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Road Transport Energy Consumption and Vehicular Emissions in Lagos, Nigeria [1]

Forthcoming: Transportation Research Interdisciplinary Perspectives

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Abstract

The "Avoid", "Shift" and "Improve" (A-S-I) approach is an effective method for transforming an unsustainable transport system to a sustainable one. This study intends to examine the possible impact of the A-S-I policy measures in transforming the transportation system in Lagos - the most populous city and the commercial capital of Nigeria. The study employs the Long Range Energy Alternative Planning (LEAP) model to project future energy demand and greenhouse gas emissions to determine the most effective A-S-I option for the city. We construct a business-as-usual scenario for Lagos as well as sustainable road transport alternative policy scenarios. The results show that Lagos' biggest obstacle to achieving its emission reduction target is the presence of very old vehicles on its roads. Our analysis shows that emission reduction in the road transport sector in Lagos is sensitive to vehicle survivability rate (i.e. the fraction of vehicles of a certain age still driven). We conclude that unless the age limit of vehicles in Lagos reduces from 40 years to 22 years, vehicle growth rate from 5% to 2% and mileage by 2% per year from 2020- 2032, Lagos may not achieve the target 50% emission reduction by 2032.

Keywords: Road transport, energy consumption, greenhouse gas emissions, LEAP, Lagos, Nigeria

1 Introduction

1.1 Background

Increasing income levels in many developing countries has resulted in some changes in the lifestyle patterns of households in these countries (Hubacek *et al.* 2007), and these changes in lifestyle have an impact on energy demand in different sectors of the economy (Wei *et al.*, 2007). The transport sector is one of such sectors. Transportation is an essential part of human activity which supports socio-economic activities at the micro and macro levels in several ways. Efficient transportation system provides access to key economic inputs such as resources, knowledge, and technology; reduces the barriers to free movement of goods and persons; and increases the market for goods and services (Akpan, 2014). Road transport, which is the main mode of transportation in many developing countries, has experienced increased activities in terms of increase in the number of personal vehicles per capita. This is because as household income increases, the need to use an improved form of mobility also increases and households tend to move from non-motorized to motorized form of mobility. Other factors that have contributed to the increase in ownership and use of personal vehicles for mobility include: socioeconomic factors (age distribution of the population, household composition, employment, educational level); the state of supply and efficiency of public transport services; availability of quality road infrastructure; government policies (e.g. tax, insurance) towards automobiles ownership; cost of vehicles; cost of fuels; cost of alternative means of transportation; etc. (Singh, 2006). The increase in ownership and use of motorized mobility in-turn increases the demand for energy, especially refined petroleum products. Presently, because of the captive state of the road transport sector with regards to the use of refined petroleum products as fuel, the transport sector remains one of the key sectors of end-use of modern energy and greenhouse gas (GHG) emissions globally (International Energy Agency, IEA, 2012).

Sustainable urban transportation is one that ensures system, trip, and vehicle efficiency. The International Energy Agency (IEA) defines this as “the maximization of travel activity with minimal energy consumption through combinations of land-use planning, transport modal share, energy intensity, and fuel type” (IEA, 2013). The features of sustainable transportation may be better understood by knowing the differences between a sustainable and an unsustainable transport system as shown in Table 1.

Table 1: Fundamental differences between unsustainable and sustainable transport

	Unsustainable transport system	Sustainable transport system
Transport volume	Requires a high level of numbers of trips and trip distances, due to sprawled urban development and inefficient logistical networks.	The demand for travel is minimized and journeys are short, owing to compact urban development, mixed land use and optimized logistical chains.
Transport modes	Reliance on private motorized transport for passengers, and heavy goods vehicles for freight.	Most passenger trips are made by public or non-motorized transport, and freight is carried by rail and other low-carbon modes.
Transport technologies	Vehicles rely on inefficient, fossil-fuel engines. The transport network is inefficiently managed.	Low carbon vehicle technologies are mainstreamed, including highly efficient engines, hybrids, plug-in hybrids and electric vehicles. New technologies such as “Intelligent Transport Systems” and “Smart Logistics” help manage transport systems in highly efficient ways.
Transport pricing	The price paid by users for vehicles, fuel, parking and road space do not cover the full external costs to society, encouraging motorised vehicle use at the expense of more sustainable choices.	The price paid by transport users fully ‘internalizes’ the true costs, managing growth in motorised vehicle use and encouraging environmentally friendly alternatives.

Source: Sakamoto et al. (2010)

The “Avoid”, “Shift” and “Improve”, and (A-S-I) approach is an effective method for transforming an unsustainable transport system to a sustainable one (IEA, 2013; Sakamoto *et al.*, 2010;Solís & Sheinbaum, 2013). “Avoid” policies aim at reducing the number of trips made and the distance travelled through the introduction of an integrated land-use planning and transport demand management (system efficiency). “Shift” policies are targeted at facilitating a modal switch from the most energy-consuming urban mode of transportation such as personal vehicles to more energy efficient modes of transport such as the use of Hybrid Electric Vehicles (HEV) and Battery Electric Vehicles (BEV). Shift policies also include policies that promote non-motorized transport and public transport (bus and rail) thereby improving trip efficiency. Policies for "Improve" concentrate on vehicle and fuel efficiency of all travel modes through the introduction of fuel-economy standards and other policies that lead to an uptake of clean vehicles and alternative fuels like compressed natural gas (CNG). The implementation of A-S-I policies in the road transport sector is expected to bring about a reduction in road transport energy consumption, emissions and noise pollution, congestion and accidents, and unsustainable growth in private motorization.

Lagos, the most populous city and the commercial capital of Nigeria, fits the criteria of a developing, sprawling, congested city. Lagos can benefit from A-S-I policies that lessen private vehicle ownership, motorized travel distance, and improved public transportation.In Lagos, road transport is the major means of transportation for passenger and freight. Public transportation, though existing, is generally inefficient due to the poor nature of town planning and road quality. Consequently, a sizable percentage of residents rely on personal vehicles for mobility (over 70% of vehicles in Lagos are private owned). The annual number of registered private vehicles in Lagos increased from about 18900 in 1995 to about 197000 in 2011 (Lagos Bureau of Statistics, 2012). This has resulted in a corresponding increase in consumption of petroleum products (gasoline and diesel) from 1.9 million metric tonnes in 1995 to 3.4 million metric tonnes in 2011[2], with a corresponding increase in greenhouse gas emissions.

Most of the trips conducted in Lagos are for economic purposes. A sample of 2,500 households in Lagos State show that work (44.3%) and business (33.4%) related activities account for two-third of trips undertaken in Lagos, with social (9.6%), shopping (7.9%) and recreation (4.9%) contributing far less than these two (Osoba, 2012). These findings are similar to those of another study that examined the behavioral pattern of commercial public transport passengers in Lagos metropolis. The latter study observed that majority of commuters traveled for business related purposes (48%) and, based on occupation, majority of travelers were civil servants (62%) (Afolabi et al., 2017). Furthermore, there is a substantial difference in the average distances travelled. Osoba's (2012) shows that 60%

[2] Data sourced from NNPC statistical bulletin. The share of consumption of petrol and diesel in Lagos is assumed to be between 37 and 40% of national consumption.

residents traveling for work cover a distance of 15.1 to 30 km daily while the majority of those traveling for business purposes (60%) cover about 5 to 20 km daily. Besides the travel distance, residents traveling for work and business related activities have the same peak hours between6.00am to 6:30am and 6:31pm and 9:30pm (according to the survey commuters arrive home at late hours due to traffic congestion) and travel mode preference (showing a preference order of commercial vehicles, and private vehicles, motorcycles, rail and ferry (accounting for less than 3%) (Osoba, 2012).

The objective of this study is to analyze A-S-I policy measures in the context of the Lagos Metropolitan Area Transport Authority (LAMATA) emission reduction goals. Specifically, the study intends to employ the Long Range Energy Alternative Planning (LEAP) model to project future energy demand and greenhouse gas emissions to determine the most effective A-S-I option for Lagos, Nigeria.

The remaining part of the study is organized as follows: Section Two is a brief overview of the Strategic Transport Master Plan (STMP) that have been proposed by the Lagos Metropolitan Area Transport Authority (LAMATA) as solutions to the transport challenges facing Lagos; and Section Three is a review of literature on road transport energy consumption and greenhouse gas emissions. In Section Four, we will present the Methodology used in the study and in Section Five we will present our results. Section Six will be the discussion and concluding remarks.

1.2 Strategic Transport Master Plan (STMP) of Lagos

The road transport sector in Lagos is a primary source of air[3] and noise pollution in Lagos and is responsible for 50% of the greenhouse gases emitted from the transport sector in Nigeria (LAMATA, 2013a). According to LAMATA, the sector is faced with four main challenges which impact severely the social, economic and environmental sustainability of the city, namely: an increasing level of air pollution, the absence of a regulatory framework, severe congestion, and long travel distances particularly for the poor. LAMATA was established with the mandate to address the transport challenges faced by Lagos specifically through the coordination of “transport policies, programmes and actions of all agencies at different tiers of government”. In fulfillment of its mandate, LAMATA developed the Strategic Transport Master Plan (STMP), a long-term plan expected to actualize the Lagos State Long-term Vision of providing “a modern integrated multi-modal public transport

[3]Vehicles alone contribute about 43% to air pollution in Lagos State, according to a LAMATA presentation on Mass Transit and Climate Change, as it affects Lagos State.

system that will make Lagos State a world class city". LAMATA envisage that this vision will be met through the following broad strategic actions contained in the STMP:

i. Diversify the modes of transport used in Lagos
ii. Adopt an integrated transport system
iii. Enhance the attractiveness of public transportation
iv. Reduce emissions from vehicles
v. Optimize usage of road networks
vi. Promote integrated land use development
vii. Secure a long-term financing plan for the STMP

Excluding strategic action 7, each of these actions is an element of a sustainable transport system, as described in Table1.

2 Review of Related Literature

Several studies have been carried out to examine energy consumption and greenhouse gas emission in the road transport sector (Bose, 1996; He *et al.*, 2005; Shabbir & Ahmad, 2010;Yan & Crookes, 2010; Mraihi *et al*. 2013; Solís & Sheinbaum, 2013; Chavez-Baeza & Sheinbaum-Pardo, 2014). These studies have employed diverse methodologies depending on their objectives. For example, Mraihi *et al*. (2013) examined the driving factors of road transport energy consumption and CO_2 emissions in Tunisia using logarithm mean divisia index (LMDI) decomposition analysis. The study decomposed the change in road transport energy consumption for the period 1990 – 2006 into five components: change of vehicle fuel intensity, change of vehicle intensity, change of economic activity, change of urbanized kilometer, and change of national road network. Limanond *et al*. (2011) employed 20 – year historical data on different drivers of transport energy demand to project future transport energy demand for Thailand using a log-linear regression model. Arora *et al*. (2011) made projections on number of highway vehicles, energy demand, and CO_2 emissions in India using a combination of different economic functions.

Most other studies have used the bottom-up approach to energy demand analysis to examine road transport energy consumption and greenhouse gas emission. The approach involves disaggregating total energy demand into the end-uses so as to examine the underlying drivers of energy demand. In the transport sector, total energy demand can be disaggregated into transport type (passenger, freight), transport mode (air, road, rail, sea), vehicle type (e.g. two wheelers, three wheelers, four wheelers), and fuel type (e.g. gasoline, diesel, compressed natural gas). The total energy consumption for each mode of transportation and for each transport type may then be expressed as a multiplicative function of the number of vehicles per vehicle type, the average mileage for each vehicle type, the fuel consumption rate per kilometer for each vehicle type and fuel type, and the average load factor for each vehicle type (Singh, 2006; Zhou & McNeil, 2009). Through such disaggregation, transport sector energy planners can make more informed projections on aggregate energy needs of the sector by taking into account the various units that are summed up into the aggregate. The greenhouse gas emission may also be expressed as a function of the energy consumption at different levels of aggregation. Studies that have employed a bottom-up approach include (Singh, 2006; Zhou & McNeil, 2009; Solís & Sheinbaum, 2013; Puksec *et al.*, 2013; Chavez-Baeza & Sheinbaum-Pardo, 2014).

Given the robustness of the bottom-up approach for transport sector energy consumption analysis, and its usefulness in understanding the different underlying factors driving energy consumption and greenhouse gas emissions in the transport sector, computer applications such as the Long Range Energy Alternative Planning(LEAP) has been developed to aid computational procedures. Consequently, several studies have used the LEAP model to analyze road transport energy consumption and CO_2 emissions (Bose, 1996;Dhakal, 2003; Shabbir & Ahmad, 2010). In one of the earliest application of the LEAP model in transport sector, Bose (1996) examined the energy demand and environmental implications of urban passenger transport in Delhi, India for a base year of 1990/91 and for future years up to 2009/2010 under different scenarios. The study examined strategies to contain with increase in fuel consumption and emissions for each time period using four scenarios other than the base-case scenario: improvement in vehicular speed, increase in the share of buses, introduction of mass rapid transport system, and a combination of the three scenarios.

Similarly, Shabbir & Ahmad (2010) applied the LEAP model to examine the transport sector energy demand and greenhouse gas emissions in Rawalpindi and Islamabad, Pakistan. The study considered the impact of some policy initiatives in reducing transport sector greenhouse gas emissions using four scenarios: business-as-usual, reduction in population, introduction of more efficient public transport and introduction of natural gas vehicles. On his part, Dhakal (2003) examined the implications of transport policies on energy and environment in Kathmandu Valley, Nepal. The study made projections on future energy demand and emissions using five scenarios: increasing average vehicle speed, increasing share of public transportation, promotion of electric vehicles, comfortable travelling, and the combination of all other scenarios. Other studies that have employed LEAP for transport sector energy demand and emissions analysis include (Ma *et al.*, 2012; Yan & Crookes, 2010; Sadri *et al.*, 2014).

To the best of our knowledge, there has been just one study that has applied the LEAP model to examine energy demand and supply in Nigeria (Emordi *et al*., 2017). The study (Emordi *et al*., 2017) focused on the whole Nigeria and applied the LEAP model to different sectors. Even though the study has a larger scope, it falls short in making detailed analyses of specific sectors. Therefore, this study intends to focus on a smaller geographic area (Lagos) and on the transport sector only so as to carry out more detailed analyses. Our study will be the first study conducted to assess road transport energy consumption and its impact on the environment for the case of Lagos, as well as the effectiveness of the STMP using empirical methodologies.

LEAP was decided as the tool of choice for this study for the reason that it allows us to analyze vehicular emissions as well as other transport indicators like mileage and energy consumption. Moreover, the option of inputting lifecycle profiles improves the quality of the forecast made through the study.

3 Methodology

We employ the LEAP model which uses an end-use or bottom-up approach for modeling final energy demand. It does this by disaggregating demand into four levels, namely: sector, sub-sector, end-uses, and devices. Macroeconomic, demographic, and other variables may be used in constructing alternative scenarios for projecting energy use in the different sectors of the economy.

The limitation of the study is the lack of publicly available baseline assessments by LAMATA upon which the long-term emission reduction target was established. In the absence of these and official Current Account data from LAMATA, the authors extracted data from official documents from other government institutions and other credible sources to build a BAU scenario, as well as alternative scenarios, by 2032 for Lagos. Furthermore, although we recognize the benefits that options such as fuel substitution and technology switching could provide towards meeting the STMP objective and target, our study has not considered these options for the reason that the current policy landscape in Nigeria do not provide positive signals for their uptake. To elaborate further on the matter of fuel substitution, in 2007 Nigeria produced the Nigerian Biofuel Policy having the objective of achieving an ethanol blending rate of up 10% with gasoline and a 20% blend of biodiesel with petro diesel (Nigerian Biofuel Policy, 2007). However these objectives are yet to materialize. A recent government communication titled 'Opportunities in Nigeria's Biofuel Industry' show that there a no biofuel producing plants in Nigeria and, although, feasibility studies have been completed for three biofuel projects, these studies are all under review (FGN, 2018). Moreover the Nigerian Biofuel Policy has been very much criticized, with Ohimain (2013) and Osunmuyiwa (2017) ascribing the policy's failure to its inaccurate articulation and calling for its review. Even though the government, through the Petroleum Products Pricing Regulatory Agency (PPPRA), announced that the policy is under review, the Agency failed to provide the commencement schedule for the revised policy[4](Off-grid Nigeria, 2017).

On issue of technology switching, for example through the deployment of Electric Vehicles (EVs), in April 2019, Nigeria's legislators (i.e. the Senate) rejected the bill calling for the phase out petrol vehicles in 2035 and introduction electric cars, citing the impracticality of such a policy action (Daily Post, 2019)[5].

Having considered this our study has excluded such policy options in the analysis to provide a better reflection of the reality in Lagos, Nigeria.

Despite this limitation, we are confident that the data used in this study adequately reflects the reality in Lagos' road transport sector.

3.1 Calculations

LEAP's' Transport analysis' was used in this study to make calculations formileage, energy consumption and distance-based pollution emissions. The Current Accounts data for each of these indicators were extrapolated to produce BAU results by 2032. Furthermore, in the calculation of the Policy Scenarios, the key data input in each of these three indicators was adjusted, as presented in later sections of the study. We defined the indicators below.

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[4]The announcement was made in a news article released by the News Agency of Nigeria (NAN) in February 2017, with the title '
Nigeria to begin production of bio-fuel to augment petrol imports-PPPRA' and republished by news outlets including Off-grid Nigeria.

[5] The news article was published by the NAN and circulated through various media outlets including the Nigerian Tribune, Daily Post and Premium Times.

3.1.1 Mileage

Mileage measures the annual distance traveled per vehicle in kilometers (km) multiplied by a Degradation Rate, which represents the change in mileage as vehicles age. The study uses a constant rate for Lagos in the absence of data showing otherwise. 'Mileage' is our indicator for measuring the impact of Avoid or System Efficiency STMP strategic actions.

3.1.2 Energy consumption

LEAP calculates energy consumption of vehicles by fuel types as: energy consumption = stock of vehicles x annual vehicle mileage x fuel economy. 'Stock of vehicles' is represented by the total number of registered vehicles based on 2011 data of newly registered vehicles and renewals. The following units selected in LEAP are as follows: for annual vehicle mileage we use kilometer (km) and for fuel economy we use kilometer per liter of gasoline or diesel (km/l of fuel equivalent). 'Energy consumption' is our indicator for assessing 'Shift' or Trip Efficiency STMP strategic actions.

3.1.3 Distance-based pollution emissions

LEAP calculates 'Distance-based pollution emissions' as: stock of vehicles x annual vehicle mileage x emission factor x emission degradation. 'Distance-based pollution emissions' is the indicator used in this study to assess 'Improve' or Vehicle Efficiency STMP strategic actions.

3.2 Current Accounts Data

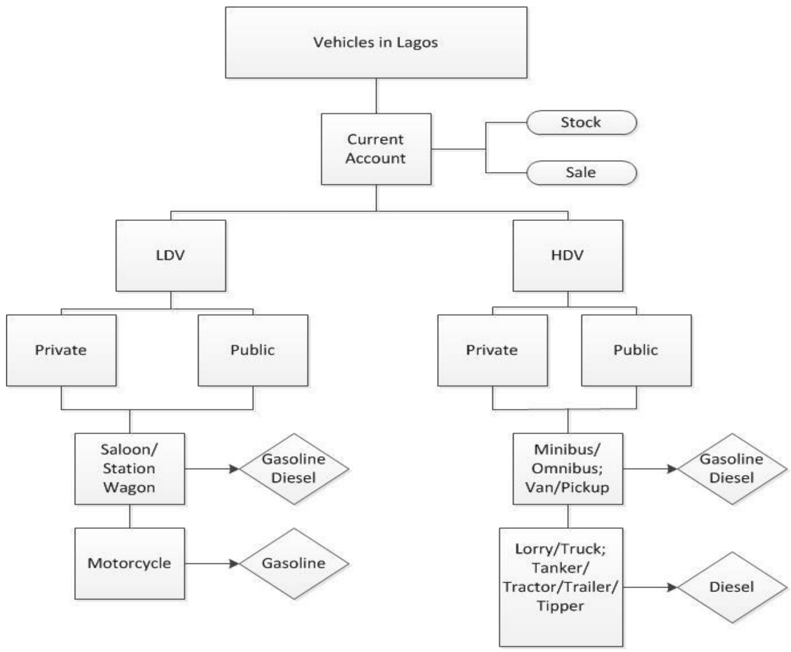

Figure 1: Graphical representation of data collected for the calculation

The current accounts data comprise of data used in calculating mileage, energy consumption and distance-based pollutions emission.

3.2.1 Current account data used in calculations for Mileage and Energy Consumption

Data fed into LEAP was gotten from data provided, at the national level, on kilometer travelled by vehicles in Nigeria (vehicle/km), vehicle fleet size and amount of gasoline and diesel consumed in litres, in the World Bank report on Assessing Low-Carbon Development in Nigeria (2013). The share of vehicle technology (i.e. gasoline or diesel) was gotten from the 2011 data on fuel consumption by vehicle type in Nigeria from the same World Bank report. Fuel economy (number of kilometer travelled per litre used by a vehicle type) was calculated for each vehicle type (i.e. truck or station wagon) and technology type (i.e. gasoline or diesel). Table 2 presents the calculated fuel economy data used in the study.

Table 2: Mileage and Fuel Economy inputs

Vehicle type	Vehicle Mileage (Veh/Km per unit)[6]	Vehicle technology	Vehicle technology (%)	Fuel Economy (km/L)[7]
Saloon & Station Wagon	17,000.07	**Gasoline**	99	11
		Diesel	1	11
Motorcycle	6,999.93	**Gasoline**	100	30.7
Van & Pickup	29,999.95	**Gasoline**	75	7.6
		Diesel	25	7.6
Tanker, Tractor, Trailer, Tipper	33,500.14	**Diesel**	100	3.5
Lorry, Truck	33,500.14	**Diesel**	100	3.5
Minibus, Omnibus	29,940.12	**Gasoline**	50	3.9
		Diesel	50	3.5

Source: Fuel Economy calculated by Authors

Data on 'Stock of vehicles' was gotten from the Lagos Bureau of Statistics' Motor Vehicle Statistics of 2012. The number of vehicles renewed and the number of newly registered vehicles were used as proxies for stock (i.e. stock of vehicles at the end of the year prior to the base year) and sale (i.e. vehicles sold in the base year) respectively. Table 3 presents the data used in LEAP.

Table 3: Vehicle data for base year (2011)

[6] In order to calculate the average annual distance traveled by unit of vehicle type, the authors divided the average distance traveled (Veh/km) by vehicle fleet (Vef_fleet), using data extracted from the abovementioned World Bank report.

[7] Fuel economy (km/l), for gasoline and diesel, was calculated by dividing vehicle distance traveled per unit (Veh/km per unit) by fuel consumed per a unit of vehicle type (F/veh_t). The data used in the calculation was also gotten from the abovementioned World Bank report.

			Stock of vehicles	
Types of Vehicles			**Stock**	**Sale**
Light Duty Vehicles (LDV)			**661,780**	**291,939**
	Private (including govt., missions/schools, businesses)		***564,520***	***212,864***
		Saloon/Station Wagon	557,691	190664
		Motorcycles	6829	22200
	Public/commercial		***97260***	***79075***
		Saloon/Station Wagon	81502	27864
		Motorcycles	15758	51211
Heavy Duty Vehicles (HDV)			**122,713**	**40,945**
	Private (including govt., missions/schools, businesses)		***28575***	***7515***
		Lorry/Truck	1042	1379
		Minibus/Omnibus	16670	356
		Tanker/tractor/trailer/tipper	6829	5699
		Van, pick-up	4034	81
	Public/commercial		***94138***	***33430***
		Lorry/Truck	35457	12122
		Minibus/Omnibus	43922	15332
		Tanker/tractor/trailer/tipper	789	1200
		Van, pick-up	13970	4776

Source: Lagos Bureau of Statistics' Motor Vehicle Statistics of 2012

Lagos is known to have very old vehicles still operating, despite not meeting national standards of roadworthiness, some of the minibuses in the city are close to 40 years (Gwilliam, K., 2011). All over Nigeria, the majority of the cars imported into the country from Western countries have exceeded their economic life, even though the country has a regulation which establishes the age of importable vehicles as 8 years for cars, 15 years for trucks and 10 years for buses (World Bank, 2013). World Bank (2013) describes the vehicle fleet in Lagos as "made up of aging and high polluting".

Thus, in addition, the following lifecycle profiles were used in the calculation of energy consumption: 'Existing Car Stocks' for Stock input and 'Car Survival' for Sale input.

Existing Car Stocks is a representation of the age distribution of vehicles. Data was collected from a PricewaterhouseCooper (PwC) 2016 study on 'Africa's Next Automotive Hub'. The study report age distribution of cars in Nigeria as follows: 0- 5 years/11%, 6- 11 years/26%, 12 – 18 years/50%, 19+ years/13%. The data was used in developing a lifecycle profile on Existing Car Stocks on LEAP.

A lifecycle profile of 'Car Survival' was also created. The profile represents the fraction of vehicles still on the road after a set number of years, being 40 years for this study. In the absence of data on the survival function of vehicles in Nigeria or Lagos in particular, the authors used a constant parameter of -0.003 for the study. The figure is based on a European Commission (2016) study on 'Exploration of EU road vehicle fuel consumption and disaggregation', which shows that vehicles of up to 40 years of age, in the EU, have a survival rate of about 2%. For the case of Lagos, Nigeria, considering that the vehicle fleets in Lagos are "made up of aging and high polluting" (World Bank, 2013), we assume that vehicles of up to 40 years of age have a survival rate of at least 9%.

3.2.2 Current account data used in calculations for distance-based pollution emissions

The study focused on three pollutants – Carbon Monoxide (CO), Nitrogen Oxide (NOx), Particulates (PM1). These key pollutants are covered by the European Emissions Standards, which is used by the Nigerian government to regulate vehicle emissions in the country.

Since 2011, Euro 2 standards were adopted in Nigeria and 2015 was set as the date for enforcement of Euro 3 standards in the country (World Bank, 2013). However the 2015 deadline for the enforcement of Euro 3 was not met as the required fuel is not in use in the country[8]. Moreover, it is important to note that, Euro 2 and Euro 3 vehicular emissions standards came into force in Europe in 1996 and 1999/2000 respectively, meaning that Nigeria is about 13 – 15 years behind.

The table below presents the emission factor data used in the study[9].

[8] The EU Directive 98/70/EC states the Motor fuel (petrol and diesel) quality for Euro standard 3. According to the EU Directive vehicles complying with the Euro standard 3 should have Sulphur values not exceeding 150 mg/kg for positive ignition engines (gasoline) and not exceeding 350 mg/kg for compressed ignition engine (diesel). However, according to the African Refiners Association (ARA), Nigeria's Sulphur levels for gasoline and diesel falls within the association fuel specification AFRI-2, with Sulphur content of 3500 mg/kg. See A Review of the Relationship between Sulphur level in Diesel Fuel and African Air Quality at: http://www.afrra.org/en

[9] Emission degradation parameters was generated by LEAP.

Table 4: Acceptable limits of Vehicular Emissions in Nigeria, as at 2011

Vehicle Class	Reference mass (RW) (kg)	Environmental Loading/ passenger cars	Gasoline			Diesel		
I	**RW≤1305**	**Saloon & Motorcycles**	**CO(g/vehicle-km)**	**NOx[10] (g/vehicle-km)**	**PM (g/vehicle-km)**	**CO(g/vehicle-km)**	**NOx(g/vehicle-km)**	**PM(g/vehicle-km)**
		Euro 2 (2011)	2.2			1		0.1
II	**1305<RW ≤1760**	**Van, pickup, minibus**	**CO**	**NOx**		**CO**	**NOx**	**PM**
		Euro 2 (2011)	4			1.25		0.14
III	**1760<RW**	**Trucks Tanker, Tractor, Trailer, Tipper**				**CO**	**NOx**	**PM**
		Euro 2 (2011)				1.5		0.20

Source: Directive 98/69/EC of the European Parliament and of the Council

[10] Euro 2 standards provide limits for HC + NOx. It's only from Euro 3 downwards that EU regulations specifically provide limits for NOx.

3.3 Scenario Building

3.3.1 Business as Usual

In the Business as Usual (BAU) scenario the assumption is that in the absence of any policy instruments, the annual sales of LDV and HDV grow at 5% respectively, until 2032. These growth rates correspond to the rate at which car ownership is reported to grow at, per annum, in Nigeria (LAMATA, 2016). For environmental loading, we assume that Nigeria does not adopt new emission standards. Average fuel economy of vehicles remains unchanged, in the absence of the enforcement of policies on age of vehicles imported and used in the country. Mileage of vehicles is expected to not improve either.

Table 5: Results of BAU, based on car survival rate of -0.003

	2011	**2032**
Stock of Vehicles (Thousand)[11]		
LDV	908	9,667.84
HDV	163.6	1,361.22
Total	1,071.60	11,027.06
Vehicle Mileage (Billion Kilometer)		
LDV	14.50	140.57
HDV	5.81	50.12
Total	21.26	190.69
Fuel use (Million Tonnes of Oil Equivalent)		
LDV	1.01	9.36
HDV	1.42	12.43
Total	2.43	21.79
Vehicular Emissions (Thousand Metric Tonnes)		
Carbon Monoxide (CO)	352.99	956.43
Nitrogen Oxides (NOx)	157.80	315.32
Particulates PM1	3.51	12.58

[11] The figure is a combination of 'Stock' and 'Sales' for 2011.

3.3.2 Policy Scenario

In 2013, the Lagos Metropolitan Area Transport Authority (LAMATA), through a press release, announced that the city is working to reduce GHG emissions from the transport sector by 45 per cent by 2030, through the STMP. At the Ecomobility Seminar in Johannesburg in 2015, LAMATA noted that the implementation of the STMP's6 strategic actions will result in emission reductions exceeding 50% from the 2032 BAU level (LAMATA, 2015).

In this section, we examine under what conditions this target maybe achieved by 2032 i.e. the minimum rates of improvement that must be met. We grouped the 6 strategic actions into their related A-S-I categories, as follows:

A-S-I	STMP 6 Strategic Actions
Avoid	Adopt an integrated transport system; Optimize usage of road networks; Promote integrated land use development
Shift	Diversify the modes of transport used in Lagos; Enhance the attractiveness of public transportation
Improve	Reduce emissions from vehicles

3.3.2.1 <u>'Avoid'or System Efficiency STMPPolicies</u>

The "Avoid" strategy is often viewed from the perspective of improved land use planning. In this policy scenario, the study assumes that LAMATA focuses on strategic actions aimed at reducing the number of trips made and distance travelled through the introduction of integrated land-use planning and transport demand management. In reality, we admit that changing the existing land-use patterns for a city like Lagos may be difficult. However, the study anticipates that improvement in information and communication technology (ICT) will see an increasing number of people working and doing businesses without needing to move around. In line with policy actions under this scenario, the study assumes that from 2020 vehicle mileage begins to shrink, declining at 2% per year for both vehicle technologies and vehicle types with other factors remaining unchanged.

3.3.2.2 *'Shift' or Trip Efficiency STMP Policies*

In this scenario, we assume that LAMATA implements policy actions in its STMP aimed at facilitating a switch to more energy efficient modes of transport including non-motorized transport and public (bus and rail) transport. Specifically, we consider the increase in the number of bus rapid transit (BRT) buses as well as the routes used by the buses. 'Shift' policies such as the promotion of HEVs and BEVs are not considered in this analysis. For this scenario, we assume that the growth rate of vehicles (both LDVs) and HDVs) deviate from the 5% annual growth rate by 2020, to growing at 2% per annum to 2032. Other factors remain unchanged.

3.3.2.3 *'Improve' or Vehicle Efficiency STMP Policies*

The authors assume that Euro 3 and Euro 4 Standards are adopted in Nigeria and strictly enforced in Lagos State by 2020 and 2025 respectively, with a target of achieving a minimum of 13%[12] increase per annum in fuel economy value of both gasoline and diesel LDVs and HDVs in the State. This assumption corresponds with strategic action 4 of the STMP.

Table 6 below presents the data used for this scenario.

3.3.2.4 *A-S-I Combined STMP Policies*

Further to the three main policy options, the authors analyze a scenario that combines all the three A-S-I options.

[12] This is the same improvement rate reported for Mexico through implementation of EURO 4 standards. See ICCT (2015) Policies to Reduce Fuel Consumption, Air Pollution, and Carbon Emissions from Vehicles in G20 Nations.

Table 6: Emission level assumptions for ‘Improve’ STMP Policies

Vehicle Class	Reference mass (RW) (kg)	Environmental Loading/ passenger cars	Gasoline		Diesel		
I	**RW≤1305**	**Saloon & Motorcycles**	**CO(g/vehicle-km)**	**NOx (g/vehicle-km)**	**CO(g/vehicle-km)**	**NOx(g/vehicle-km)**	**PM(g/vehicle-km)**
		Euro 3 (2020)	2.3	0.15	0.64	0.5	0.05
		Euro 4 (2025)	1	0.08	0.5	0.25	0.025
II	**1305<RW ≤1760**	**Van, pickup, minibus**	**CO**	**NOx**	**CO**	**NOx**	**PM**
		Euro 3 (2020)	4.17	0.18	0.80	0.65	0.07
		Euro 4 (2025)	1.81	0.10	0.63	0.33	0.04
III	**1760<RW**	**Trucks Tanker, Tractor, Trailer, Tipper**			**CO**	**NOx**	**PM**
		Euro 3 (2020)			0.95	0.78	0.10
		Euro 4 (2025)			0.74	0.39	0.06

Source: Directive 98/69/EC of the European Parliament and of the Council

4 Results and discussion

4.1 Results

As presented in Table 7, Stock of vehicles only decrease with policy measures to reduce their number; a decrease of 16% can be expected if the government implements policies that directly discourages people from owning vehicles, ensuring that the number of vehicles in Lagos grow at 2% from 2020, instead of the 5% growth rate currently experienced. Policy measures that improve fuel economy and reduce vehicle mileage may not necessarily discourage people from owning vehicles, as shown by the result.

The average annual distance traveled by vehicles in Lagos (i.e. mileage) decrease for all policy measures excluding measures that improve fuel economy. A combination of measures that encourage people to use public transportation and measures that promote integrated land use development may have the highest impact on reducing the distance traveled by vehicles in Lagos, rather than if 'Avoid' or 'Shift' policies are implemented on their own.

As can be expected, policies that improve fuel economy significantly reduce fuel use, second only to policies that combine all A-S-I measures. Also, we expected and found that all A-S-I measures reduce fuel use. And the same for vehicular emissions, where a combination of the sustainable transport policies have the greatest impact on reducing emissions.

Concerning the target of 45% - 50% emission reduction by 2032, it is important to note that none of the A-S-I policy scenarios, independently or combined, achieve this target by 2032 for any of the pollutants. Considering that the policy scenarios used in this study are already based on achieving significant improvement rates by 2020, setting more ambitious improvement rates might prove impractical. We, therefore, examined the root-causes of Lagos emission issues, i.e. the presence of aging and high polluting vehicles, some of up to 40 years of age.

We examined the effect of retiring old vehicles using functions of - 0.006 (i.e. only 1% of 40 years old vehicles are on the road) and -0.02 (i.e. the maximum age of vehicles on the road are about 22 years old, representing just 1%). Table 8 present results of the sensitivity analysis. The results show that Lagos can achieve over 50% emission reduction from the BAU scenario, for each of the pollutants studied, if it cuts down the age of vehicles on the road, setting a maximum of 22 years, and if this is done alongside a combination of A-S-I policies.

Table 7: RESULT OF BAUVS A-S-I BY 2032

	BAU	**Avoid**	**Shift**	**Improve**	**A-S-I**
Stock of Vehicles (Thousand) [13]					
LDV	9667.84	9,667.84	8,163.53	9,667.84	8,163.53
HDV	1,361.22	1,361.22	1,150.44	1,361.22	1,150.44
Total	11,029.06	11,029.06	9,313.97	11,029.06	9,313.97
% reduction		0%	16%	0%	16%
Vehicle Mileage (Billion Kilometer)					
LDV	140.57	125.00	118.73	140.57	106.67
HDV	50.12	44.49	42.35	50.12	38.06
Total	190.69	169.48	161.09	190.69	144.73
% reduction		11%	16%	0%	24%
Fuel use (Million Tonnes of Oil Equivalent)					
LDV	9.36	8.33	7.91	6.45	5.16
HDV	12.43	11.06	10.54	8.63	6.95
Total	21.79	19.38	18.44	15.08	12.12
% reduction		11%	15%	31%	44%
Vehicular Emissions (Thousand Metric Tonnes)					
Carbon Monoxide (CO)	956.43	907.24	888.14	826.19	768.35
% reduction		5%	7%	14%	20%
Nitrogen Oxides (NOx)	315.32	308.91	306.26	298.88	290.95
% decrease		2%	3%	5%	8%
Particulates PM1	12.58	11.74	11.38	8.55	7.94
% reduction		7%	10%	32%	37%

[13] The figure is a combination of 'Stock' and 'Sales' for 2011.

Table 8: Sensitivity Analysis – Vehicular Emissions using a car survival parameter of -0.006 and -0.02

	BAU	Avoid	Shift	Improve	A-S-I
Based on a survivability function of -0.006					
Vehicular Emissions (Thousand Metric Tonnes)					
Carbon Monoxide (CO)	529.41	482.17	463.86	403.09	348.49
% reduction		9%	12%	24%	34%
Nitrogen Oxides (NOx)	101.87	95.72	93.18	85.87	78.41
% reduction		6%	9%	16%	23%
Particulates PM1	8.42	7.61	7.26	4.63	4.05
% reduction		10%	14%	45%	52%
	BAU	**Avoid**	**Shift**	**Improve**	**A-S-I**
Based on a survivability function of -0.02					
Vehicular Emissions (Thousand Metric Tonnes)					
Carbon Monoxide (CO)	273.5	233.19	217.69	162.59	118.92
% reduction		15%	20%	41%	57%
Nitrogen Oxides (NOx)	37.19	31.97	29.84	23.02	17.12
% reduction		14%	20%	38%	54%
Particulates PM1	4.77	4.08	3.78	1.79	1.32
% reduction		14%	21%	62%	72%

4.2 *Discussion of Results*

The poor state of the road transport infrastructure in Lagos is a deterrent to the increased use of public transportation and facilitator for the increased use of private vehicles (Afolabi *et al*., 2017; Agarana *et al*., 2017; Soyinka *et al*., 2016; Osoba, 2017). The increased use of private vehicles in-turn increases road transport energy consumption and GHG emissions. This suggest that strategies to achieve sets targets on road transport GHG emissions has to be designed in a manner that addresses the root causes of the problem. Sustainable Urban Transport Planning should be carefully applied to optimize transport choices and encourage harmonious urban development (i.e. ensuring a close proximity of residential, commercial and recreational centers). (Soyinka *et al*., 2016). The introduction of integrated land-use planning and transport demand management (i.e. 'Avoid' policies) and 'Shift' policies, will support Lagos in transforming its road transport sector into a more sustainable one by leading to a decline in its transport volume, i.e. lead to a decline in the average annual distance traveled by vehicles in Lagos. On fuel economy and Vehicular emission, our findings and recommendations correspond to the same findings and recommendations of the World Bank which there will be greater emissions savings by implementing policies that regulate vehicular emissions in new and imported vehicles based on current Euro standards (World Bank, 2013).

5 Conclusion and Policy Implications

The government of Lagos has made a political declaration to reduce road transport emission to over 50% by 2032. To this end, the Lagos Metropolitan Area Transport Authority (LAMATA) developed a Strategic Transport Master Plan (STMP), having 6 strategic actions that align with sustainable transport policy measures known as "Avoid", "Improve", and "Shift" (A-S-I). If it has one, LAMATA, is yet to make publicly available the study showing what improvement rates are expected, for the key transport indicators, in order to achieve this target by 2032. It is against this background that this study was undertaken to fill this lacuna. By conducting a baseline assessment, using secondary data from government publications and studies done by development institutions like the World Bank, we are now able to determine if the political declaration can be realistically met and, if so, at what conditions. Our result shows that even if the average distance traveled by vehicles in Lagos was to reduce by 2% from 2020 leading to 2032, the growth rate of vehicles were to reduce from the current 5% to 2% from 2020 to 2032 and if through the implementation of Euro 4 standards Lagos achieves a 13% fuel economy improvement rate, the target of achieving 45% – 50% emission reduction would not still be attainable by 2032. Our sensitivity analysis however points to a key policy potential action for Lagos. We find that by reducing the age limit of vehicles on the road, from 40 years to 22 years, Lagos can achieve emission reductions of 57%, 54% and 72% for CO, NOx and PM1 respectively, if done in combination with measures that improve system, trip and vehicle efficiency.

A policy on regulating the use of ageing vehicles in Lagos (and in Nigeria as a whole) needs to be considered by government. Given that a large percentage of vehicles used in Nigeria is imported, regulating the importation of vehicles that are beyond a certain age may also be helpful. Employing technology services in the area of passenger mobility may also be useful in reducing travel behaviors and in-turn, road transport energy consumption and GHG emissions. It is noteworthy that Mobility as a Service (MaaS) and Delivery as a Service (DaaS), referred to as new concepts by Wang and Lin (2019), are already taking root in Lagos as well as other tech-enabled, on-demand transport company such as *Gokada* which provides MaaS and Daas, via motorbike, through a mobile application available on smartphones. Wang and Lin (2019) note that such innovations help in shifting the mindset of owning vehicles. Thus, it can be expected that policies that facilitate technology innovation could have a positive effect on A-S-I measures in Lagos. Finally, the bus rapid transit (BRT) scheme piloted in Lagos needs to be revised and improved to achieve greater impact in reducing the number of passenger vehicles on the roads.

Authors' contributions

MM participated in the writing of the manuscript and data analysis. USA participated in the writing of the manuscript and data analysis. SRI participated in the writing of the manuscript and revision. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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