGT) and two sustainable-development-driven scenarios (SD1 and SD2). The results from the FF scenarios indicate this is the preferred outcome if the aim is to expand electricity access at the lowest capital costs. However, the annual costs and environmental impacts increase significantly as a consequence. The SD1 scenario, characterised by increased penetration of renewables, leads to a reduction of a wide range of environmental impacts while increasing the annual costs slightly. The SD2 scenario, also with an increased share of renewables, is preferred if the aim is to reduce GHG emissions; however, this comes at an increased annual cost. Both the SD1 and SD2 scenarios also show significant increases in the capital investment compared to the Government's plans. These results can be used to help inform future policy in the Nigerian electricity sector by showing explicitly the range of possible trade-offs between environmental impacts and economic costs both in the short and long terms.

1. Introduction

The Government's current power expansion plan in Nigeria, through its 'Electric Power Sector Reform act', suggests that the electricity sector will undergo significant changes within the short to medium time period (Energy Commission of Nigeria (ECN) and United Nations Development Programme (UNDP), 2005; Ikeme and Ebohon, 2005; Obadote, 2009). The power sector reforms aim to address the many challenges facing the Nigerian electricity sector from electricity generation to transmission and distribution through improved electricity access by the population. From the Government's proposals, the generation capacity of the grid is set to increase by almost four times from the installed capacity of about 6500 MW in 2003 to over 25,000 MW by 2030, with Independent Power Producers (IPPs) expected to play the prominent role in the future of this sector (Ibitoye and Adenikinju, 2007). Through its Renewable Energy Master Plan (REMP), the Government aims to introduce more renewable energy systems into the electricity mix including solar, biomass, small hydro and wind (Energy Commission of Nigeria (ECN) and United Nations Development Programme (UNDP), 2005). There are also plans to reduce significantly transmission and distribution losses from the electricity grid, which stood at a staggering 40% in the early part of the decade (Ibitoye and Adenikinju, 2007). Another major aim of the reforms is to increase electricity access to the total population from the current 40% (Babatunde and Shuaibu, 2009; Sambo, 2009; Mbendi, 2005) to about 75% of the total population by 2025 (Energy Commission of Nigeria (ECN), 2003). The Government has already established the Rural Electrification Fund (REF) aimed at rapidly facilitating the expansion and improvement of grid electricity access in rural areas (Ikeme and Ebohon, 2005), which currently stands at 10% of rural inhabitants (Mbendi, 2005; Obadote, 2009).

The Government has proposed and listed a number of power plants to be added to the national grid in addition to specific targets for the introduction of biomass, small hydro, solar PV, solar thermal and wind power systems to the grid. Licences have also been granted to Joint Venture Independent Power Producers (JVIPPs) and IPPs to generate and distribute electricity. In our previous paper, the environmental and economic implications of the existing and the Government's proposed future power plants in the short to medium term have been studied (Gujba et al., 2010). The key assumption in that study was that the proposed power plants would be delivered according to the Government's plan. This assumption is strengthened by the power sector reforms in the country (Ikeme and Ebohon, 2005), number of projects already completed and the number of JVIPPs and IPPs that expressed interest in the electricity sector (Ibitoye and Adenikinju, 2007). For example, about five[1] new gas power plants have already been

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[1] The completed gas plants include Olorunsogo (335 MW), Okpai (480 MW), Geregu (414 MW), Omoku (150 MW) and Omotosho (335 MW).

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Table 1
Current and future electricity mix—BAU scenario (National Electric Power Authority (NEPA), 2000, 2004; Amioku, 2002; Okpanefe and Owolabi, 2002; ECN and UNDP, 2005; Ibitoye and Adenikinju, 2007; Obadote, 2009).

Technology type	Capacity (MW) 2003	Additional capacity (MW) 2010	Additional capacity (MW) 2020	Additional capacity (MW) 2030
Gas	4520	6901	2284	1320
Coal	n/a	388	n/a	1320
Oil	32	n/a	n/a	n/a
Hydro	1920	n/a	4740	5748
Biomass	n/a	n/a	5	5
Wind	n/a	n/a	20	20
Solar PV	n/a	n/a	75	425
Solar thermal	n/a	n/a	1	20
Total addition		**7289**	**7125**	**8858**
Cumulative total	**6472**[a]	**13,761**[b]	**19,276**	**25,394**

[a] Note that only about 60% of the installed capacity was in operation in the base-year. This has been taken into account in the modelling.
[b] At the time of writing, the 2010 scenario is far from the target of at least 10,000 MW generation capacity planned by the Government due to the on-going unrests in the Niger Delta region and on-going construction of gas pipelines. The Government has however reiterated its position to achieving this target by end of 2011 (African Development Bank (AfDB), 2009)).

completed while several are already in progress since the power sector reforms in 2005 (Obadote, 2009). The first phase of two of the proposed hydropower plants[2] is also in progress (McDonald et al., 2009).

However, despite the Government's spirited efforts to implement its electricity generation expansion plan, some policy changes could affect the direction of the energy mix. For example, the Government is currently mainly focused on meeting the increasing electricity demand in the country and thus may concentrate solely on conventional systems such as gas and coal as they are cheaper and the fuels are readily available in Nigeria. On the other hand, there are on-going discussions on climate change taking place as the world moves towards reaching an agreement that would replace the Kyoto protocol which expires in 2012. It means that Governments would need to think carefully about their future energy plans and therefore may not wish to avoid locking too much long-term investment in carbon-intensive generation technologies. Another factor which calls for a proper reflection is the precarious nature of the security situation in the oil-producing regions, which could potentially disrupt supply. Hence, there is plenty of justification to aim for diversifying the fuel mix for generation in order to minimise the vulnerability of the electricity system. If the Nigerian Government considers seriously the environmental and social dimensions of sustainability, as well as the security conditions in the oil-producing regions then more localised renewable energy sources could play a significant role in the future energy mix.

Therefore, in this paper, an exploratory study on the life cycle environmental and economic implications of other possible scenarios in the future electricity mix in Nigeria is carried out. This paper builds on our previous paper (Gujba et al., 2010), taking the Government's proposed future electricity mix as the 'business-as-usual, BAU' scenario. Four other scenarios have been created to indicate other possibilities, comprising two fossil-fuel-driven scenarios (FF and CCGT) and two sustainable development scenarios (SD1 and SD2). These scenarios are compared with the BAU scenario.

The paper has six main sections. Section 2 provides a brief overview of the BAU scenario, Section 3 describes the methodology and Sections 4 and 5 provide the results and their discussion, respectively. The conclusions are given in Section 6.

[2] These are the Mambilla (2600 MW) and Zungeru (950 MW) hydropower projects.

2. Background

The BAU scenario analysed in the previous work (Gujba et al., 2010) is shown in Table 1. This scenario suggests an annual growth rate of about 5% in electricity generation capacity over the period 2003–2030. The key question is whether the Government will be able to regulate the types of power system to be used in the future electricity sector. For example, all the additional 7289 MW generation capacity to be added to the grid in the short term will be from fossil-fuelled systems (gas and coal) and this trend is likely to continue, thus taking the country on a predominantly fossil-fuel based electricity generation pathway. Although planned renewable energy accounts for about 68% and 70% of the additional 7125 and 8858 MW to be added to the grid by 2020 and 2030, respectively, the majority of that is large-scale hydropower plants aimed at addressing irrigation and water supply problems in addition to power supply. This suggests that renewables such as wind, biomass and solar power will contribute only small amounts to the grid.

A major concern, therefore, is that the Government has focused on the economic and technical viability within its own means to develop its energy plans and policies and has not seriously considered and incorporated environmental (and social) issues in its plans. The life cycle assessment (LCA) results in the previous study indicate a significant increase in the environmental impacts from the electricity sector (BAU scenario) over the period studied (2003–2030). Most of the life cycle environmental impacts occur due to the use of natural gas, oil (diesel) and coal in the energy mix. The economic analysis of the BAU scenario also shows the need for significant investment to meet the objectives proposed by the Government with the total cost of the grid projected at over US$9.4 billion per year by 2030 (Gujba et al., 2010), representing over a five-fold increase over the period. In terms of costs, the renewable energy options (solar, wind and biomass) are the least favourable electricity generation options. Thus achieving a sustainable electricity mix in Nigeria will require a trade-off between economic costs and environmental benefits. For this reason, other scenarios are studied to explore the implications of policy changes that could affect the future electricity mix. The following sections describe the methodology used for these purposes.

3. Methodology

The methodology for evaluating the environmental and economic sustainability of the future electricity mix in Nigeria is

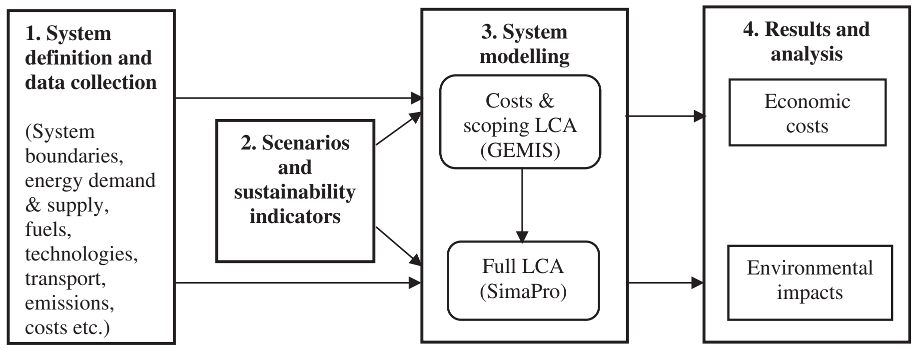

Fig. 1. Overview of the methodology used to evaluate the environmental and economic sustainability of the electricity system in Nigeria (Gujba et al., 2010).

outlined in Fig. 1. The same methodology was also utilised to assess the above-mentioned BAU scenario (Gujba et al., 2010). As shown in the figure, the methodology integrates LCA with economic costing and it consists of four main steps:

1. defining the system boundaries and characteristics of the electricity systems as well as the collection of appropriate data for the study;
2. development of the current and future electricity scenarios as well as appropriate environmental and economic indicators to be used in the modelling stage;
3. modelling of the scenarios in the GEMIS 4.3[3] and SimaPro 6[4] softwares and databases;
4. analysis, interpretation and discussion of the environmental and economic results obtained in the modelling stage.

3.1. *System definition and data collection*

This analysis considers only electricity generation from the national grid which comprises the national power plants and IPPs that supply or will supply power to the national grid. Private electricity generation by individuals and businesses is not included in this analysis due to the lack of data. The sources and type of data used for this study have been described in detail in the previous work (Gujba et al., 2010).

3.2. *Scenario development and sustainability indicators*

This step involves the use of economic, environmental and technological data obtained from the previous step to develop the scenarios. This is detailed below, followed in Section 3.2.2 by an overview of the sustainability indicators used in this work.

3.2.1. *Scenario development*

The scenarios have been developed using BAU as a reference scenario. In developing these scenarios, it has been assumed that the short-term goals in electricity expansion are achieved so that the electricity generation mix in year 2010 – in addition to the base-year (2003) – for all the scenarios is the same as that in the BAU scenario. It is also assumed that the total electricity generation in the developed scenarios over the time period is the same as in the BAU scenario. The scenarios are outlined and discussed below; a summary can be found in Tables 2 and 3.

3.2.1.1. Base-year (2003). The technical and economic data for the base-year have been described in detail in the previous work (Gujba et al., 2010) so that only the scenarios introduced in this paper are discussed below.

3.2.1.2. Future years—technical data. The electricity generation capacity mix of the BAU scenario has been described in Section 2. In this section, the four scenarios, i.e. fossil fuel (FF), combined-cycle gas turbine (CCGT), sustainable development 1 (SD1) and sustainable development 2 (SD2) are described. It should be noted that the scenarios are created by substituting the capacities of already planned power plants in the BAU scenario with other fuel types.

(A) *Fossil-fuels scenario (FF)*:
Nigeria has the eighth largest reserve of natural gas in the world estimated at over 5.3 trillion m^3 (Organisation of Petroleum Exporting Countries (OPEC), 2009). Proven coal reserves in Nigeria are also estimated at almost 640 million tonnes with the inferred reserves estimated at about 2.75 billion tonnes (Sambo, 2008). Since these fuels are readily available in Nigeria coupled with the lower investment costs compared to renewable energy systems, the Government's drive to meet electricity demand can spark a fossil-fuelled electricity future. This trend is already being exhibited by countries such as China, India and the USA in terms of coal power. For example, Ecoshock (2007) reports that over 560 coal-fired power units were constructed across 26 countries from 2002 to 2006, of which China accounted for over 66%.
This scenario is characterised mainly by conventional systems with the major players in the electricity sector in the future being the IPPs that will rely on cheap and conventional fuels (gas and coal) for electricity generation. Thus, the main assumption is that by 2020 and 2030, no renewable energy systems apart from hydropower will be present in the electricity grid. This scenario also follows the historical trends in the Nigerian energy mix consisting of natural gas, hydro, coal[5] and a minute contribution of oil-fired power plants. As a consequence of moving in the direction of lower investment costs and readily available fuels in the FF scenario, it is assumed that some of the hydropower plants planned in these periods

[3] GEMIS-Global Emission Model for Integrated Systems-Version 4.3 is an integrated LCA and economic analysis software and database for energy systems developed by the Öko Institute in Germany. More information Available at: http://www.oeko.de/service/gemis/en/index.htm.

[4] SimaPro 6 is an LCA software developed by Pré Consultants, The Netherlands. It contains the LCI of a wide range of materials and processes including energy and transport systems. More information Available at: http://www.pre.nl/simapro.html.

[5] The only coal-fired plant at Oji in the country was scrapped in 2001 due to its high maintenance costs caused by aging (National Electric Power Authority (NEPA), 2004). Nevertheless, there are plans by the Government to utilise coal power in the future.

Table 2
Overview of the scenario assumptions.

	BAU (Gujba et al., 2010)	FF	CCGT	SD1	SD2
Driving philosophy	Follows the Government's proposed power plants in the power sector reforms	Driven by cheaper capital costs and readily available fuels (natural gas and coal) in the country	Motivated by cleaner gas power technologies	Driven by the concerns on energy security and pollution from fossil-fuels in the Niger-Delta	Based on the clean technology principles for mitigating global climate change
Scenario characteristic	Mixture of conventional and renewable energy systems	Increased fossil-fuelled energy systems—gas and coal	Future conventional gas power plants replaced by CCGT technology	Increased renewable energy systems—wind, biomass and solar systems	More renewable energy systems—increased biomass, solar and wind systems
General assumptions for all scenarios	• Total electricity generation remains the same in all periods • Decommissioning of 1610 MW of gas power plants by 2020 • The installed capacity of oil-fired power plant remains constant in all scenarios • Short-term goals for electricity capacity expansion (2010) are achieved • Further decommissioning of 2640 MW of gas power plants by 2030				
Scenario-specific assumptions	Installed capacity by 2020=19,276 MW (see Table 1)	Installed capacity by 2020=19,221 MW • Gas=12,141 MW • Coal=2858 MW • Hydro=4190 MW • No other renewables	Installed capacity by 2020=19,221 MW • Gas=9561 MW • CCGT=2580 MW • Coal=2858 MW • Hydro=4190 MW • No other renewables	Installed capacity by 2020=20,080 MW • Gas=9130 MW • Coal=same as BAU • Hydro=same as BAU • Biomass=383 MW • Wind=2976 MW • Solar=510 MW	Installed capacity by 2020=21,177 MW • Gas=7337 MW • Coal=same as BAU • Hydro=same as BAU • Biomass=1913 MW • Wind=1275 MW • Solar =3571 MW
	Installed capacity by 2030=25,394 MW (see Table 1)	Installed capacity by 2030=25,047 MW • Gas=13,499 MW • Coal=6290 MW • Hydro=5226 MW • No other renewable	Installed capacity by 2030=25,047 MW • Gas=7139 MW • CCGT=6360 MW • Coal=6290 MW • Hydro=5226 MW • No other renewables	Installed. capacity by 2030=28,700 MW • Gas=8415 MW • Coal=same as BAU • Hydro=same as BAU • Biomass=1326 MW • Wind=4716 MW • Solar=1415 MW	Installed capacity by 2030=29,458 MW • Gas=5930 MW • Coal=same as BAU • Hydro=same as BAU • Biomass=3979 MW • Wind=1769 MW • Solar =4952 MW

Table 3
Contribution of different power systems to total electricity generation in different scenarios.

Fuels	BAU scenario		FF scenario		CCGT scenario		SD1 scenario		SD2 scenario	
	2020 (%)	2030 (%)	2020 (%)	2030 (%)	2020 (%)	2030 (%)	2020 (%)	2030 (%)	2020 (%)	2030 (%)
Coal	2.0	6.7	15.9	25.2	15.9	25.2	2.0	1.6	2.0	1.6
Gas	62.8	42.4	60.7	53.8	47.7	28.5	53.3	34.8	43.3	24.9
CCGT	–	–	–	–	12.9	25.3	–	–	–	–
Oil	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1
Hydro	34.5	48.5	23.2	20.9	23.3	20.9	34.5	48.5	34.5	48.5
Biomass	<0.001	<0.001	–	–	–	–	2.0	5.0	10.0	15.0
Wind	0.1	0.2	–	–	–	–	7.0	8.0	3.0	3.0
Solar	0.4	2.1	–	–	–	–	1.0	2.0	7.0	7.0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

are not constructed. The main rationale behind this alternative scenario is that lower investment costs of conventional fossil-fuelled systems are given priority over costlier, in terms of capital costs, large-scale hydropower options. An additional constraint is also the long lead time for the construction of hydroelectric power plants, which goes against the trend of demand growth, calling for the rapid deployment of generation infrastructures. Hence, the shortfalls are compensated with either gas or coal power plants.

The main characteristics and distinguishing properties of the scenarios are shown in Tables 2 and 3. The assumption in this scenario (FF) is that coal power plants account for about 15% and 25% to the grid capacity by 2020 and 2030, respectively. Gas power capacity contribution to the grid is expected to reach 12,141 and 13,499 MW by 2020 and 2030, respectively, despite the assumption that some of the existing gas power plants will have been decommissioned.[6] The implication is that

[6] In our previous study (Gujba et al., 2010), it has been assumed that some of the existing gas power plants will have been decommissioned by 2020 and 2030.

hydropower contribution to the grid reduces to less than 22% of the installed capacity in 2020 and 2030.

(B) *Combined-cycle gas turbine scenario (CCGT)*:
If Nigeria is to take advantage of its readily available gas resources in meeting electricity demand at lower fuel costs, then the efficiency of the technologies being deployed should play a key role. The current focus on meeting electricity demand in Nigeria suggests the electricity mix may follow the trend of the FF scenario, dominated by conventional gas power plants. Thus more efficient gas power technologies – Combined Cycle Gas Turbines (CCGT) – have been used to study the environmental and economic cost implications of using this technology in place of conventional gas turbines. The CCGT scenario has been developed from the FF scenario by replacing all the new gas power plants in 2020 and 2030 in the FF scenario with CCGT power plants. Thus less amount of fuel (gas) is required in this scenario to generate the same amount of electricity as the FF scenario due to higher efficiencies. The implication is that CCGT power plants will account for 13% and 25% of the electricity generation mix by 2020 and 2030, respectively, as shown in Tables 2 and 3.

(C) *Sustainable development scenario (SD1)*:
The use of fossil-fuels in Nigeria has caused huge environmental impacts especially with regards to resource extraction, which has caused major pollution and conflicts in the Niger-Delta areas of Nigeria (Environmental Rights Action (ERA), 2005; Human Rights Watch (HRW), 2005). The on-going security problem along the Niger Delta means that long-term reliability of fossil-fuel dependence is in question, which means that a new approach would be needed that takes on board these cross-cutting concerns and explores region-specific energy solutions, based on renewable energy sources. With 50% of the Nigerian population living in rural areas (The World Bank Group (WBG), 2007) and only 10% of rural areas connected to the national grid, connecting the entire population to the national grid is also almost impossible given the huge investments required. Off-grid and mini-grid renewable energy systems could offer a better solution to a secure and reliable source of electricity, especially in isolated communities. The Government therefore could take advantage of the huge renewable energy potential of the country.
In terms of the biomass potential, Amioku (2002) estimates the wood and animal & crop residue reserves to be 43.3 and 144 million tonnes/yr, respectively. The hydropower potential of Nigeria is estimated at 14,750 MW, of which 824 MW is from small-scale hydropower (ECN and UNDP, 2005). The ECN and UNDP (2005) also state that the potential of small-scale hydropower in the country could be as large as 3500 MW. With the inland wind speeds between 3.0 and 7.0 m/s (Amioku, 2002) and offshore wind speeds greater than 6 m/s (Iloeje, 2004), Nigeria stands to gain from wind energy in the future. There is also a huge solar energy potential mostly in the northern part of the country where annual temperature averages 30–35° C and solar radiation intensities can reach up to 7.0 kWh/m^2 day (Iloeje, 2004).
The SD1 scenario assumes a contribution of 10% and 15% from renewables (wind, biomass and solar) to the electricity generation mix by 2020 and 2030, respectively (see Tables 2 and 3). These renewables replace some of the proposed gas power plants by 2020 and the proposed coal power plants by 2030. There is a rapid rise of biomass in this scenario in 2020 and 2030 to 2% and 5% due to the technology requiring less new technical capacity within the Nigerian context. Moreover, the resource is widely spread across the country and could be part of a reforestation initiative. Wind power accounts for 7% and 8% of total electricity generation in this scenario by 2020 and 2030, respectively, due to its falling costs over the years and thus could be a viable option for Nigeria. For example, wind power technology costs have fallen by more than 80% between the 1980s and the early part of the decade (American Wind Energy Association (AWEA), 2008). Solar power technology costs are still high and thus they are assumed to contribute 1% and 2% to the total electricity generation by 2020 and 2030, respectively. On the other hand, hydropower is integral if Nigeria is to achieve its millennium development goals (MDGs) as it can also supply irrigation and portable water to the economy. Thus its contribution to the grid in this scenario remains almost the same as that of the BAU scenario.

Table 4
Characteristics of future energy systems.

Technology	Efficiency (%)	Lifetime (yr)	Operating hours (h/yr)
Gas	33.5	30	8500
Gas—CCGT	60	30	8500
Coal	38.25	30	8500
Hydro	35	80	8500
Solar—PV	100	20	3000
Biomass	35	30	8000
Wind	100	20	3600
Solar—thermal	100	25	3000

(D) *Sustainable development scenario (SD2)*:
There is a need to adopt strict and drastic measures to mitigate global climate change as stipulated by The Intergovernmental Panel on Climate Change (IPCC) (2007). However, Nigeria is not among the Annex I and II countries and does not have emission reduction targets. It is even more intriguing that Nigeria does not yet have a climate change policy (Department for International Development (DFID), 2009) despite the obvious signs that this impact could cause devastating effects in the country. For example, DFID (2009) states that climate change impacts could cause further desertification and droughts, flooding, water shortages and increased diseases in the country. The low-lying areas where most of the country's revenue is derived could also be at a huge risk of flooding. It is therefore imperative that the Government develops and implements critical climate change policies to reduce environmental impacts from electricity generation. The Government has already passed a bill to set-up a national climate change commission in Nigeria to address and plan for the impacts of climate change in the country (Nigeria Climate Action Network (NigeriaCAN), 2010). Pressure groups in Nigeria such as the Climate Change Network Nigeria (CCNN) are working to promote effective mitigation, adaptation and national response to the deadly impacts and vulnerability of climate change in the country (United Nations Environment Programme (UNEP), 2010). Thus policies that will promote the use of renewables in the energy sector could be introduced in the near future.
This scenario therefore assumes increased renewables (solar, biomass and wind) to account for 20% and 25%[7] of total electricity generation by 2020 and 2030, respectively (see Tables 2 and 3). The scenario assumes a rapid rise in biomass power for the same reason as the SD1 scenario. Biomass power in this scenario accounts for 10% and 15% of the total electricity generation in 2020 and 2030. Despite solar power being the most expensive of the renewables considered, it is a reliable resource in Nigeria and thus its contribution to the electricity generation mix is increased to 7% in both 2020 and 2030. Although wind energy is the cheapest of the renewables, its contribution to the total electricity generation reduces to 3% in both 2020 and 2030 due to concerns about reliability as a resource in Nigeria compared to solar and biomass.

[7] This is within the range of the EU target of about 30% of electricity generation from renewables by 2020 (European Renewable Energy Council (EREC), 2004). However, this target for EU also includes hydropower.

Table 5
Future projections for fuel prices.

Fuels	Prices 2010 (US$2005 per tonne)	Prices 2020 (US$2005 per tonne)	Prices 2030 (US$2005 per tonne).	Annual price growth rate (%), EIA (2006)
Natural gas	191	211	233	1.1
Diesel (international)	475	567	678	1.8
Diesel (domestic)	355	424	507	1.8
Biomass (fuel wood)[a]	25	25	25	0.1
Coal	42	43	43	0.1

[a] The price growth rates for biomass have been assumed to be the same as for coal (0.1%) due to the biomass prices being mostly independent of market forces in Nigeria.

(E) *General assumptions*:
The efficiencies, annual operating hours and lifetimes of the future power plants as obtained from literature sources are shown in Table 4. The efficiencies for solar PV, solar thermal and wind power plants represent the electrical efficiencies as obtained from GEMIS (Öko Institute, 2006). The average operating hours and lifetimes for the power plants have also been obtained from GEMIS.

3.2.1.3. Future years—economic costs. The future costs of fuels have been projected from growth rates published by Energy Information Administration (EIA) (2006), as shown in Table 5. The domestic prices of these fuels have been used to model the economic costs, except for the imported portion of petroleum products in 2003 and 2010, which have been modelled with international prices. The future costs of the new power plants and technologies have been obtained from the Energy Information Administration (EIA) (2007a, b); these are summarised in Table 6.

3.2.2. Sustainability indicators

Life cycle environmental impacts and economic costs have been used as the sustainability indicators for the purposes of the analysis. The life cycle environmental impacts[8] include global warming (GWP), abiotic depletion (ADP), Ozone depletion (ODP), human toxicity (HTP), freshwater toxicity (FTP), marine toxicity (MTP), terrestrial toxicity (TTP), photochemical oxidation (POCP), acidification (AP) and eutrophication (EP). The economic costs[9] represent the 'total capital investment' per period and the 'total cost' comprising the annualised capital cost,[10] annual fixed cost, annual variable cost and annual fuel costs. The 'unit' costs, which are calculated as the total cost divided by the total energy demand, have also been estimated.

3.3. System modelling

As shown in Fig. 1, the third stage of the methodology involves modelling of the scenarios. The GEMIS model has first been used to carry out a preliminary (scoping) LCA and also to calculate the economic costs of the electricity scenarios. The preliminary results and secondary data generated from GEMIS have then been used to carry out a full environmental impacts analysis in the SimaPro software.

[8] The LCA impacts have been calculated using the CML 2001 method (Guinée et al., 2001).
[9] See the previous work for more details on the economic costs (Gujba et al., 2010).
[10] A discounting rate of 13% (Central Bank of Nigeria (CBN), 2006) has been used to calculate the annualised capital cost.

Table 6
Projected future prices of technologies (EIA, 2007a, b, 2009; Energy Commission of Nigeria (ECN), 2004).

Technology type	Investment cost (US$2005 per kW)	Fixed costs (US$2005 per kW)	Variable costs (US$2005 per kWh)
Gas turbine 2010	594	11	0.003
Gas turbine 2020	576	11	0.003
Gas turbine 2030	561	11	0.003
Gas CCGT—2020	845	11.8	0.003
Gas CCGT—2030	734	11.8	0.005
Steam turbine 2020	405	11	0.005
Steam turbine 2030	399	11	0.005
Coal 2010	830	8	0.004
Coal 2030	800	8	0.004
Biomass 2020	1721	50	0.008
Biomass 2030	1534	50	0.008
Solar thermal 2020	2309	53	–
Solar thermal 2030	2067	53	–
Solar PV 2020	3923	11	–
Solar PV 2030	3569	11	–
Large hydro 2020	1500	13	0.0005
Large hydro 2030	1426	13	0.0005
Small hydro 2020	1980	12	–
Wind 2020	1194	29	–
Wind 2030	1194	29	–

4. Results and analysis

4.1. LCA of the electricity sector

This section presents the LCA results for the electricity scenarios. The results for the BAU scenario are first summarised (Table 7) and then compared against the three scenarios developed in this study.

4.1.1. System boundary

The system boundary is from 'cradle to grave'; comprising the extraction and processing of fuels, transport of the fuels to the power plants and electricity generation from the power plants; building of the infrastructure is also included (see Fig. 2).

4.1.2. Unit of analysis (functional unit)

The analysis is based on the total electricity produced in a given year, that is

- 56,160 TJ/yr (15.6 million MWh/yr) for 2003;
- 346,000 TJ/yr (96.1 million MWh/yr) for 2010;
- 551,000 TJ/yr (153.1 million MWh/yr) for 2020 and
- 764,000 TJ/yr (212.2 million MWh/yr) for 2030.[11]

[11] The above figures take into account the current or projected plant efficiencies, availability and operating hours as appropriate for each time period.

Table 7
Summary of the LCA results in the BAU scenario (Gujba et al., 2010).

Life cycle impact category	Unit	2003 (tonnes)	Increases compared to base-year over the period		
			2010 (increase)	2020 (increase)	2030 (increase)
Global warming (GWP100)	CO_2 eq	5.67E+06	10-fold	11-fold	13-fold
Abiotic depletion (ADP)	Sb eq	5.16E+04	10-fold	11-fold	13-fold
Ozone layer depletion (ODP)	CFC-11 eq	8.20E-02	7-fold	8-fold	12-fold
Human toxicity (HTP)	1,4-DB eq	6.35E+05	12-fold	14-fold	25-fold
Freshwater aquatic ecotoxicity (FTP)	1,4-DB eq	3.50E+04	18-fold	21-fold	59-fold
Marine aquatic ecotoxicity (MTP)	1,4-DB eq	7.65E+07	119-fold	122-fold	509-fold
Terrestrial ecotoxicity (TTP)	1,4-DB eq	1.07E+03	24-fold	25-fold	78-fold
Photochemical oxidation (POCP)	C_2H_4 eq	2.91E+02	13-fold	14-fold	27-fold
Acidification (AP)	SO_2 eq	3.47E+03	18-fold	19-fold	49-fold
Eutrophication (EP)	PO_4 eq	8.57E+02	11-fold	12-fold	17-fold

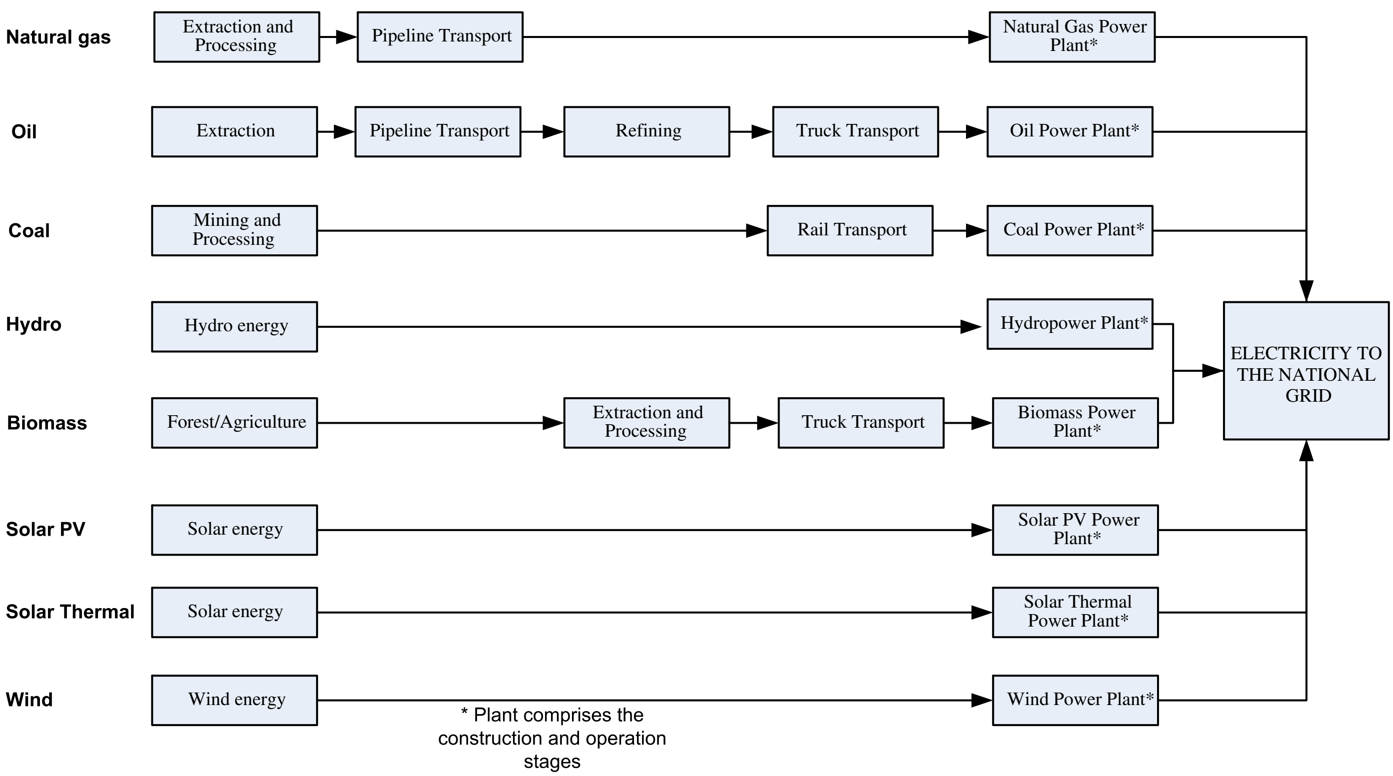

Fig. 2. Life cycle stages of the electricity system.

4.2. LCA results

The summary of the BAU scenario is shown in Table 7. As shown, all the impacts increase significantly within the period due to increasing electricity generation and consumption but at different rates depending on the types of technologies and energy mix deployed over the time period.

The LCA results of the scenarios are shown in Figs. 3–12. Comparing all the scenarios, the SD1 scenario yields on average the most favourable results for all impacts while the SD2 scenario gives the best results with respect to reducing CO_2 equivalent emissions (Fig. 3). These broad observations are fleshed out further in the following sections.

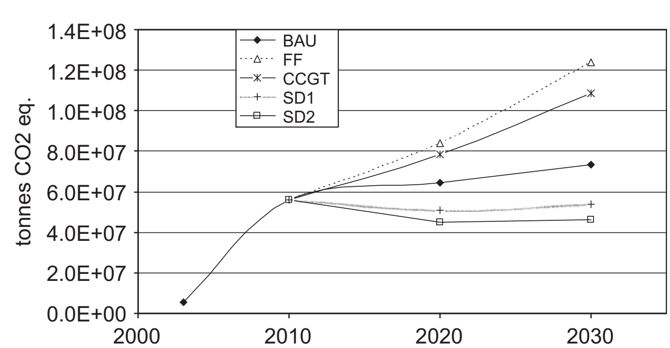

Fig. 3. Global warming potential for the electricity scenarios.

4.2.1. Fossil-fuels scenario (FF)

As shown in Table 8 and Figs. 3–12, the results show significant increases in all the impact categories in the FF scenario compared to the BAU scenario. For example, the total GWP100 increases by about 30% and almost 70% in 2020 and 2030 in the FF scenario, respectively, compared to the corresponding years in the BAU scenario. This outcome is not surprising given the increased consumption of fossil fuels in the FF scenario. In real terms, these

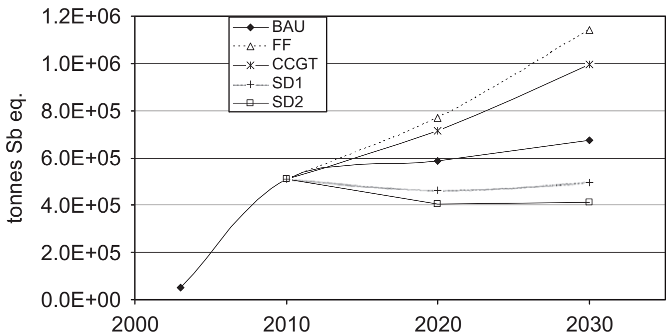

Fig. 4. Abiotic depletion potential for the electricity scenarios.

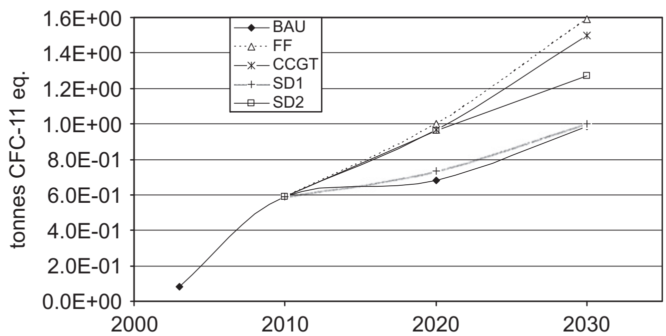

Fig. 5. Ozone depletion potential for the electricity scenarios.

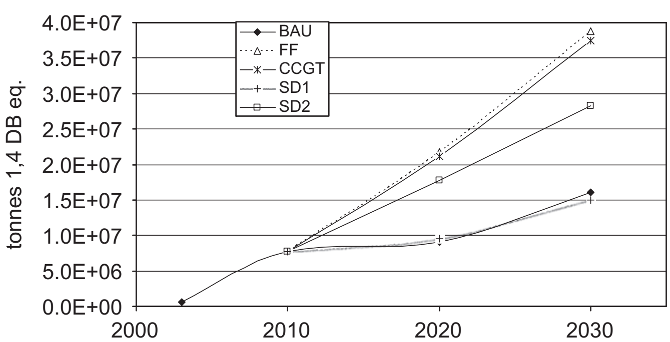

Fig. 6. Human toxicity potential for the electricity scenarios.

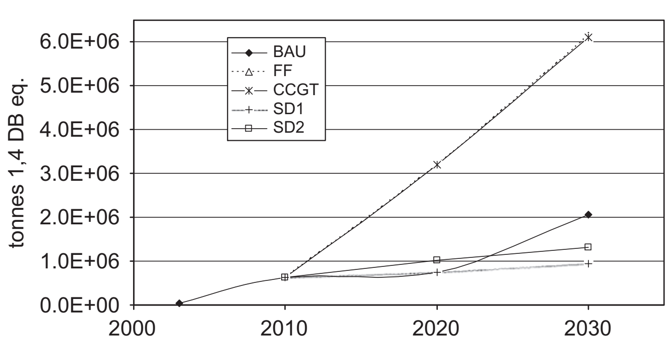

Fig. 7. Freshwater toxicity potential for the electricity scenarios.

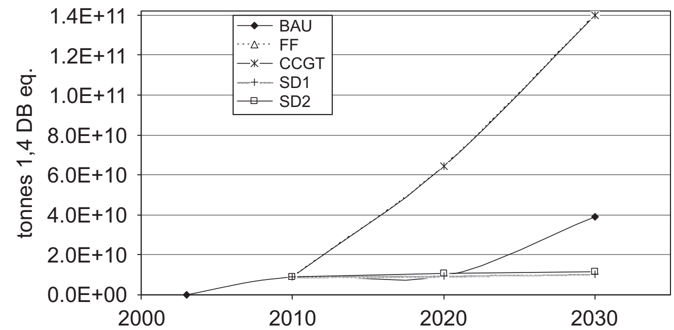

Fig. 8. Marine toxicity potential for the electricity scenarios.

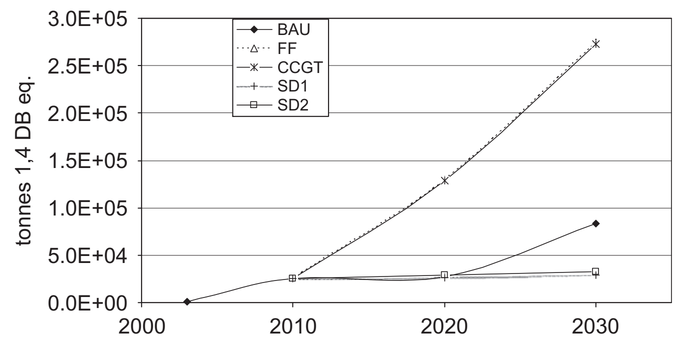

Fig. 9. Terrestrial toxicity potential for the electricity scenarios.

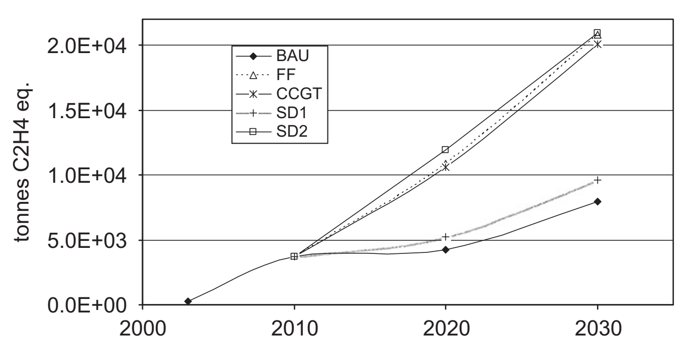

Fig. 10. Photochemical oxidation potential for the electricity scenarios.

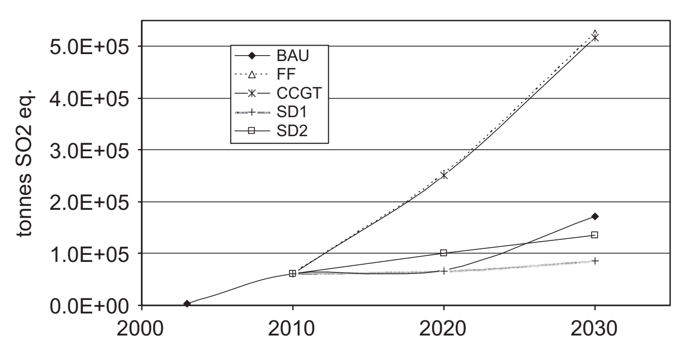

Fig. 11. Acidification potential for the electricity scenarios.

percentage increases amount to a total GWP100 figures of 84.2 million tonnes CO_2 eq. and 124 million tonnes CO_2 eq. in 2020 and 2030 in the FF scenario, respectively; see Appendix A for more detailed results. Impacts such as the total MTP increases almost seven times and 3.5 times in 2020 and 2030 in the FF scenario, respectively, compared to the corresponding years in the BAU scenario. This is attributed mainly to the increase in coal power consumption. There are thus significant environmental disadvantages in this scenario compared to the Government's power generation plans (BAU scenario).

4.2.2. Combined-cycle gas turbines scenario (CCGT)

The CCGT scenario shows environmental improvements when compared to the FF scenario. This is due to the higher efficiencies and related reduced consumption of gas in the CCGT power plants compared to the conventional gas plants. For example, the total ADP and GWP100 reduce by about 12% in 2030 in the CCGT scenario compared to the same year in the FF scenario. However, the increase in environmental impacts in the CCGT scenario is still significant compared to the BAU scenario mainly due to the increased fossil fuels consumption in this scenario (see Table 8 and Figs. 3–12). For example, both the total ADP and GWP100 increase by almost 50% in 2030 in the CCGT scenario compared to the respective year in the BAU scenario. Nonetheless, this is still much better than the FF scenario where the total ADP and GWP100 increase by almost 70% in 2030 compared to the respective year in the BAU scenario.

4.2.3. Sustainable development scenario (SD1)

The SD1 scenario shows improvements in six impact categories in 2020 and eight impact categories in 2030 compared to the corresponding years in the BAU scenario (see Table 8 and Figs. 3–12). For example, the total ADP and GWP100 of 463,000 tonnes Sb eq. and 50.8 million tonnes CO_2 eq., respectively, in 2020 in the SD1 scenario are over 20% lower than in the corresponding year in the BAU scenario. A further decrease of about 26% is achieved by 2030. This is due to the increased share of the renewable energy systems in the SD1 scenario. However, at the same time, POCP increases by about 24% and 21% in 2020 and 2030, respectively, in the SD1 scenario compared to the corresponding years in the BAU scenario. This is attributed to the significant increases in carbon monoxide and nitrogen oxide emissions from burning biomass, due to the increase in the share of biomass in the electricity mix to 2% and 5% in 2020 and 2030, respectively, in the SD1 scenario (see Table 3).

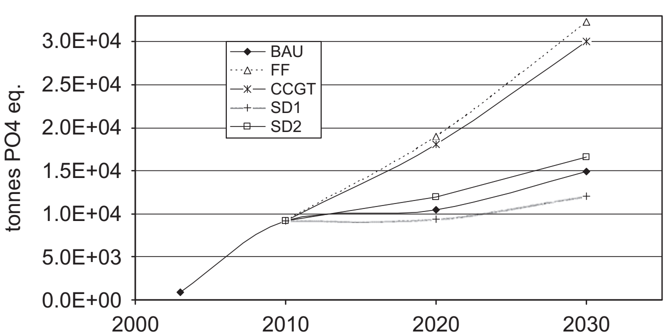

Fig. 12. Eutrophication potential for the electricity scenarios.

4.2.4. Sustainable development scenario (SD2)

More renewable energy (biomass and solar) is deployed in the electricity generation mix in the SD2 scenario. However, this translates to improvements in impacts in only two categories in 2020 and growing to six impact categories in 2030. There is a significant reduction in ADP and GWP100 in this scenario. Both impacts are reduced by about 31% and over 37% in 2020 and 2030, respectively, compared to the corresponding years in the BAU scenario (see Table 8 and Figs. 3–12). This increase from 2020 levels is attributed to the further increase in renewable energy systems in this scenario. The disadvantages in the other impact categories imply that there are also other environmental impacts associated with renewables such as, the addition of more biomass power systems in 2030 in this scenario increases the total POCP and EP by about two times and 11%, respectively, compared to 2030 in the BAU scenario. The reason is the increased CO and NO*x* emissions from burning biomass, respectively. Another factor associated with introducing renewable systems is that more units of renewables such as wind and solar need to be installed to generate the same amount of power as the conventional systems, thus construction of these renewable power plants adds to the impacts categories; however, this contribution is not significant. For example, a 265 MW solar power plant operating at 3000 h per year is required to generate the same amount of electricity as a 100 MW coal-fired power plant operating for 8000 h per year.

4.3. Economic analysis of the electricity sector

The results of the economic analysis are summarised in Table 9 and Figs. 13–15; more detail can be found in Appendix A. A discounting

Table 8
Comparison of the electricity LCA results with the BAU scenario.

Impact category	Compared to 2020 BAU				Compared to 2030 BAU			
	FF 2020 (%)	CCGT 2020 (%)	SD1 2020 (%)	SD2 2020 (%)	FF 2030 (%)	CCGT 2030 (%)	SD1 2030 (%)	SD2 2030 (%)
GWP100	30.3	21.2	−21.4	−30.7	68.9	47.8	−26.3	−37.3
ADP	30.8	21.7	−21.3	−31.2	69.1	47.9	−26.7	−38.6
ODP	46.3	41.3	7.5	41.1	61.7	52.7	1.7	29.3
HTP	139.0	132.7	4.9	95.3	141.0	132.7	−7.1	75.9
FTP	327.4	326.1	−0.6	34.9	198.1	196.3	−53.8	−36.3
MTP	588.0	587.7	1.9	14.5	259.9	259.1	−73.6	−69.7
TTP	376.2	372.2	−5.2	5.3	230.5	228.1	−65.5	−61.2
POCP	158.9	151.8	24.0	183.9	161.3	152.4	20.7	162.8
AP	280.6	275.8	−0.7	49.8	207.6	202.3	−49.4	−21.1
EP	81.0	72.4	−11.0	13.4	116.8	101.6	−19.4	11.6

Table 9
Cost comparison for different scenarios.

Costs	Compared to 2020 BAU				Compared to 2030 BAU			
	FF 2020 (%)	CCGT 2020 (%)	SD1 2020 (%)	SD2 2020 (%)	FF 2030 (%)	CCGT 2030 (%)	SD1 2030 (%)	SD2 2030 (%)
Capital costs	−10.6	−6.9	15.7	61.0	−25.2	−18.9	26.8	64.3
Total costs	1.3	−2.2	−4.9	11.5	9.6	0.1	7.1	23.2
Unit costs	1.4	−2.2	−4.8	11.6	9.0	0.2	7.1	23.2

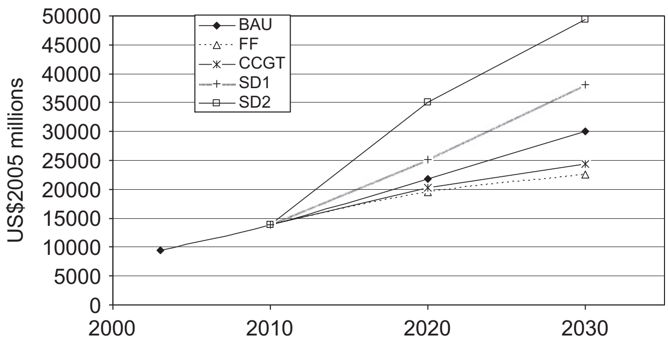

Fig. 13. The capital costs of the electricity scenarios.

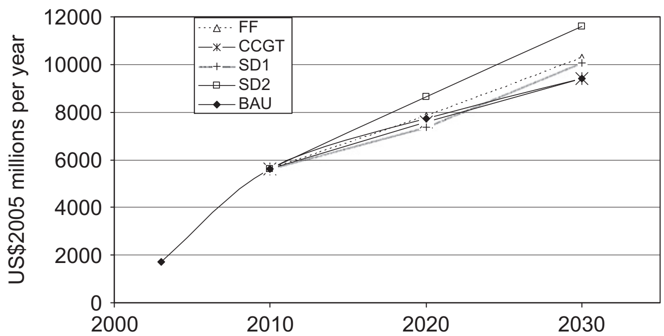

Fig. 14. The total costs of the electricity scenarios.

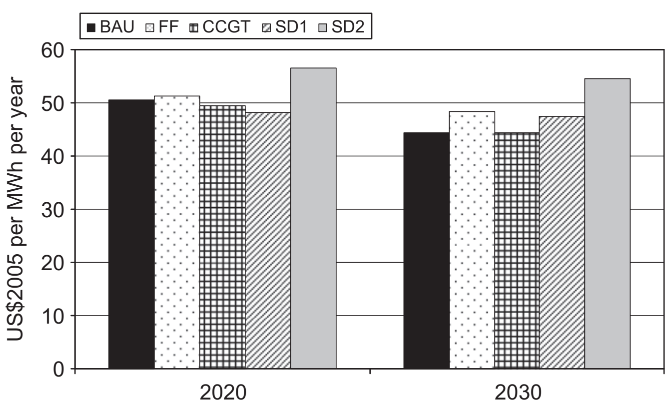

Fig. 15. Unit costs of the electricity scenarios.

rate of 13% (CBN, 2006)[12] has been used for calculating the annualised capital costs throughout.

4.3.1. Capital costs

The capital costs for the SD1 and SD2 scenarios show a considerable increase compared to the BAU scenario, mainly due to the higher costs of renewable systems compared to conventional power systems (see Fig. 13). For example, the total capital cost of over US$49.5 billion in 2030 in the SD2 scenario is about 64% higher than that of the corresponding year in the BAU scenario (see Table 9 and Fig. 13). On the other hand, the total capital costs of the FF and CCGT scenarios are lower than that of the BAU scenario due to higher share of conventional systems in these scenarios. Thus, the FF scenario indicates savings of over 10% and 25% by 2020 and 2030, respectively, in the capital costs compared to their corresponding years in the BAU scenario. However, higher capital investment is required to introduce CCGT technologies into the electricity mix compared to the FF scenario. The CCGT scenario requires 4% and 8% higher capital requirements in 2020 and 2030 compared to the respective years in the FF scenario. This is ultimately due to the higher capital costs of the CCGT technologies compared to the conventional gas power technologies. Thus the savings in the capital investments costs in the CCGT scenario are about 7% and 19% in 2020 and 2030, respectively, compared to their corresponding years in the BAU scenario.

4.3.2. Total and unit costs

The results in Table 9 and Fig. 14 show that the total costs in the SD1 scenario in 2020 are almost 5% lower than in the BAU scenario for the same year. However, these costs increase by 7% in 2030 mainly due to the sheer size of the renewables that are added to the mix in the SD1 scenario. This ultimately increases the annualised capital costs despite the low or no fuel costs associated with the renewables. The increased capital costs of renewables also increase the total costs in the SD2 scenario. Another major impact on the costs are the capacity utilisation factors of renewables such as solar and wind systems. As mentioned in Section 4.2.3, more installed capacity of renewable systems is needed to generate the same amount of energy as conventional systems thus increasing the capital cost, which ultimately influences the total cost. There is also an increase in the total costs in the FF scenario compared to the BAU scenario; this is expected because the FF scenario is characterised by more fossil-fuelled systems that may have lower capital costs but are associated with high fixed, variable and fuel costs thus increasing the total costs. However, deploying CCGT technologies will significantly reduce the total costs as shown in the CCGT scenario. For example, the total cost in 2030 in the CCGT scenario is the same as that of the BAU scenario while this cost increases by almost 10% in the corresponding year in the FF scenario compared to the BAU scenario. This could be attributed to the lower fuel consumption in the CCGT scenario compared to the FF scenario.

The trend for the average unit costs follows that of the total costs (see Table 9 and Fig. 15). The results of the unit costs suggest that by 2020, it is cheaper to generate electricity in the CCGT and SD1 scenarios compared to the other scenarios including the BAU scenario. However, by 2030, the BAU and CCGT scenarios offer the cheapest means to generate electricity compared to all other scenarios. The SD2 scenario is the most expensive mainly due to the high capital costs of renewables which increase the total cost.

5. Discussion

Much of what has been developed in this paper relates to the outcome of assumptions on potential policy directions in the energy sector that Nigeria may take. With 60% of the population yet to have access to electricity in Nigeria, the power sector will continue to grow into the foreseeable future. How demand is met will depend on resource availability, access to finance, and the extent to which environmental and social concerns are embedded into the country's energy policy. This paper recognises those policy-level uncertainties with respect to the future trajectory of electricity generation and how that may play out in a concrete sense.

In essence, if the appropriate choice of the future electricity scenario mix is based on a trade-off between environmental impacts and capital costs, the SD1 scenario offers the most favourable option to consider. This is because there are considerable improvements in the life cycle environmental impacts, lower total costs in 2020 and less than 10% increase in the total costs in 2030 compared to the corresponding years in the BAU scenario.

[12] The minimum discount rate dropped from 20.5% in 2001 to 15% in 2003 and 2004 and then to 13% in 2005 and first quarter of 2006. Thus the discount rate of 13% has been used in all the costing calculations.

The major trade-off, however, is in the capital costs which requires between 15% and 27% higher capital investments.

If the policy focus is leaning towards climate change and low carbon development, the SD2 scenario offers highest improvements in GWP100 compared to the BAU scenario. However, the dramatic increase in the capital costs in the SD2 scenario (61–64%) makes this a less attractive option from an economic point of view. The environmental impact results from this scenario also imply that care must be taken as to which renewable energy systems are to be introduced into the electricity generation mix, as biomass burning is shown to increase the POCP and EP. Hence, trading one environmental impact for another is an area that requires further deliberation. The SD1 and SD2 scenarios also have the potential to increase the pressure on the existing biomass reserves thereby further increasing rates of deforestation, which has already exceeded 3% per annum (Food and Agriculture Organisation of the United Nations (FAO), 2006). Biomass, though a renewable resource, is being consumed at a significantly higher rate than the rate of replenishment in Nigeria (Akinbami, 2001), and the future looks more uncertain as more of biomass continues to be used as the main domestic fuel in households, thus contributing to deforestation. However, the adoption of stringent policies to grow sustainable biomass (such as poplar and miscanthus) for use in power plants is a real possibility with enormous social benefits such as creation of jobs, in addition to reduced environmental impacts in several categories. On the other hand, if the policy emphasis remains rooted in costs, the FF scenario is the most attractive option. This scenario also has the potential to reduce the effects of changes to the ecosystem as well as social implications associated with relocation and compensation due to construction of large hydropower dams since the consumption of hydropower is reduced in this scenario.

The current trends in the electricity sector suggest that Nigeria may follow the trend of the FF scenario, where fossil-fuels will significantly dominate the electricity generation mix. This is evidenced by a large increase in applications for gas power plant licenses (Ibitoye and Adenikinju, 2007; Obadote, 2009) and the Government's concentrated efforts in boosting electricity supply by all means. The results obtained in this work indicate that following the trend of the FF scenario offers advantages in terms of the capital investment but this would mean all the life cycle environmental impacts will increase significantly. If Nigeria chooses to take a fossil-based expansion of its power sector, an alternative strategy which is already finding supporters in policy and business circles in Nigeria would be to use more efficient fossil-fuel technologies (as for example in the CCGT scenario) as a compromise between the environmental impacts and economic costs.

6. Conclusions

The Government's current efforts at restructuring and expanding the electricity sector suggests future electricity generation in Nigeria will increase significantly—almost four times from 2003 to 2030. The major issue is whether the Government is able to stimulate and regulate a sustainable future electricity system taking into account environmental and social imperatives. There is an increasing awareness of environmental issues associated with energy systems especially in the Niger Delta region, accompanied by political unrests, militancy and ultimately posing a severe threat to energy security. Thus the Government may try to shift burdens away from the conventional energy sources to more sustainable fuels. On the other hand, the Government also faces a number of dilemmas in crafting policies that address multiple priorities in the provision of public service needs. This is evidenced by the Government's concentrated efforts in meeting electricity demand and also addressing poverty reduction concerns in the near future, which may conflict with the need to invest in more sustainable energy options to meet the medium- to long-term environmental priorities. However, there are considerable uncertainties that characterise the choice of a range of possible strategies. Thus future electricity generation in Nigeria may shift towards a number of different directions.

However, the results from this study point to a number of possible policy initiatives. Future policy initiatives in the electricity sector should include the introduction of more renewables into the electricity mix as they have the potential to reduce considerably the life cycle environmental impacts, as demonstrated in the SD1 and SD2 scenarios. Although renewable energy systems require significant investment costs, the total costs will even out over time due to little or no fuel costs. However, appropriate measures must be taken for the introduction of renewable energy options such as biomass; for example, the sources of fuel should be sustainable. Similarly, since large hydropower dams will have a significant contribution to the future electricity mix, the policy initiatives must include the social impacts of relocation and occupational changes to the affected communities. Although there are potential gains in developing the hydropower potential of Nigeria, relocation and social costs such as changes to livelihood conditions and cultural resources of the surrounding communities can be a sensitive and potentially divisive issue. Thus proper compensation and job creation for the people in the affected areas should be a priority to ensure political stability and social security amongst others.

In the event of a fossil-fuel future in the electricity sector, more efficient gas-driven technologies (CCGT) should be employed in preference to conventional gas-technologies as this will reduce the life cycle environmental impacts as well as the annual costs. Future policy initiatives should also consider the introduction and implementation of stringent emission standards. This is particularly important in the event that this sector moves towards a predominantly fossil-fuelled future and also given the role of the private producers in the future electricity sector. Such policies will also stimulate the introduction of more efficient technologies such as CCGT, IGCC and CHP.

Appendix A

See Tables A1–A4.

Table A1
Life cycle environmental impacts of the BAU scenario.

Impact category	Unit	2003	2010	2020	2030
Global warming (GWP100)	tonne CO_2 eq	5.67E+06	5.60E+07	6.46E+07	7.34E+07
Abiotic depletion (ADP)	tonne Sb eq	5.16E+04	5.09E+05	5.88E+05	6.74E+05
Ozone layer depletion (ODP)	tonne CFC-11 eq	8.20E-02	5.92E-01	6.83E-01	9.83E-01
Human toxicity (HTP)	tonne 1,4-DB eq	6.35E+05	7.74E+06	9.08E+06	1.61E+07
Freshwater aquatic ecotoxicity (FTP)	tonne 1,4-DB eq	3.50E+04	6.26E+05	7.51E+05	2.06E+06
Marine aquatic ecotoxicity (MTP)	tonne 1,4-DB eq	7.65E+07	9.08E+09	9.36E+09	3.89E+10
Terrestrial ecotoxicity (TTP)	tonne 1,4-DB eq	1.07E+03	2.55E+04	2.73E+04	8.32E+04
Photochemical oxidation (POCP)	tonne C_2H_4 eq	2.91E+02	3.70E+03	4.21E+03	7.96E+03
Acidification (AP)	tonne SO_2 eq	3.47E+03	6.11E+04	6.70E+04	1.71E+05
Eutrophication (EP)	tonne PO_4 eq	8.57E+02	9.18E+03	1.05E+04	1.49E+04

Table A2
Life cycle environmental impacts comparison of the scenarios.

Impact category	Unit	2020 BAU	2020 FF	2020 CCGT	2020 SD1	2020 SD2	2030 BAU	2030 FF	2030 CCGT	2030 SD1	2030 SD2
Global warming (GWP100)	tonnes CO_2 eq	6.46E+07	8.42E+07	7.83E+07	5.08E+07	4.48E+07	7.34E+07	1.24E+08	1.09E+08	5.41E+07	4.60E+07
Abiotic depletion (ADP)	tonnes Sb eq	5.88E+05	7.69E+05	7.16E+05	4.63E+05	4.05E+05	6.74E+05	1.14E+06	9.97E+05	4.94E+05	4.14E+05
Ozone layer depletion (ODP)	tonnes CFC-11 eq	6.83E-01	9.99E-01	9.65E-01	7.34E-01	9.64E-01	9.83E-01	1.59E+00	1.50E+00	1.00E+00	1.27E+00
Human toxicity (HTP)	tonnes 1,4-DB eq	9.08E+06	2.17E+07	2.11E+07	9.52E+06	1.77E+07	1.61E+07	3.88E+07	3.75E+07	1.50E+07	2.83E+07
Freshwater aquatic ecotoxicity (FTP)	tonnes 1,4-DB eq	7.51E+05	3.21E+06	3.20E+06	7.46E+05	1.01E+06	2.06E+06	6.14E+06	6.10E+06	9.52E+05	1.31E+06
Marine aquatic ecotoxicity (MTP)	tonnes 1,4-DB eq	9.36E+09	6.44E+10	6.44E+10	9.54E+09	1.07E+10	3.89E+10	1.40E+11	1.40E+11	1.03E+10	1.18E+10
Terrestrial ecotoxicity (TTP)	tonnes 1,4-DB eq	2.73E+04	1.30E+05	1.29E+05	2.59E+04	2.88E+04	8.32E+04	2.75E+05	2.73E+05	2.87E+04	3.23E+04
Photochemical oxidation (POCP)	tonnes C_2H_4 eq	4.21E+03	1.09E+04	1.06E+04	5.22E+03	1.20E+04	7.96E+03	2.08E+04	2.01E+04	9.61E+03	2.09E+04
Acidification (AP)	tonnes SO_2 eq	6.70E+04	2.55E+05	2.52E+05	6.65E+04	1.00E+05	1.71E+05	5.26E+05	5.17E+05	8.66E+04	1.35E+05
Eutrophication (EP)	tonnes PO_4 eq	1.05E+04	1.90E+04	1.81E+04	9.35E+03	1.19E+04	1.49E+04	3.23E+04	3.00E+04	1.20E+04	1.66E+04

Table A3
Economic costs of the BAU scenario.

Cost type	2003	2010	2020	2030
The capital and total costs of the BAU scenario (US$2005 million)				
Capital costs	9.42E+03	1.38E+04	2.18E+04	3.01E+04
Total cost (per year)	1.70E+03	5.61E+03	7.75E+03	9.40E+03
The 'Unit' costs of the BAU scenario (US$2005/MWh.yr)				
Unit costs	9.40E+01	5.83E+01	5.06E+01	4.43E+01

Table A4
Economic costs comparison of the scenarios.

Cost type	2020 BAU	2020 FF	2020 CCGT	2020 SD1	2020 SD2	2030 BAU	2030 FF	2030 CCGT	2030 SD1	2030 SD2
The capital and total costs comparison of the scenarios (US$2005 million)										
Capital costs	2.18E+04	1.95E+04	2.03E+04	2.52E+04	3.51E+04	3.01E+04	2.25E+04	2.44E+04	3.82E+04	4.95E+04
Total costs (per year)	7.75E+03	7.85E+03	7.58E+03	7.37E+03	8.64E+03	9.40E+03	1.03E+04	9.41E+03	1.01E+04	1.16E+04
The 'Unit' costs comparison of the scenarios (US$2005/MWh yr)										
Unit costs	5.06E+01	5.13E+01	4.95E+01	4.82E+01	5.65E+01	4.43E+01	4.83E+01	4.44E+01	4.74E+01	5.46E+01

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