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Passenger transport in Nigeria: Environmental and economic analysis with policy recommendations

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HIGHLIGHTS

- ► The life cycle environmental impacts of passenger transport in Nigeria estimated for 2003–2030.
- ► The tradeoffs between economic costs and environmental impacts discussed.
- ► Scenarios considered: business as usual; sustainable transport; high economic growth.
- ► Public transport is more sustainable than transport by cars and motorcycles.
- ► Ending gas flaring would improve substantially environmental, economic and social impacts.

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ABSTRACT

This paper presents the life cycle environmental impacts and economic costs of the passenger transport sector in Nigeria for 2003–2030. Four scenarios are considered: business as usual (BAU); increased use of public transport (buses) at the expense of cars (LOWCAR) and motorcycles (LOWMC), respectively; and high economic growth with increased car ownership and decline of public transport (HICAR). The findings show that for the BAU scenario the life cycle environmental impacts double over the period, despite the assumption of increased fuel and vehicle efficiency of 35% over time. The total fuel costs at the sectoral level increase three times, from US$3.4 billion/yr in 2003 to US$9.7 billion in 2030. Increasing the use of buses would reduce the environmental impacts on average by 15–20% compared to BAU; at the same time, the total fuel costs would be 25–30% lower. If the use of cars grows much faster due to a high economic growth as in HICAR, the environmental impacts and fuel costs would increase by 16% and 26%, respectively. These results demonstrate clearly that future transport policy in Nigeria should promote and incentivise public (bus) transport as a much more environmentally and economically sustainable option than transport by cars and motorcycles.

1. Introduction

The transport sector was globally responsible for 62% of world oil consumption and 25% of total final energy demand in 2011 (IEA, 2011). In Nigeria, the oil consumption by the transport sector is even greater, consuming 80% of the total petroleum products (IEA, 2008) and making it the largest consumer of fossil fuels in the country. Road transport dominates, accounting for over 90% of all transport in terms of kilometres travelled (FOS, 2004; CFA, 2005; Oni, 2010). This is similar to the overall average for Africa, with road transport contributing to 80% and 90% of goods and passenger movements, respectively (UN, 2009). In Nigeria, this is due to a decline in other transport sectors, especially rail. For example, the number of rail passengers declined from 14 million to less than 1 million between 1980 and 2005 while rail freight decreased from 3 million tonnes to less than 500,000 tonnes within the same period (AfDB, 2007). This has led to an enormous pressure on the already inadequate and deteriorating road infrastructure in the country. For instance, only about 15% of the total 193,200 km of roads are paved (AfDB, 2006).

The high consumption of petroleum products in Nigeria translates into the daily sales volumes of about 26 and 4.2 million litres of petrol and diesel, respectively (NNPC, 2008; Mitchell et al., 2008). However, the four (Government-owned) refineries operate at about 40% of their capacity so that petroleum products have to be imported to supplement the demand (NNPC, 2006). For example, in 2005, the Government imported about 69% of the petrol and 43% of the diesel consumed in the country (NNPC, 2006). Given that all

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the fuel imports are paid for at international prices and are then subsidised for local affordability, this represents a significant drain on the country's already stretched financial resources.

The consumption of fossil fuels (mainly petrol and diesel) in the transport sector contributes 25.4 million tonnes of CO_2 or 50% of the national emissions; almost all of this (99%) is from road transport (IEA, 2010). Gas flaring adds further CO_2 emissions – this is a significant issue for Nigeria, since up to 75% of the gas extracted together with oil is flared (ERA, 2005; Sonibare and Akeredolu, 2006). However, this amount is gradually reducing and gas flaring in Nigeria is set to end in the near future (Nzeshi, 2010).

The huge dependence on road transport and a lack of an effective regulatory framework have also led to other societal concerns. Notably, the increase of motor vehicles from 1.3 million in 2000 to 2.2 million in 2004, representing an annual increase of about 17% (AfDB, 2006), has led to congestion in urban areas as well as increased noise and air pollution (Adegbulugbe et al., 2008), contributing to a wide range of health impacts (Krzyzanowski et al., 2005). The increase in road accidents is also a major concern; for example, an average of 18,387 cases of road accidents per year were reported between 2003 and 2007 with the number of fatalities averaging 8672 (NBS Nigeria, 2009).

With a population of over 158 million people (IEA, 2011), depending heavily on fossil fuel based transport, it is important to understand fully the environmental and economic impacts of the current passenger transport sector in Nigeria as well as how these may change in the future as the sector develops. Therefore, this paper considers the life cycle environmental impacts and economic costs of the passenger transport sector over the period 2003–2030. For these purposes, scenario analysis is used to explore possible ways in which the sector could develop. In addition to 'business as usual', three further scenarios are considered: two are based on sustainable transport development promoting public transport by buses, with one assuming reduced use of cars and another decrease in the use of motorcycles; the final scenario assumes increased ownership and use of cars at the expense of public transport. While there are numerous studies of the passenger transportation sector in different parts of the world, they are rarely assessed on a life cycle basis and even if so, only energy use and greenhouse gas emissions are considered (e.g. Eriksson et al., 1996; Bouwman and Moll, 2002; McCollum and Yang, 2009; Chester et al., 2010; Ou et al., 2010; Akerman, 2011; Hao et al., 2011; Croft McKenzie and Durang-Cohen, 2012). No such studies have been found in literature for Nigeria. Thus, as far as the authors are aware, this is the first life cycle assessment study of the passenger transport sector in Nigeria providing a full picture of the sector's environmental impacts from 'cradle to grave', indicating 'hot spots' and opportunities for improvements over the whole life cycle. This is also the first study showing the trade-offs between the life cycle environmental impacts and economic costs for the sector, aiming to inform future transport policy in Nigeria.

The paper is structured as follows: Section 2 provides a description of the current transport system as well as the scenarios considered; the results are presented in Section 3 and the conclusions and policy recommendations in Section 4.

2. Methodology

The methodology developed and used in this research is outlined in Fig. 1. As shown, it consists of three main steps:

1. definition of the current passenger transport system and future scenarios;
2. system modelling using life cycle assessment and economic (fuel) costs;
3. estimation of life cycle environmental impacts and economic costs for the current passenger transport system and future scenarios.

These are described in more detail in the following sections.

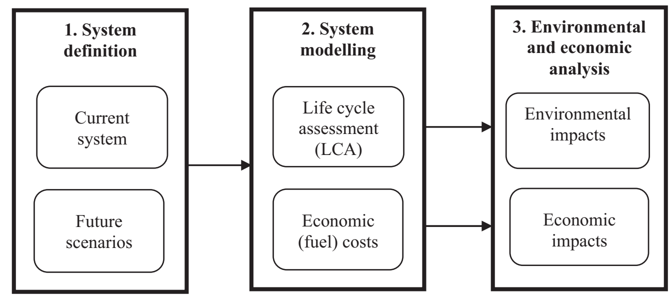

Fig. 1. The methodology used for environmental and economic analysis of the passenger transport sector in Nigeria.

2.1. System definition

The passenger transport system considered here is outlined in Fig. 2. The system boundary is drawn from 'cradle to grave', encompassing all activities from the extraction of crude oil to the production of petrol and diesel and use of the fuels for road and rail transportation. Both domestic and imported fuels are considered, as appropriate. Manufacture of vehicles and trains as well as the construction of roads, rail networks, pipelines, etc. are also included in the system boundary. The following sections provide more detail on the current transport system and the assumptions made in the definition of the scenarios.

2.1.1. Current passenger transport system

This study considers passenger transport within Nigeria and focuses on road transport as the major transportation mode in the country which, as mentioned earlier, contributes to over 90% of all passenger travel. Rail transport is also considered, although its contribution is small (0.25%). Domestic air and water transport are not considered due to a lack of data.

The characteristics of the current road and rail transport are summarised in Table 1, showing traffic volume, vehicle load factors and fuel intensities for different transportation modes and vehicles. Due to a limited data availability, the data from the ECN (2004, 2010) which refer to the year 2000 have been extrapolated to the year 2003 using the growth rate projections from the ECN. These data are considered fairly representative of the current Nigerian transport system as the overall characteristics of the sector have remained more or less constant over time (ECN, 2010). Some data on railway transport for the year 2003 have also been sourced from the FOS (2004). Therefore, for consistency and as a reference point for future scenarios, 2003 is considered as the base year throughout the work.

As shown in Table 1, the total number of passenger-kilometres travelled by road is 467 billion and 1.13 billion by rail. The large majority of travel is by bus (44.8%) and car (42.5%); motorcycle travel contributes 12.6% and rail only 0.24%. Intercity travel dominates in both bus and car transportation, contributing respectively 35% and 26% of all passenger travel. Over 61% of travel is by petrol vehicles and the rest by diesel.

The prices for the domestic and imported fuels used for the economic analysis are given in Table 2. As shown, the imported fuels are 35% more expensive but are subsidised by the Government to bring them in line with the domestic prices and so reduce

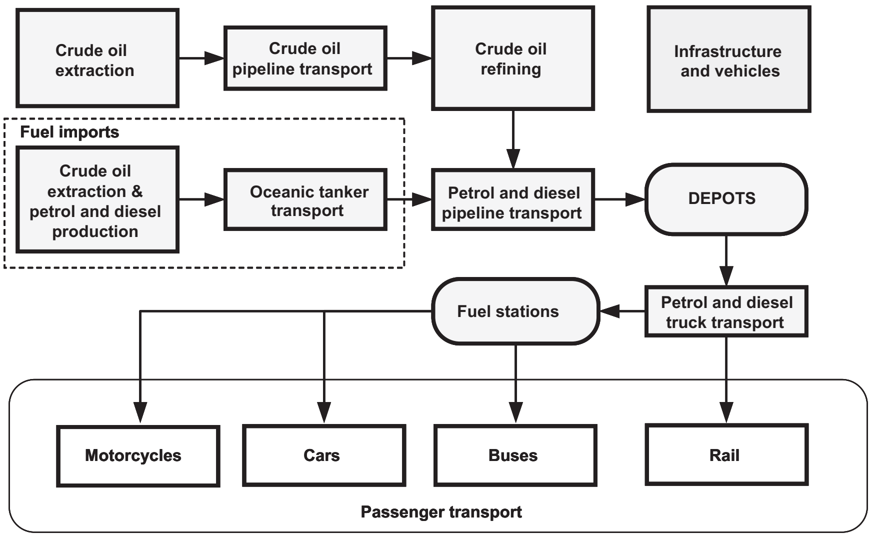

Fig. 2. The passenger transport system and system boundaries.

Table 1
Characteristics of the current passenger transport for the base year 2003 (ECN, 2004, 2010; FOS, 2004).

Transport mode	Vehicle type	Fuel	Traffic volume (billion person km/yr)	Load factor (persons/vehicle)	Fuel intensity (litres/100 km)
Motorcycle	Motorcycle (urban)	Petrol	58.6	1.7	4.1
Car	Car (urban)	Petrol	75.7	3.4	13.7
	Car (intercity)	Petrol	122	4.2	12.6
Bus	Mini-bus (urban)	Petrol	10.9	11.1	16.8
	Mini-bus (intercity)	Diesel	14.6	16.5	17.9
	Medium bus (urban)	Petrol	18.7	43.7	29.6
	Medium bus (intercity)	Diesel	80.5	33.4	18.4
	Luxurious bus (intercity)	Diesel	84.5	45.6	29.2
Rail	Train	Diesel	1.13	507	423.3

Table 2
Costs of fuels in Nigeria in 2003 (CBN, 2003; OPEC, 2003; NNPC, 2004).

Fuels	Prices (N/litre)	Reference	Prices (US$2005 per tonne)[a]
Petrol (domestic)	33.50	(McCollum and Yang, 2009)	371
Petrol (imported)	45.25	(Krzyzanowski et al., 2005)	501
Diesel (domestic)	32.50	(McCollum and Yang, 2009)	313
Diesel (imported)	43.50	(Krzyzanowski et al., 2005)	419

[a] Prices for 2003, converted to US$2005, using the conversion rate for the Nigerian Naira (N) for 2003: US$1 = N130 (CBN, 2003). The international (imported) prices refer to the actual cost of importing these fuels into Nigeria. The Government then subsidises these costs to match the prices of fuels produced by the domestic refineries (domestic prices). The average prices of fuels have been calculated taking into account the ratios of imported and domestically produced fuels.

fuel poverty. As mentioned earlier, 69% of petrol and 43% diesel are imported and the rest is provided from the domestic supply.

2.1.2. Definition of scenarios

Building on from the base year, the following four scenarios have been considered for the years 2020 and 2030:

1. business as usual (BAU) scenario;
2. sustainable transport development promoting public transport by buses: increased use of buses instead of private cars (LOWCAR);
3. sustainable transport development promoting public transport by buses: increased use buses instead of motorcycles (LOWMC); and
4. high economic growth: increased car ownership (HICAR) and decline of public (bus) transport.

In all the scenarios, it is assumed that the petrol and diesel demand are met by the local refineries, eliminating the need for fuel importation. This assumption is supported by the fact that licences for private refineries have already been issued and proposals made by the Government to build three new installations (EIA, 2005). There is also an on-going construction of US$2.5 billion Tonwei refinery in Bayelsa state with a capacity of 200,000 barrels per day (The Guardian Nigeria, 2011).

The assumed future costs of fuels are based on the growth rates projected by the EIA (2005) and they are shown in Table 3. Overall, the fuel costs increase by around 60% over the period. Although this may be a conservative assumption given the more recent excursions of fuel prices, the assumptions are the same for all the scenarios and are meant for relative comparisons of different scenarios rather than the actual prediction of future fuel prices.

With respect to the associated gas flaring, which in the base year was at the level of 75% (ERA, 2005; Sonibare and Akeredolu, 2006), it is assumed that the zero gas flare target is achieved by 2020 (based on Nzeshi (2010)).

The traffic volume projections are based on the scenario analysis for future economic growth and traffic demand carried out by ECN (2004). The ECN reference scenario is considered here, assuming

721 billion person.km in 2020 (around 50% increase on the base year) and 942 billion person.km for 2030, or double the base year (see Table 4). Using the data from FOS (2004) and based on the current Government efforts to improve and grow rail transport, it is assumed that travel by train doubles by 2020 and doubles again by 2030; this however still only represents 0.8% of the passenger transport system considered here (Table 5).

Furthermore, it is assumed that the fuel intensities decrease linearly on average by 35% by 2030 for both petrol and diesel vehicles due to the anticipated improvements in technology. Following the previous trends and the anticipated future economic development whereby the number of vehicles per capita increases with economic growth, the load factors for cars and city buses are assumed to decrease linearly on average by 17% by the end of the period. For intercity buses and trains, this variable is kept constant, assuming that they continue to run at capacity. These data are summarised in Table 4; note that the same assumptions shown in this table apply for all the four scenarios, with the only difference being the percentage contribution of different transportation modes to the total person-kilometres travelled. These differences are summarised in Table 5. Further differences between the scenarios are outlined below.

2.1.2.1. BAU scenario. This scenario assumes that the current passenger situation with respect to the transportation modes continues over the period; the only difference is that the contribution of rail transport quadruples by 2030. The other differences between the base year and this scenario have been outlined in the previous section (see Table 5).

2.1.2.2. LOWCAR and LOWMC scenarios. The development of these two scenarios has been driven by the need to identify and implement practical measures for a more sustainable development of the sector. Examples include increasing fuel efficiency, using alternative technologies such as fuel cells and promoting the use of buses and rail for public transport as well as market-based measures such as taxes. However, many of these emissions and traffic reduction options are not applicable within the Nigerian context.

For example, an average fuel efficiency increase of 35% over the time-period has already been assumed in this study and increasing this further in a developing country such as Nigeria would be difficult. The introduction of alternative technologies requires high capital and infrastructure investments and leads to higher costs to the consumer. Moreover, funding such capital-intensive measures would conflict with the immediate priorities of the millennium development goals aimed at poverty reduction, education, health and basic energy supplies. Thus, the most viable option for the Government, within the short to medium term, is to increase or promote the use of public transport as a means of reducing traffic congestion, environmental impacts and consumer costs. Therefore, the LOWCAR and LOWMC scenarios consider different levels of penetration of public transport (buses) into the passenger travel sector as follows (see Table 5).

Table 3
Assumptions for future fuel prices[a].

Fuels	Annual growth rate (%) (Mitchell et al., 2008)	2020 prices (US$2005/ tonne)	2030 prices (US$2005/ tonne)
Petrol (domestic)	1.8	503	601
Petrol (imported)	1.8	679	812
Diesel (domestic)	1.8	424	507
Diesel (imported)	1.8	567	678

[a] The costs have been converted to US$2005 using the consumer price index (CPI).

Table 4
Business as usual (BAU) scenario[a].

Transport mode	Vehicle type	BAU (2020)			BAU (2030)		
		Traffic (million person.km)	Load factors (persons/vehicle)	Fuel intensity (litre/100 km)	Traffic (million person.km)	Load factors (persons/vehicle)	Fuel intensity (litre/100 km)
Motorcycle	Motorcycle (urban)	9.54E+04	1.5	3	1.28E+05	1.3	2.5
Cars	Cars (urban)	1.23E+05	3.1	10	1.66E+05	3	8.2
	Cars (intercity)	1.83E+05	3.6	9.3	2.33E+05	3.3	7.6
Bus	Mini-bus (urban)	1.78E+04	10.4	12.3	2.39E+04	9.7	10.1
	Mini-bus (intercity)	2.19E+04	16.5	13.9	2.79E+04	16.5	12
	Medium-bus (urban)	3.04E+04	40	21.7	4.09E+04	36.3	17.7
	Medium-bus (intercity)	1.20E+05	33.4	14.3	1.54E+05	33.4	12.3
	Luxurious bus (intercity)	1.26E+05	45.6	22.8	1.61E+05	45.6	19.6
Rail	Train	3.00E+03	507	384.8	7.50E+03	507	342
Total		7.21E+05			9.42E+05		

[a] Note that the same data are used for the other scenarios, with the only difference being the percentage contribution of different transportation modes, as shown in Table 5.

Table 5
Contribution of different transportation modes to the passenger travel for different scenarios and time periods.

Transport mode	Base year	BAU		LOWCAR		LOWMC		HICAR	
	2003 (%)	**2020** (%)	**2030** (%)	**2020** (%)	**2030** (%)	**2020** (%)	**2030** (%)	**2020** (%)	**2030** (%)
Motorcycles	12.6	13.2	13.6	13.2	13.6	9.2	8.2	13.2	13.6
Cars (total)	42.4	42.5	42.3	29.7	25.4	29.7	25.4	55.6	59.7
Buses (total)	44.8	43.9	43.3	56.7	60.2	60.7	65.6	30.8	25.9
Railway	0.2	0.4	0.8	0.4	0.8	0.4	0.8	0.4	0.8
TOTAL	100	100	100	100	100	100	100	100	100

2.1.2.2.1. LOWCAR scenario. This scenario assumes a policy that encourages the use of buses and discourages car transportation. Thus it assumes that by 2020, the contribution to total passenger travel from buses increases from 45% in the base year to 57% and then to 60% by 2030. At the same time, the car share is reduced from 42% in the base year to 30% and 25% in 2020 and 2030, respectively. All other assumptions are the same as for the BAU scenario (see Table 4).

2.1.2.2.2. LOWMC scenario. This scenario assumes that the policy to reduce car traffic in the future is also extended to motorcycles. This scenario is also a possibility as the federal and some state governments have already banned or placed curfews on motorcycle transport in the capital city, Abuja, and cities such as Lagos and Port-Harcourt, mainly due to safety concerns. Thus this scenario assumes that the contribution of motorcycle traffic goes down from 12.6% in the base year to 8% while the share from bus transport grows to 65.6% by 2030 (see Table 5). This implies the bus transport growth of about 4% annually over the time period against $<0.7\%$ and 1% annual growth of car and motorcycle transport, respectively. As in LOWCAR, all other assumptions in this scenario are the same as for the BAU scenario (see Table 4).

2.1.2.3. HICAR scenario. Car ownership and traffic in a country normally increase with economic growth. Examples include countries such as China, India and Indonesia (Bouachera and Mazraati, 2007). With the average annual GDP growth of over 6% between 1998 and 2008 (World Bank, 2010), it is expected that increased levels of income will increase car ownership in Nigeria. This trend is already noticeable; for example, between 2002 and 2007, the number of passenger cars per 1000 people has more than doubled, increasing from 14 to 31 (World Bank, 2010). It is expected that the population growth of 2% and the urbanisation rate of 3.5% per year (UN, 2012) will also contribute to this trend.

This scenario thus assumes that car usage increases at the expense of bus transport owing to the economic growth. The assumption is that car transport increases to almost 60% in 2030, a 40% increase on the base year. Bus travel reduces to 26%, down from 45% in the base year (see Table 5). This means that car traffic grows by 3.8% annually and bus travel increases by only 0.5% annually over the study period.

2.2. System modelling

2.2.1. Life cycle assessment

The environmental impacts of the transport sector for the base year and the four scenarios have been estimated using life cycle assessment (LCA). The functional unit is defined as 'the total number of person.kilometres travelled per year' as follows:

- 467 billion person.km in 2003;
- 721 billion person.km in 2020; and
- 942 billion person.km in 2030.

The number of person.km travelled is the same for all four scenarios.

The LCA software SimaPro 6 (Pré Consultants, 2010) has been used for LCA modelling. The life cycle inventory data have been sourced from GEMIS 4.3 (Öko Institute, 2010) as well as the databases available within SimaPro. The environmental impacts have been estimated using the CML 2001 method (Guinée et al., 2001) and the following impact categories included in the method are considered: global warming potential (GWP), abiotic depletion potential (ADP), ozone depletion potential (ODP), photochemical oxidation creation potential (POCP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP).

2.2.2. Economic costs

The economic analysis focuses on the fuel costs which have been estimated for the base year and the four scenarios. The costs of infrastructure and vehicles are not considered due to a lack of data. The fuel costs should be treated with care as any future cost projections are by nature uncertain, particularly in the highly-volatile energy markets. Nevertheless, as they are assumed to be the same across the different scenarios, they are valid for relative comparisons of the economic implications of the potential future passenger transport systems.

3. Results

3.1. Life cycle environmental impacts

The LCA results are given in Figs. 3–9. As shown, all environmental impacts in all four scenarios increase over time due to the increased transport demand, despite the assumptions of improved fuel efficiency of 35%. Overall, the LOWMC scenario (increased use of buses at the expense of motorcycles) has the lowest impacts for all the impacts categories, followed closely by the LOWCAR scenario (increased use of buses at the expense of cars). The HICAR scenario exhibits the highest impacts overall due to the assumed high contribution of car transport compared to the other scenarios (see Table 5). The impacts from the BAU scenario are between the impacts from LOWCAR and HICAR. To put the results in context, the differences between the scenarios are compared relative to BAU in Table 6. For example, the improvements in the LOWCAR scenario over BAU range from 8.3% for ADP to 18.7% for POCP in 2020; in 2030, they are 10.5% and 24%, respectively. The impacts improve further for the LOWMC scenario; for instance, in 2020, ADP and POCP are reduced by 10% and 26.3%, respectively, compared to the same year in the BAU scenario. In 2030, the reductions in impacts are even higher and range from 13% for ADP to about 34.7% for POCP. At the same time, the impacts from HICAR are 8.6–19.4% worse than BAU in 2020 and 10.4–24.7% in 2030. For all the scenarios, most of the environmental impacts are from the combustion of fuels during the use of vehicles; some impacts are also from gas flaring. These results are discussed below in more detail for each impact in turn.

3.1.1. Global warming potential (GWP)

Compared to the base year, the total GWP for the BAU scenario increases by around 70% by 2030, from 76 to 131 million tonnes CO_2 eq. (see Fig. 3). The majority of the impact (61%) is due to the car transport. Carbon dioxide emissions, mainly from the exhaust

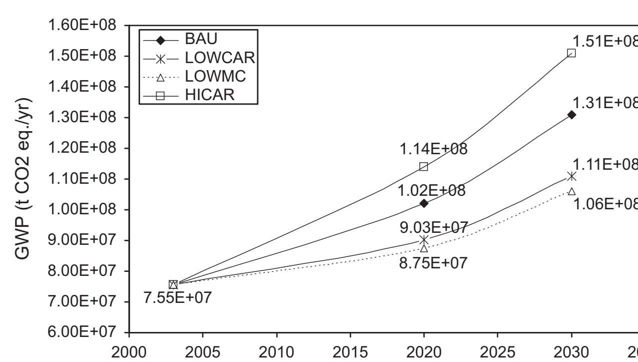

Fig. 3. Global warming potential (GWP) for different scenarios.

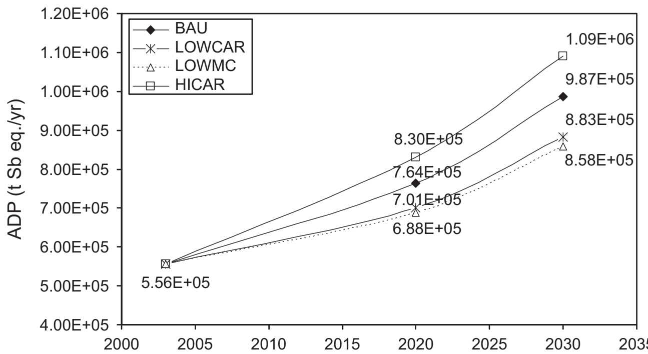

Fig. 4. Abiotic depletion potential (ADP) for different scenarios.

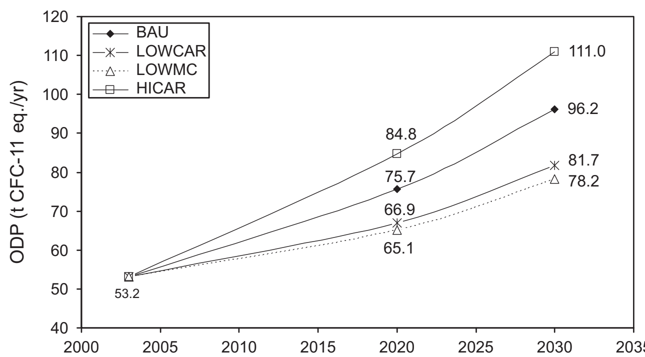

Fig. 5. Ozone depletion potential (ODP) for different scenarios.

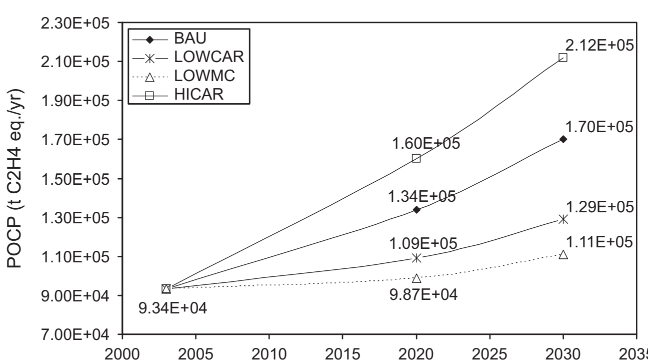

Fig. 6. Photochemical oxidation creation potential (POCP) for different scenarios.

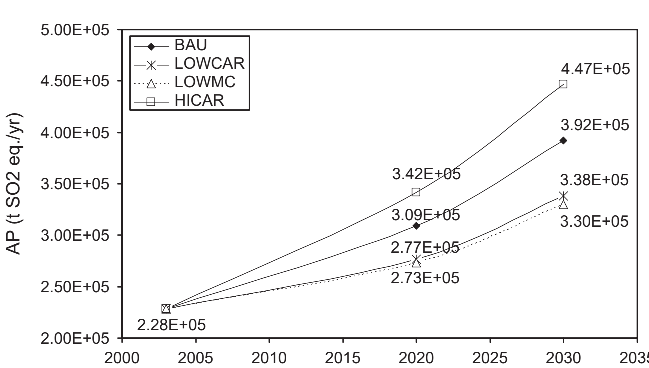

Fig. 7. Acidification potential (AP) for different scenarios.

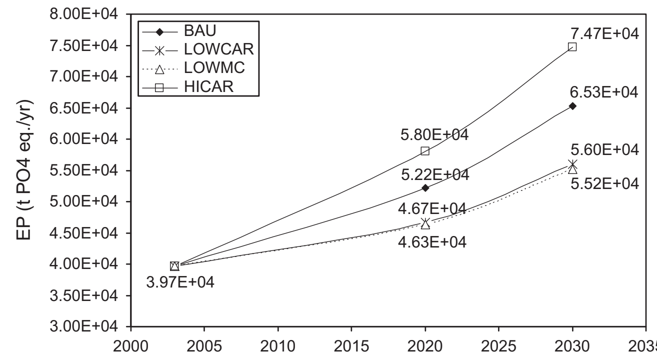

Fig. 8. Eutrophication potential (EP) for different scenarios.

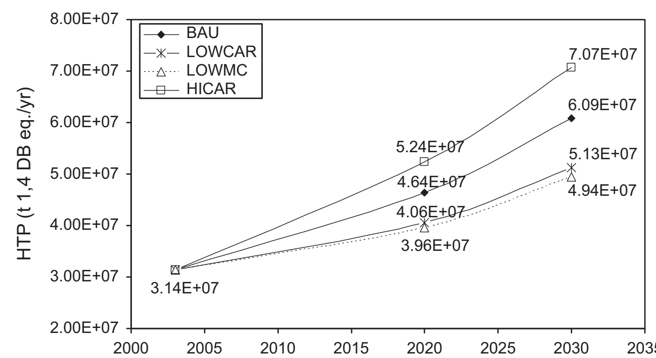

Fig. 9. Human toxicity potential (HTP) for different scenarios. **[**DB—dichlorobenzene**].**

of vehicles, account for most (82%) of the total GWP. The lowest GWP is achieved in LOWMC, increasing by 40% by 2030 compared to the base year; this is 19% lower than in the BAU scenario. By contrast, the GWP for HICAR increases by around 15% compared to BAU.

3.1.2. Abiotic depletion potential (ADP)

The total ADP in the base year is around 560,000 tonnes Sb eq. and this is expected to increase by about 1.8 times to almost 1 million tonnes Sb eq. in 2030 in the BAU scenario (Fig. 4). Car transport is responsible for 57% of the total ADP, of which petrol and diesel contribute 60% and coal and natural gas (used elsewhere in the life cycle), contribute 21% and 8.5%, respectively. By contrast, the contribution of natural gas to ADP in the base year is 16%, due to gas flaring. However, its contribution reduces to 8.5% in 2020 and 2030 due to the assumption of zero gas flare. The impact of gas flaring on the environmental impacts is discussed further below.

As for the other impacts, LOWMC has the lowest ADP, increasing by 2030 by 1.5 times on the base year; this represents an improvement of 13% on the BAU scenario. The ADP for HICAR almost doubles compared to the base year and is 10% higher than for BAU.

3.1.3. Ozone layer depletion (ODP)

This impact is mostly due to the crude oil production and the associated emissions of bromotrifluoro-methane emissions, so that the increase in transport results in an increase in this impact. In the BAU scenario, ODP increases on the base year by 80% by 2030, from 53 to 96 tonnes CFC-11 eq. (Fig. 5). The impact from LOWMC is around 19% lower and from HICAR 15% higher than from BAU, respectively.

Table 6
Comparison of LCA results for the LOWCAR, LOWMC and HICAR scenarios relative to the BAU scenario.

Impact category	Compared to BAU 2020			Compared to BAU 2030		
	LOWCAR 2020 (%)	LOWMC 2020 (%)	HICAR 2020 (%)	LOWCAR 2030 (%)	LOWMC 2030 (%)	HICAR 2030 (%)
Global warming potential (GWP)	−11.5	−14.2	11.8	−15.3	−19.1	15.3
Abiotic depletion potential (ADP)	−8.3	−10.0	8.6	−10.5	−13.1	10.4
Ozone depletion potential (ODP)	−11.6	−14.0	12.0	−15.1	−18.7	15.4
Photochemical oxidation creation potential (POCP)	−18.7	−26.3	19.4	−24.1	−34.7	24.7
Acidification potential (AP)	−10.4	−11.7	10.7	−13.8	−15.8	14.0
Eutrophication potential (EP)	−10.5	−11.3	11.1	−14.2	−15.5	14.4
Human toxicity potential (HTP)	−12.5	−14.7	12.9	−15.8	−18.9	16.1

3.1.4. Photochemical oxidant creation potential (POCP)

The POCP in the BAU scenario increases from 93,400 tonnes C_2H_4 eq. in the base year to about 170,000 tonnes by 2030 (see Fig. 6). Similar to the other impacts, car transport is the major contributor, accounting for around 60% of this impact with carbon monoxide emitted from the vehicles contributing 90%. Up to 35% of the BAU impact can be reduced if the LOWMC scenario is realised; on the other hand, increasing the use of cars as in HICAR would lead to a 25% increase or 210,000 tonnes C_2H_4 eq. by 2030, compared to BAU.

3.1.5. Acidification potential (AP)

In the base year, the acidification potential is estimated at 225,000 tonnes SO_2 eq.; this increases 1.7 times to 380,000 tonnes by 2030 in the BAU scenario (Fig. 7). Car transport accounts for about 60% of the impact owing to the emissions of nitrogen oxides and sulphur oxides from the exhaust, contributing 58% and 37% to the AP, respectively. The impact from LOWMC and LOWCAR is 14% and 16% lower respectively than from BAU and 14% higher from HICAR.

3.1.6. Eutrophication potential (EP)

As shown in Fig. 8, the eutrophication potential increases from 40,000 tonnes PO_4 eq. in the base year to about 65,000 tonnes by 2030 in the BAU scenario. Like the AP, car transport accounts for about 60% of the impact, of which 90% is due to the emissions of nitrogen oxides from the vehicles. The impact from LOWCAR and LOWMC is similar and on average 14.5% lower than for BAU. The increased use of cars in HICAR leads to a 14% increase of the EP on the BAU scenario by 2030.

3.1.7. Human toxicity potential (HTP)

By 2030, this impact doubles in the BAU scenario on the base year (see Fig. 9). This is due to the growing transport volume, with car transport accounting for about 64% of the total. The main contributors are barite and polyaromatic hydrocarbon emissions to water, which occur during crude oil production, accounting for 23% and 13% of the total HTP. In addition, nickel emissions to air, mostly due to the use of petrol vehicles contribute further 20% of this impact. Up to 19% of this impact could be avoided if policy supported the use of public transport as in the LOWMC scenario; the growth in the car ownership as in the HICAR scenario would on the other hand lead to a 16% increase in HTP by 2030, compared to the business as usual.

3.1.8. Impacts of gas flaring

As already mentioned, up to 75% of the associated gas is flared during the extraction of crude oil. To determine the effect of gas flaring on the environmental impacts, two options are considered: 75% flaring and zero flare. For comparative purposes, this modelling is based on the base year 2003.

The results shown in Fig. 10 indicate that the life cycle impacts from the passenger transport sector would be reduced by between 10% and 15% if gas flaring was discontinued. For example, GWP and ADP reduce by 13%, AP by 10%, and EP by 15%. Therefore, even without any other changes in the passenger transport system, there would be a significant advantage in pursuing the zero flare goal.

3.2. Economic impacts: fuel costs

As indicated in Fig. 11, the fuel costs follow the same trend as the environmental impacts, increasing over time owing to the increase in the costs of fuels and transport demand. The LOWMC and LOWCAR scenarios have the lowest and HICAR the highest costs. For example, by 2030, the fuel costs for LOWMC double on the base year, from $3.4 to $6.7 billion while for HICAR they increase 3.5 times to $12.2 billion. By comparison, the costs for BAU increase 2.8 times to $9.7 billion. Overall, comparing the BAU to the other scenarios, it can be observed that pursuing the policy of increased share of public transport through LOWCAR and LOWMC would reduce the overall fuel costs by 25% and 31%, respectively (Table 7) owing to a lower amount of fuel required per unit of transport. For example, bus transport which constitutes over 40% of the passenger transport in the BAU scenario (based on person.km travelled) accounts for only 10–12% of the total fuel costs while cars account for around 75%.

4. Concluding remarks and policy recommendations

As shown in this work, if business as usual continues, passenger transport in Nigeria is set to double by 2030, leading to a substantial increase in the number of vehicles on the roads. This in turn would almost double the current life cycle environmental impacts from this sector, despite the anticipated improvements in fuel efficiency and vehicle technology. The total fuel costs would reach US$9.7 billion per year by 2030, up three times from US$3.4 billion in 2003. Therefore, there is a need to incorporate sustainability considerations as a priority in the future plans for the transport sector before irreversible changes are made. However, policy and infrastructure options are limited within the Nigerian context as the Government also faces other dilemmas in crafting policies that address multiple priorities in the provision of public service needs. These priorities include concentrated efforts in meeting electricity demand and addressing poverty and education concerns in the near future. Due to limited resources, these may compete with the need to invest in more sustainable development of passenger transport. However, measures such as promoting the use of public transport are within the grasp of the Nigerian Government.

As also shown in this work, car transport accounts for most of the environmental impacts (on average 60%) and fuel costs (75%),

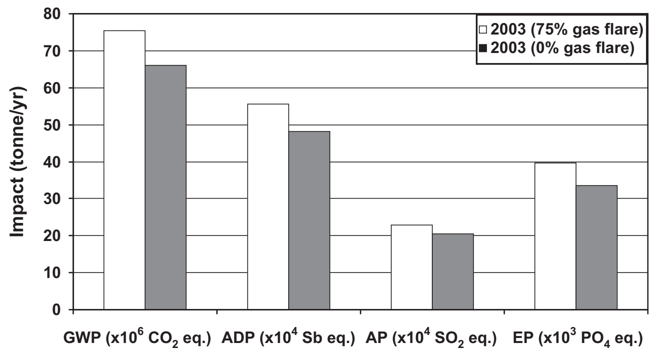

Fig. 10. The effect of gas flaring on the life cycle impacts for the base year 2003.

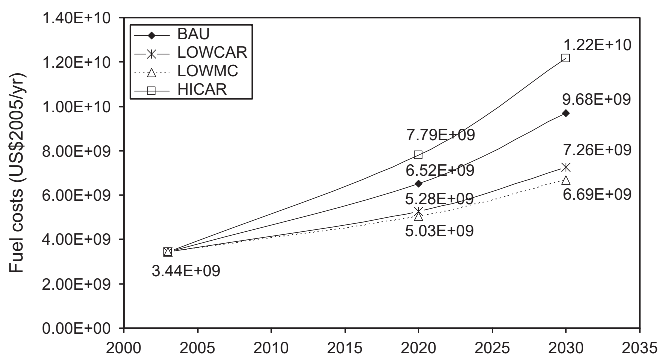

Fig. 11. Fuel costs for different scenarios.

Table 7
Comparison of the fuel costs for the LOWCAR, LOWMC and HICAR scenarios relative to the BAU scenario.

Scenario	Change relative to the BAU scenario	
	2020 (%)	**2030** (%)
LOWCAR	−19.0	−25.0
LOWMC	−22.9	−30.9
HICAR	19.6	26.0

so any measures to improve sustainability in this sector should target car transport as priority interventions. The results from this study show that bus transport is much more environmentally and economically sustainable than transport by cars and motorcycles. Thus, vigorous promotion and incentivisation of bus transport is likely to deliver beneficial outcomes, but this would require considerable policy dexterity and political audacity in a country where representative democracy is still in its early stages. For example, the Government could ban motorcycles (as it has done in some states for safety reasons), introduce taxes and levies on cars and provide more incentives for bus operators. More could also be done to improve further the sustainability of the sector by rebuilding, upgrading and expanding the railway infrastructure. Although this would require significant investments, railway transport is more sustainable than road transport and would therefore be a better long-term option.

It has also been shown in this study that gas flaring contributes up to 15% of the life cycle environmental impacts from passenger transport. Ending gas flaring would not only reduce the environmental impacts but also contribute to the Government's revenues from oil production. Perhaps more importantly, ending gas flaring along with other environmentally responsible interventions could deliver tangible outcomes to the communities in the Niger Delta whose livelihoods have been affected by gas flaring and other local contamination associated with oil extraction. Increased revenues from the sale of the this additional amount of gas can also be used to support economic and social development in the region.

However, sustainability considerations in this sector should not only be limited to environmental and economic variables but broadened to address health and other social impacts. For example, increased number of vehicles on the roads will increase traffic and add significant pressure on road infrastructure. There are also increased health risks from pollution in addition to increased risks of accidents. Thus policy initiatives in the transport sector should aim to address these concerns as a priority.

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References

Adegbulugbe, A.O., Adenikinju, A., Momodu, A.S., 2008. Developing a strategy for the application of emerging hydrogen and fuel-cell technologies in Nigeria's transport sector. In: Mytelka, L.K., Boyle, G. (Eds.), Making Choices About Hydrogen: Transport Issues for Developing Countries. UNU Press/IDRC Chapter 16.
AfDB, 2006. Africa Economic Outlook 2005–2006: Nigeria. African Development Bank. 〈www.globalcompetitionforum.org/regions/africa/Nigeria/OECD%202006.pdf〉.
AfDB, 2007. Rural Access and Mobility Project. Appraisal Report on Federal Republic of Nigeria. African Development Bank. 〈www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/NG-2007-038-EN-ADF-BD-WP-NIGERIA-RURAL-ACCESS-AND-MOBILITY-PROJECT.PDF〉.
Akerman, J., 2011. The role of high-speed rail in mitigating climate change—the Swedish case Europabanan from a life cycle perspective. Transportation Research Part D: Transport and Environment 16 (3), 208–217.
Bouachera, T., Mazraati, M., 2007. Fuel demand and car ownership modelling in India. OPEC Review 31 (1), 27–51.
Bouwman, M.E., Moll, H.C., 2002. Environmental analyses of land transportation systems in The Netherlands. Transportation Research Part D: Transport and Environment 7 (5), 331–345.
CBN, 2003. Economic Trends. Central Bank of Nigeria. 〈www.cenbank.org〉.
Chester, M.V., Horvath, A., Madanat, S., 2010. Comparison of life-cycle energy and emissions footprints of passenger transportation in metropolitan regions. Atmospheric Environment 44, 1071–1079.
CFA, 2005. Our Common Interest: Report of the Commission for Africa. 〈http://webarchive.nationalarchives.gov.uk/20050606200944/〉 〈http://www.commissionforafrica.org/english/report/thereport/english/11-03-05_cr_report.pdf〉.
Croft McKenzie, E., Durango-Cohen, P.L., 2012. Environmental life-cycle assessment of transit buses with alternative fuel technology. Transportation Research Part D: Transport and Environment 17, 39–47.
ECN, 2004. Energy master plan study for Nigeria. Energy Demand Project with the International Atomic Energy Agency (IAEA). Energy Commission of Nigeria.
ECN, 2010. Data on Nigeria's Transport Sector. Energy Commission of Nigeria. Personal Communication (e-mail).
EIA, 2005. Country Analysis Briefs: Nigeria. Energy Information Administration. 〈www.eia.doe.gov〉.
ERA, 2005. Gas Flaring in Nigeria: A Human Right's, Environmental and Economic Monstrosity. Environmental Rights Action. 〈www.foe.co.uk/resource/reports/gas_flaring_nigeria.pdf〉.
Eriksson, E., Blinge, M., Lövgren, G., 1996. Life cycle assessment of the road transport sector. Science of The Total Environment 189–190, 69–76.
FOS, 2004. Statistics for Transport Sector 2001–2003. Federal Office of Statistics, Nigeria.
Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., van Oers, L., et al., 2001. Life Cycle Assessment: An Operational Guide to the ISO Standards. Parts 1, 2a & 2b. Kluwer Academic Publishers, Dordrecht, The Netherlands.
Hao, H., Wang, H., Ouyang, M., 2011. Fuel conservation and GHG (Greenhouse gas) emissions mitigation scenarios for China's passenger vehicle fleet. Energy 36, 6520–6528.
IEA, 2008. 2005 Energy Balances for Nigeria. International Energy Agency. 〈www.iea.org/Textbase/stats/index.asp〉.
IEA, 2010. CO_2 Emissions From Fuel Combustion. Highlights: 2010 Edition. International Energy Agency. 〈www.iea.org/co2highlights/co2highlights.pdf〉.
IEA, 2011. Key World Energy Statistics 2011. OECD/IEA, Paris. 〈www.iea.org/textbase/nppdf/free/2011/key_world_energy_stats.pdf〉.
Krzyzanowski, M., Kuna-Dibbert, B., Schneider, J. (Eds.), 2005. World Health Organisation.

McCollum, D., Yang, C., 2009. Achieving deep reductions in US transport greenhouse gas emissions: scenario analysis and policy implications. Energy Policy 37, 5580–5596.

Mitchell, J., Stevens, P. and Cassinadri, E., 2008. Resource Depletion, Dependence and Development: Nigeria. Working Paper: EEDP 07/08, Chatham House, November 2008. ⟨www.chathamhouse.org/sites/default/files/public/Research/Energy,%20Environment%20and%20Development/13184_1108rddd_nigeria.pdf⟩.

NBS Nigeria, 2009. Annual Abstract of Statistics 2009. National Bureau of Statistics. ⟨www.nigerianstat.gov.ng⟩.

NNPC, 2004. Annual Statistical Bulletin 2003. Nigerian National Petroleum Corporation. ⟨www.nnpc-nigeria.com⟩.

NNPC, 2006. Annual Statistical Bulletin 2005. Nigerian National Petroleum Corporation. ⟨www.nnpc-nigeria.com⟩.

NNPC, 2008. Annual Statistical Bulletin 2008. Nigerian National Petroleum Corporation. ⟨www.nnpc-nigeria.com⟩.

Nzeshi, O., 2010. Nigeria: Gas flare deadline now December 2012. This Day, Lagos 14 January 2010. ⟨http://allafrica.com/stories/201001140228.html⟩.

Öko Institute, 2010. GEMIS—Global Emission Model for Integrated Systems, Version 4.3. Öko Institute, Germany. ⟨www.oeko.de/service/gemis/en/index.htm⟩.

Oni, O.A.G., 2010. Sustainable transport planning in the UK—adaptation to Nigeria's transport planning policies. Journal of Applied Sciences Research 6 (5), 543–558.

OPEC, 2003. Average Prices of Petroleum. Organisation of Petroleum Exporting Countries ⟨www.opec.org⟩.

Ou, X., Zhang, X., Shiyan Chang, S., 2010. Scenario analysis on alternative fuel/vehicle for China's future road transport: life-cycle energy demand and GHG emissions. Energy Policy 38, 3943–3956.

Pré Consultants, 2010. SimaPro 6. Pré Consultants, The Netherlands. ⟨www.pre.nl/simapro.html⟩.

Sonibare, J.A., Akeredolu, F.A., 2006. Natural gas domestic market development for total elimination of routine flares in Nigeria's upstream petroleum operations. Energy Policy 34, 743–753.

The Guardian Nigeria, 2011. Private Refineries: Confusion, as Govt Renews only 9 Licences. 31 October 2011. ⟨http://odili.net/news/source/2011/oct/31/1.html⟩.

UN, 2009. Africa Review Report on Transport: A Summary. Report No. E/ECA/CFSSD/6/6, United Nations, New York, USA. ⟨www.un.org/esa/dsd/csd/csd_pdfs/csd-18/rims/AfricanReviewReport-on-TransportSummary.pdf⟩.

UN, 2012. UN Data, Nigeria. ⟨http://data.un.org/CountryProfile.aspx?crName=NIGERIA⟩.

World Bank, 2010. Indicators. ⟨http://data.worldbank.org/indicator/IS.VEH.PCAR.P3⟩.