GREY MODEL ANALYSIS OF VEHICLE POPULATION, ROAD TRANSPORT ENERGY CONSUMPTION AND VEHICULAR EMISSIONS

Nuhu Caleb Amulah[1,*], Ekwe Bassey Ekwe[2], Muhammad Idriss Ishaq[1], Fasiu Ajani Oluwole[1]

[1]Department of Mechanical Engineering, Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria
[2]Energy, Exergy and Environment Research Group (EEERG), Department of Mechanical Engineering, Michael Okpara University of Agriculture Umudike, Umuahia, Nigeria

*E-mail of corresponding author: amulahn@unimaid.edu.ng

Nuhu Caleb Amulah ⬤ 0000-0003-0515-6357

Resume

This study employs the grey models to explore Nigeria's road transport energy consumption, vehicle population and vehicular emissions. The vehicular emissions were evaluated using the European Environment Agency Tier 1 Approach, based on the fuel consumption. A baseline scenario, based on historical data and three other alternative scenarios were developed. The study considered fuel quality, vehicle technology and survival rates as the key drivers of scenario formulation. Results show that vehicle population increases by about 3.58 % annually from 12.9 million units in 2018 to 38.5 million in 2050. Analysis of the alternative pathways reveals that their adoption would significantly reduce road transport energy consumption and air pollutant emissions.

1 Introduction

The transport system forms an integral part of human activity; it necessitates mobility, enhances socio-economic interaction and contributes greatly to economic growth and development [1-2]. Nigeria's transportation sector in 2017 accounts for about 13 % of the total final energy consumption and about 92 % of the total final oil product consumption [3]. Of all the modes of transportation, road transport is the most commonly used in Nigeria [4] and it accounts for about 98 % of the total fossil fuel consumption in the transport sector [3]. The demand for energy in this sector is expected to rapidly increase due to many factors, including but not limited to an increase in population, urbanization and household income and the resulting increase in the number of vehicles and movement of people [5].

The challenges facing Nigeria's road transport system are twofold; on one hand, there is a poor infrastructure; on the other hand, there is a poor state of vehicle technology and fuel quality. Only about 27 % of the federal road network is in good condition, another

30 % is in fair condition and about 40 % is not in a condition fit for use [6]. Similar or worse can be said of the condition of state and local government roads. The infrastructural challenges are due to problems of design specifications and function below the required standards [7], lack of proper maintenance and non-continuity of projects by successive governments [8], as well as lack of equipment and funding for maintenance agencies [9]. The state of the vehicles plying the roads also poses a significant challenge. It is estimated that about 90 % of vehicles imported into the country have already been used somewhere [10] and these vehicles stay on the road for up to 40 years [11]. The fossil fuel and fossil fuel products used in Nigeria's vehicles contain approximately 100 times the sulphur level permissible in Europe [10]. In 2020, the ECOWAS[1] Commission

---

[1]The Economic Community of West African States (ECOWAS) is a 15-member regional organization whose principal purpose is to promote economic integration and shared development among the west African sub-regions. Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo make up its membership.

proposed a vehicle emission policy that seeks to limit fuel sulphur content to 50 ppm for both diesel and petrol[2] and also reduce the age of used vehicles imported to the region to 5 years for light vehicles and 10 years for heavy vehicles [12]. Critics of this policy posit that it will likely pose a significant economic challenge to the populace while having minimal environmental benefits [13-14]. More recently, in the first quarter of 2022, off-the-specification petroleum products were imported by the Nigerian National Petroleum Corporation (NNPC) and were widely distributed across the country[3]. The state of the quality of such fuels makes the implementation of vehicle emission standards very difficult. Despite the efforts by the Ministry of Transport to ban the importation of vehicles that have already been used for over 15 years, efforts to enforce this law are still lacking, mainly due to the porous state of the country's border, smuggling and corruption [10]. The state of the road transport sector makes it one of the key contributors to greenhouse gas (GHG) emissions and the resulting ambient air pollution.

The studies on Nigeria's transport sector cut across energy utilization, GHG emissions as well as vehicle ownership and its determinants. Badmus et al. [4] analyse the consumption of energy in the transportation sector using exergy methods by employing historical data of transport energy consumption from 1980 to 2010. They reported a 17.11 % overall mean energy efficiency and an overall mean exergy efficiency of 15.97 % for the period under study. The results further inferred that the importation of already used vehicles into the country has negatively affected the performance of the road subsector. Maduekwe et al. [11] used the Long-Range Energy Alternative Planning (LEAP) model to determine the best A-S-I (avoid, shift and improve) option for Lagos State by projecting future energy consumption and GHG emissions from vehicles in the road transport sector. They concluded that a 50 % emission reduction by 2032 is achievable if the age limit of vehicles and the growth in vehicle ownership are reduced from 40 years to 22 years and from 5 % to 2 %, respectively. Abam et al. [15] studied the Nigerian transport sector through decomposition and decoupling analysis using historical data from 1988 to 2019. The study, based on the Logarithmic Mean Divisa Index (LMDI) and the Tapio approach, estimated the overall impact of carbon emissions from the transport sector at 44.45 million tonnes of CO_2, which is about a 163 % increase in the overall country's carbon emissions during the period under study. Dioha and Kumar [5] considered five alternative policy pathways for the Nigerian transport

sector based on fuel switching, improved fuel economy, modal shifting, improved logistics and carbon tax for the period 2010-2050 using the TIMES model. The results indicate that, compared to the reference scenario, the alternative pathways would lead to a considerable reduction in CO_2 emissions. Gujba et al.'s [16] study on passenger transportation in Nigeria, using life cycle assessment and economic costs highlights that the more environmentally and economically sustainable option is the promotion of the use of passenger transport (public bus). Although many of such studies reported on the road transport energy consumption, only a few studies discussed the effects of fuel quality and vehicle technology on the environment; and air pollutant emissions are often not considered.

On vehicle ownership, Ukonze et al. [17] mention a gross domestic product, per capita income, fuel price, literacy level and stock of public transport vehicles as the determinants of vehicle ownership in Nigeria. The extent to which these vehicles stay on the road depends on vehicle mileage [18], economy [19], as well as users' travel-behavioural attitudes [20]. Road transportation's impact on the environment can be greatly influenced by factors related to the vehicle population, such as fleet renewal rates, new technology penetration in the vehicle market, age-related emissions degradation and the significance of additional technological measures that apply to both new and used vehicles [21]. There is however, dearth of research in the lifespan distribution and survival rates of vehicles in Nigeria.

There are many techniques and approaches for analysing and projecting energy demand and GHG emissions ranging from the LEAP model [11, 22-23], TIMES model [5, 24], artificial neural network [25-26], as well as econometric approaches [25, 27]. However, most of these approaches require a lot of input. For instance, LEAP requires a lot of demographic and macroeconomic data, which is either not recorded in Nigeria or not publicly available. Of the models used in future projections, one fascinating model is the grey forecasting model, established in 1982 [28], which makes use of partially known information that describes an uncertain system to generate useful information. Since then, many variations of the model have been developed to improve its accuracy. The model has been used to investigate the CO_2 emissions in Asia-Pacific Economic Cooperation (APEC) member countries [29], to forecast route passenger demand in the air transport industry, to project natural gas consumption [30], to forecast municipal waste generation [31], to investigate biofuel production and consumption in top CO_2 emitting countries [32], to forecast electricity consumption [33-34] among many other applications in several fields. The model has found wide applications because of its simplicity, low data requirement and high prediction accuracy [35-36]. The grey system theory posits that a system whose information structure, functions and connections with its environment are partially known

---

[2]All imported fuels to the region must comply with this standard by January 2021, while local refinery production is to meet the standard by 2025.

[3]A lot of vehicles were affected by the distribution of these adulterated products. The article can be found at https://guardian.ng/features/motorists-lose-engines-pay-more-for-repairs-over-dirty-fuel-purchase/ [Last accessed 09 May 2022]

and partially unknown is called grey[4].

A good and well-functioning transport system provides an important framework for a country's growth and development. The growth in energy demand in the transport sector and its associated environmental effects, has prompted the shift towards the improvement of road transport infrastructure and network, as well as vehicle standards and this has been a key point on the policy agenda of many nations. Consequently, the interconnectivity between road transport energy consumption, vehicle population and vehicular emissions is complex and has so many determinants. There is, however, paucity of research that captures this relationship. Therefore, the objective of this study is to explore the development trend in vehicle population and energy demand in Nigeria's road transport, as well as the resulting GHG and air pollutant emissions from the sector. The study considers Nigeria's road transport sector as a "grey system". The grey forecasting model is employed to study the trend in these three dynamic complexities under four different scenarios. The baseline scenario is developed to reflect the country's historical trend in road transport energy consumption and vehicle population; the improved fuel scenario is designed to reflect improvement in fuel quality and vehicle technology according to Euro 3 Standards; the proposed ECOWAS scenario adopts some of the components of the proposed ECOWAS vehicle emissions regulation; and finally, the electric vehicle substitution scenario assumes the gradual substitution of fossil fuel-powered vehicles with electric vehicles in the future.

2 Methodology

In developing the models, both the first-order grey model in one variable (GM(1,1)) [28, 37] and a novel optimised grey model with quadratic polynomials term (BNGM(1,1,k^2)) proposed by [38] were employed. The European Monitoring and Evaluation Programme/European Environment Agency (EMEP/EEA) Tier 1 Approach[5] was used to calculate air pollutant emissions [39].

2.1 Model construction

I GM(1,1) model formation

The GM(1,1) model construction involves conversion of the sequence of raw data into a grey differential equation to create a time response function.

Let the sequence of raw data be denoted as

$$X^{(0)} = (x^{(0)}(i))_{i=1}^{n} = (x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), ..., x^{(0)}(n)), \quad (1)$$

where $X^{(0)}$ represents historical data sequence for energy consumption and vehicle registration.

Let the accumulated generated sequence be denoted as

$$X^{(1)} = (x^{(1)}(i))_{i=1}^{n} = (x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), ..., x^{(1)}(n)), \quad (2)$$

Then, the original form of the GM(1,1) model is given as

$$x^{(0)}(k) + ax^{(1)}(k) = b. \quad (3)$$

If the background value, $Z^{(1)} = (z^{(1)}(i))_{i=2}^{n} = (z^{(1)}(2), z^{(1)}(3), ..., z^{(1)}(n))$ is the sequence generated from the adjacent neighbour means, i.e.,

$$z^{(1)}(k) = \frac{1}{2}(x^{(1)}(k) + x^{(1)}(k-1)), k = 2, 3, ..., n, \quad (4)$$

then the basic form of the GM(1,1) model is given as

$$x^{(0)}(k) + az^{(1)}(k) = b. \quad (5)$$

For a given sequence of raw data, the accumulated sequence and the sequence generated from the adjacent means, if $\hat{a} = (a, b)^{T}$ represents a sequence of parameters such that

$$Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix}, X_N = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix}, \quad (6)$$

using all the notations from Equation (3) and providing that $[a, b]^{T} = (B^{T}B)^{-1}B^{T}X_N$, then

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (7)$$

is called the whitenization or image equation of the GM(1,1) model.

Consequently, the solution of Equation (7) is given as

$$x^{(1)}(t) = \left(x^{(1)}(1) - \frac{b}{a}\right)e^{-at} + \frac{b}{a} \quad (8)$$

and the time response sequence of the GM(1,1) model is given as

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{b}{a}\right)e^{-ak} + \frac{b}{a}, \quad k = 1, 2, ..., n, \quad (9)$$

where $\hat{x}^{(1)}$ is the simulated accumulated value.

---

[4]"Black" is used to denote unknown or no information, and "white" is used to indicate that all the characteristic features of the system are known. "Grey" is between black and white.

[5]The Tier 2 approach (distance driven based) and Tier 3 approach (derived from experimental data) are more accurate, but they cannot be applied to Nigeria because of inconsistent statistical records and lack of data such as vehicle kilometre, mean speed of travel and specific vehicle technology.

The parameters a and b are the development coefficient and the grey action quantity, respectively. The development coefficient reflects the variation in the raw data and is paramount in the development of $\hat{x}$. Since GM(1,1) is a model developed on a single sequence, it uses only the behavioural sequence (referred to as output sequence or background values) of the system without considering any externally acting sequences (or referred to as input sequences, or driving quantities). Therefore, it is generally recommended that variables that affect the system of interest be external or predetermined. Proof of the development of this model can be found in [37, 40].

II BNGM(1,1,k²) model formation

The BNGM(1,1,k²) model, in which the background value is reconstructed based on the Simpson formula, was developed to increase the effectiveness and applications of the grey models. The general modelling procedure for this model is as follows:

The first step is to generate $X^{(1)}$ from $X^{(0)}$ as in Equations (1) and (2). The background value of the model is then calculated according to the Simpson formula

$$z^{(1)}(k) = \int_{k-1}^{k+1} x^{(1)}(t)dt = \frac{1}{6}[x^{(1)}(k-1) + {} + 4x^{(1)} + x^{(1)}(k+1)], \quad k = 2,3,...,n\text{-}1. \tag{10}$$

The development coefficient and the grey quantity parameters are estimated as $[a_1,b_1,c_1,d_1]^T = (B_1^T B_1)^{-1} B_1^T Y_1$, where B_1 and Y_1 are as given in equation (11).

The model's time response sequence is then given by Equation (12). [38] provides proof of the development of this model.

III Error evaluation

The accuracy and effectiveness of the two models are assessed by comparing the values of their mean relative errors. The absolute relative error for each data entry in the sequence is given by Equation (13) and the mean relative error of prediction is given by Equation (14).

2.2 GHG and air pollutant emissions computation

Yearly road transport energy consumption data was entered into the EnergyPLAN simulation software to simulate CO_2 emissions[6] [41]. Air pollutant emissions (CO, NO_x and PM) are considered to be a function of energy consumption and fuel-specific emission factors. The EMEP/EEA Tier 1 Approach is applied to calculate for these emissions using Equation (15). The emission factors are given in Table 1.

$$E_i = \sum_j \left(\sum_m (FC_{j,m} \cdot EF_{i,j,m}) \right), \tag{15}$$

where: E_i = emission of pollutant i [g],
$EC_{j,m}$ = fuel consumption of vehicle category j using fuel m [kg],
$EF_{i,j,m}$ = fuel consumption-specific emission factor of pollutant i for vehicle category j and fuel m [g/kg].

The SO_2 emissions for each fuel type are calculated using the formula

$$E_{SO2,m} = 2 \cdot k_{s,m} \cdot FC_m , \tag{16}$$

where: $E_{SO_2,m}$ = emissions of SO_2 per fuel m [g],
$k_{s,m}$ = weight-related sulphur content in fuel of type m [g/g fuel],
FC_m = fuel consumption of fuel m [g].

2.3 Vehicle survivability

Oguchi and Fuse [42] provide an expression for the vehicle survival rate in Equation (17). However, the expression does not account for used imported vehicles and can only be applied to countries with a negligible number of used vehicle imports. For countries whose car market is highly dominated by the import of used vehicles (such as Nigeria), Held *et al.* [43] proposed a method to correct for the imports in definition of survival rates by Oguchi and Fuse [42], as shown in Equation (18).

[6]The EnergyPLAN assumes a CO_2 content of 74kg/GJ for both petrol and diesel. More on the tool can be found at https://www.energyplan.eu

$$B_1 = \begin{bmatrix} -\dfrac{x^{(1)}(1) + 4x^{(1)}(2) + x^{(1)}(3)}{6} & \dfrac{13}{3} & 2 & 1 \\ -\dfrac{x^{(1)}(2) + 4x^{(1)}(3) + x^{(1)}(4)}{6} & \dfrac{28}{3} & 3 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ -\dfrac{x^{(1)}(n-2) + 4x^{(1)}(n-1) + x^{(1)}(3)}{6} & \dfrac{3n^2 - 6n + 4}{3} & n-1 & 1 \end{bmatrix}, Y_1 = \begin{bmatrix} \dfrac{x^{(0)}(2) + x^{(0)}(3)}{2} \\ \dfrac{x^{(0)}(3) + x^{(0)}(4)}{2} \\ \vdots \\ \dfrac{x^{(0)}(n-1) + x^{(0)}(n)}{2} \end{bmatrix} \tag{11}$$

$$\hat{x}^{(1)}(k) = \left(x^{(0)}(1) \frac{b_1 + c_1 + d_1}{a_1} + \frac{2b_1 + c_1}{a_1^2} + \frac{2b_1}{a_1^2} \right) e^{-a_1(k-1)} + \frac{b_1}{a_1}k^2 + \left(\frac{c_1}{a_1} - \frac{2b_1}{a_1} \right)k + \frac{d_1}{a_1} - \frac{c_1}{a_1^2} + \frac{2b_1}{a_1^3} \tag{12}$$

$$\Delta_k = \frac{x^{(0)} - \hat{x}^{(0)}}{x^{(0)}} \tag{13}$$

$$\Delta = \frac{1}{n} \sum_{k=2}^{n} \Delta_k \tag{14}$$

Table 1 Tier 1 Emission standards for air pollutants, [39]

Vehicle Category	Fuel	CO (g/kg fuel)		NO$_x$ (g/kg fuel)		PM (g/kg fuel)	
		Min.*	Max.ᵃ	Min.*	Max.ᵃ	Min.*	Max.ᵃ
Passenger Car	Petrol	49.0	269.5	4.48	29.89	0.02	0.04
	Diesel	2.05	8.19	11.20	13.88	0.80	2.64
Light Commercial Vehicle	Petrol	68.7	238.3	3.24	25.46	0.02	0.03
	Diesel	6.37	11.71	13.36	18.43	1.10	2.99
Heavy-Duty Vehicle	Diesel	2.20	15.00	28.34	38.29	0.61	1.57

*The minimum value of the emission factor, which corresponds to Euro 3 emission factors, was used for the improved fuel scenario.

ᵃThe maximum values were used for the baseline scenario where the vehicle technology and fuel standards were considered to be uncontrolled.

$$R_t(c) = \frac{N_t(c)}{RP_{t-c}}, \quad (17)$$

$$R_t(c) = \frac{N_t(c)}{RP_{t-c} + Imp_{t-c}^{used} - Exp_{t-c}^{used}}, \quad (18)$$

where c corresponds to the first (initial) registration, RP_{t-c} as the number of new car registrations at time $t - c$, Imp_{t-c}^{used} is the number of imported used cars that are in the stock of the observed country at time t and that have been registered for the first time (abroad) in the year $t - c$ and Exp_{t-c}^{used} is the number of exported used cars that have been registered in the observed country in the year $t - c$ but have been exported until year t.

Equation (18) requires data such as c, Imp_{t-c}^{used} and the number of vehicles in stock with their corresponding age distribution. The data obtained from the Federal Road Safety Corps (FRSC) does not include the age distribution of the registered vehicles. However, pwC Nigeria [44] estimated that about 11 %, 26 %, 50 % and 13 % of vehicles in Nigeria are, respectively, within the age range of 0-5 years, 6-11 years, 12-18 years and 19+ years. Cervigni et al. [45] surveyed vehicle fleet characteristics and reported an average vehicle age of 14 years, 24 years and 16 years for private (passenger) cars, light commercial vehicles and large buses, respectively. Maduekwe et al. [11] also reported that vehicles in Nigeria stay on the road for close to 40 years. Based on these reports and reports on the road traffic accidents [46-47], we regressed vehicle survival rate based on data on vehicle registration from 1993 to 2020 and vehicle stock population from 2018 to 2020 using the exponential function in:

$$SR_{j,y} = b_0 e^{b_1 d}, \quad (19)$$

where $SR_{j,y}$ is the survival rate of a vehicle of category j in stock at the end of year y, b_0, b_1 are the estimated parameters and d is the age of the vehicle in Nigeria at the end of year y.

In using Equation (19), one takes into consideration the fact that the total population of vehicles at the end of year y is the summation of the previously registered vehicles that are still in the fleet, including the registered vehicles in year y. In that way, a survival rate profile was created for each vehicle classification (see Part C of the supporting information (SI)). A passenger car (PC) was estimated to last for about 25 years after its first registration in Nigeria, a light commercial vehicle (LCV) 30 years and a heavy-duty vehicle (HDV) 35 years.

2.4 Data sources

The energy consumption in the road transport sector from 1998 to 2017 was extracted from the IEA Energy Statistics records. Petrol fuel consumption increased from 3193 thousand tonnes of oil equivalent (ktoe) in 1998 to 12823 ktoe in 2017, a 301.6 % increase. Diesel fuel consumption grew by 50.8 % over the same period. The data is in a random vibrating sequence; for instance, diesel fuel consumption was 2198 ktoe in 1998, 519 ktoe in 2015 and 3314 ktoe in 2017. The data were adjusted to reflect data from later years (2016, 2017), which were thought to be more accurate and models were created using this adjusted data.

Table 2 Transposition of the vehicle classification

FRSC Data Classification	EMEP/EEA Classification	% Transposed
Private car	Passenger car	100
Commercial car	Light commercial vehicle	80
	Heavy-duty vehicle	20
Government	Passenger car	50
	Light commercial vehicle	25
	Heavy-duty vehicle	25

Table 3 *PE-S Emission factors*

Vehicle Category	Fuel	CO (g/kg fuel)	NO$_x$ (g/kg fuel)	PM (g/kg fuel)
Passenger Car	Petrol	46.83	4.50	
	Diesel	1.99	11.24	
Light Commercial Vehicle	Petrol	65.66	3.26	0.69
	Diesel	6.19	13.40	0.94
Heavy-Duty Vehicle	Petrol	2.25	28.16	0.59

Vehicle registration data was obtained from the Federal Road Safety Corps (FRSC) [48]. The data is based on number plate production data from 1933 to 2020 and is categorized into private, commercial and government (Federal and state parastatals/agencies/departments, as well as military and paramilitaries) vehicles. The data was transposed to meet the EMEP/EEA [39] vehicle classification as shown in Table 2.

2.5 Developing scenarios

Upon developing the model for prediction of the vehicle registration, energy consumption and the resulting GHG and air pollutant emissions, four scenarios are developed to study the long-term road transport energy demand and its corresponding effect on the environment. The drivers for the scenarios' development are improved fuels and vehicle technology. All projections for the road transport fuel consumption and vehicle population are based on historical data. Although the economic situations, such as changes in household income, as well as the population, could result in a change in vehicle population and the resulting change in energy demand [17, 49], the study assumes that this change would continue as reflected in the historical data.

I   Baseline scenario (B-S)

In this scenario, it is expected that there would be no change in the trend of the road transport energy demand, vehicle technology and quality of fuel. The scenario assumes that there is no regulation on the age of vehicles being imported into the country and that the sulphur content for petrol and diesel is set at 1000 ppm and 3000 ppm, respectively.

II   Improved fuel scenario (IF-S)

The scenario assumes that by the year 2025, there will be an improvement in the fuel quality and vehicle technology, according to Euro 3 standards (see Table 1 for the emission factors used). The sulphur content for diesel and petrol for this scenario is set at 300 ppm and 130 ppm, respectively.

III   Proposed ECOWAS scenario (PE-S)

This scenario adopts some of the components of the proposed ECOWAS vehicle emission regulation. The components of the regulations are:

a)   Imported vehicles (used and new) will conform to EURO 4/IV vehicle emission standards;

b)   improved vehicle technology and fuel efficiency;

c)   fuel sulphur standard of 50 ppm for both diesel and petrol.

The emission factors used for this scenario were corrected to account for improved fuel properties based on Equation (20).

$$EF_{i,k,m,PE-S} = \frac{F_{C,i,k,PE-s}}{F_{C,i,k,base}} \cdot EF_{i,k,m,base} , \qquad (20)$$

where: $EF_{i,k,m,PE-S}$ = fuel consumption-specific emission factor of pollutant i for vehicle category k and fuel m used for PE-S [g/kg],

$F_{C,i,k,PE-s}$ = the PE-S fuel standard correction for pollutant i, vehicle category k, determined from the equations in Table B2 of the SI using improved fuel properties in Table B1 of the SI,

$F_{C,i,k,base}$ = the base fuel correction for pollutant i, determined from the equations in Table B2 using base fuel properties (for IF-S) in Table B1,

$EF_{i,k,m,base}$ = fuel consumption-specific emission factor of pollutant i for vehicle category k and fuel m used for IF-S[g/kg].

The result of the emission factor obtained from Equation (20) is tabulated in Table 3.

IV   Electric vehicle substitution scenario (EVS-S)

This scenario assumes that there is a gradual technological switch to electric vehicles (EVs). Due to the impracticability of phasing out the use of fossil fuel-powered cars in the near future[7], the scenario assumes a geometric increase in electric vehicle acceptability beginning at 40,000 units in 2025 until they make up about 24 % of the total passenger car population over a 25-year period. Fuel sulphur standards for PE-S are adopted in this scenario.

[7]The Nigerian Senate rejected a bill seeking to adopt the use of electric vehicles and phase out fossil fuel-powered vehicles by 2035, citing economic challenges as one of the threats to the bill. More information is available at https://www.vanguardngr.com/2019/04/breaking-senate-rejects-bill-to-phase-out-petrol-cars-adopt-electric-ones/amp/ [Last accessed 11 May 2022].

3   Results and discussion

3.1 Model development and prediction

The development coefficients and the grey action quantity for the two grey models are tabulated in Table A1 of the SI. The GM(1,1) and BNGM(1,1, k^2) simulation results based on historical data are shown in Tables A2-A6 of the SI. Petrol and diesel fuel energy consumption, respectively, have an average simulation error of 3.69 % and 1.65 % for the GM(1,1) model and 2.09 % and 0.67 % for the BNGM(1,1,k^2) model. The BNGM(1,1, k^2) model is thus adopted to predict future energy consumption. Vehicle registration simulation results show an average simulation error of 34.47 %, 19.43 % and 18.51 % for PC, LCV and HDV, respectively. The BNGM(1,1, k^2) model likewise has an error of 39.46 %, 25.31 % and 24.63 %. The GM(1,1) was slightly adjusted to reduce the error and is being adopted to forecast future vehicle registration.

Predictions of petrol and diesel energy consumption and cumulative vehicle population are shown in Figure 1. The demand for petrol increases gradually from 14800.09 ktoe in 2020 to 30097.49 ktoe in 2050 for B-S, IF-S and PE-S, but decreases to 24979.24 ktoe in 2050 for EVS-S. Diesel fuel increases by about 1.80 % annually for B-S, IF-S and PE-S and increases by 1.47 % per year for EVS-S. In the process of projecting the vehicle population, we used the predicted vehicle survival rates and the vehicle registration projection for each year. The vehicle population prediction resulting from the model shows an annual increase of 3.58 % from 12.9 million units in 2018 to 38.5 million in 2050, with PC, LCV and HDV representing about 69.09 %, 24.03 % and 6.88 % of the total population, respectively.
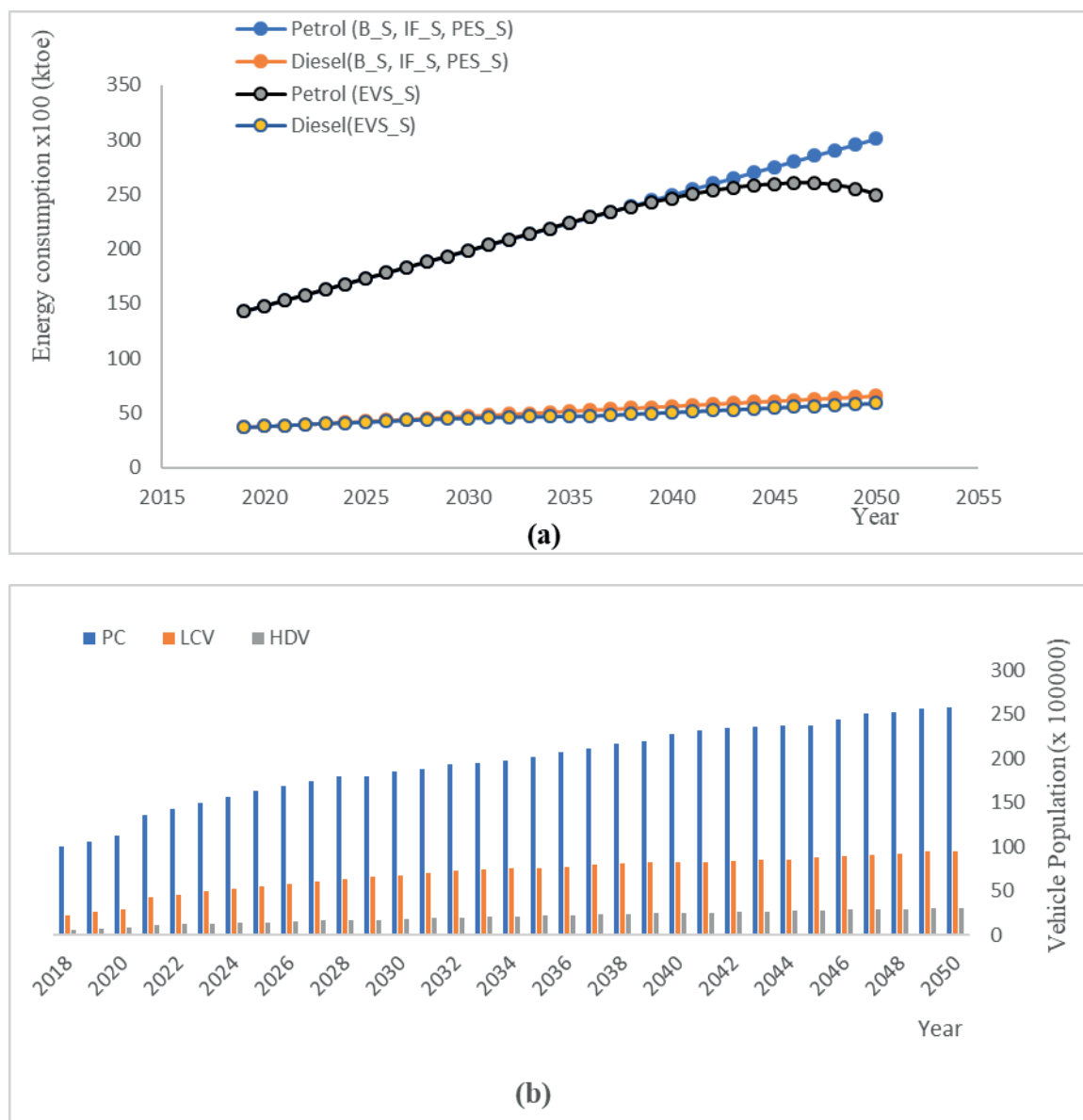
Figure 1 (a) Projection of the road transport energy consumption through 2050. (b) Vehicle population forecast through 2050

3.2 Comparing scenarios

I   Energy consumption and vehicle population

The energy demand in all the scenarios, except for the EVS-S, is the same. It is assessed that introducing electric vehicles to the vehicle fleet will reduce the demand for petrol and diesel in the road transportation. Electric vehicles are expected to replace fossil fuel-powered passenger cars starting from 40, 000 units in 2025 to about 6.3 million in 2050 making about 24.22 % of the total passenger cars. The net reduction in energy consumption, obtained by subtracting EVS-S energy consumption from the energy B-S energy consumption for each year, is shown in Figure 2. By implementing EVS-S, there will be a 10.00 % and 17.00 % decrease in petrol and diesel consumption respectively as compared to other scenarios.

II CO_2 emissions

The CO_2 emission calculation is based on the total fuel consumption and as such, the emissions for all the scenarios are the same, except for the EVS-S, where there is a reduction in fuel consumption due to the introduction of EVs. The CO_2 emissions, ensuing from the implementation of each scenario, are shown in Figure 3. The emissions for EVS-S start to decline in 2025 when EVs are introduced, whereas they increase 2.32 % annually until they reach 113.545 Mtoe in 2050 for the other scenarios.

III   Air pollutants

The air pollutants emissions, covered in this study, include CO, NO_x, SO_2 and PM[8]. Air pollutants emission

[8]The emission of PM in vehicle exhaust usually falls in the size range of $PM_{2.5}$. Therefore, we refer to $PM_{2.5}$ as PM throughout this paper.
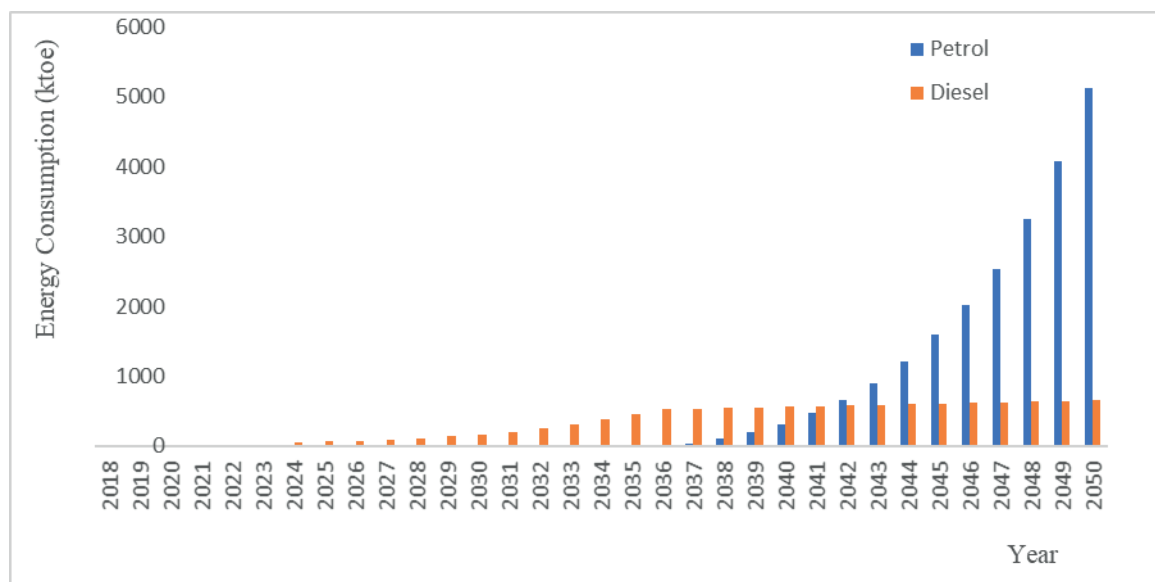

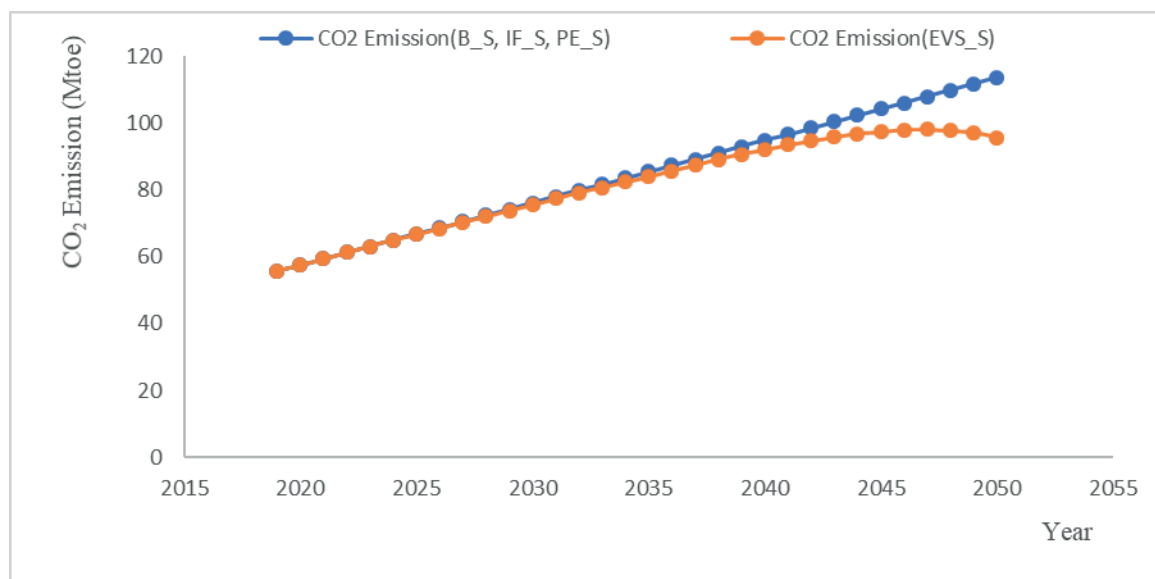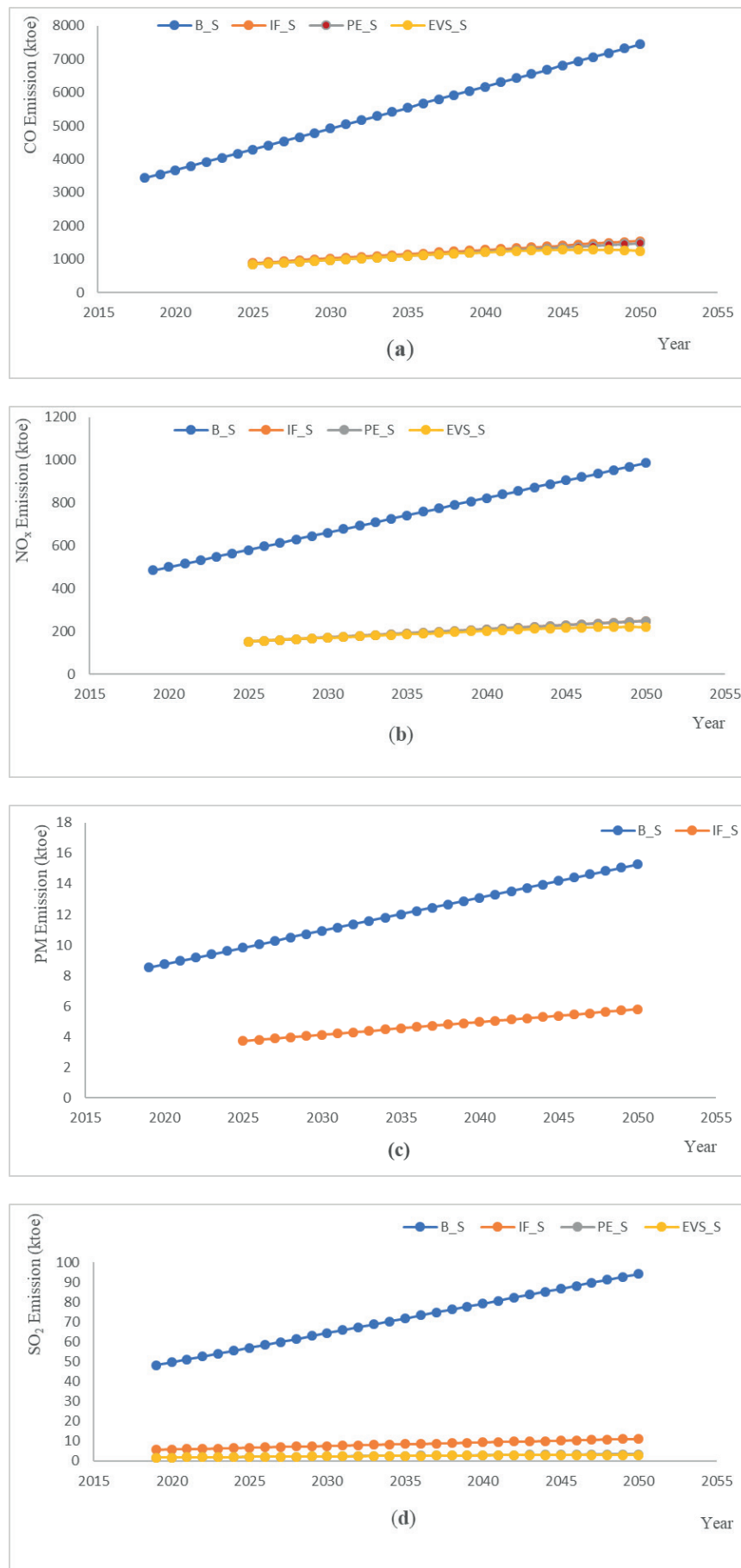*Figure 2* Net reduction in energy consumption by implementing EVS-S

Figure 3 The CO_2 emission projections through 2050

Figure 4 *Scenario projections of air pollutants. (**a**) CO, (**b**) NO$_x$, (**c**) PM and (**d**) SO$_2$*

projections for the scenarios are shown in Figure 4. The rise in air pollutant emissions for the baseline is due to uncontrolled fuel standards and vehicle technology in the country. The key premise of the other scenarios is an improvement in the quality of fuel. This is particularly shown in the striking reduction of air pollutant emissions in the other scenarios as compared to the baseline. While there seem to be commonalities between the three other scenarios, there is, however, a substantial difference between them. The CO emissions for B-S continue to increase from 3434.84 ktoe in 2018 to about 7443.39 ktoe in 2050 (216.70 % increase). It rises from 888.68 ktoe, 849.82 ktoe and 849.70 ktoe in 2025 to 1541.19 ktoe, 1473.70 ktoe and 1248.44 ktoe in 2050 for the IF-S, PE-S and EVS-S, respectively. NO_x emissions increase by 2.32 % per year from 2018 to 2025 for B-S and by 1.97 %, 197 % and 1.50 % for IF-S, PE-S and EVS-S, respectively. Total PM emissions were calculated for B-S and IF-S only. The result is shown in Figure 4(c). The SO_2 emissions in 2050 are 94.24 ktoe, 11.11 ktoe, 3.45 ktoe and 2.90 ktoe, respectively for B-S, IF-S, PE-S and EVS-S. The reduction in the amount of SO_2 emitted, as compared to the baseline, is due to an improvement in the sulphur content of fuels. A comparison of emissions, based on the fuel type, is given in Part D of the SI.

4   Concluding remarks

In this paper, the grey model and the EMEP/EEA Tier 1 approach were used to predict energy consumption, vehicle population and the resultant environmental effects of the road transportation in Nigeria. While there are more accurate approaches to evaluating the road transport emissions, implementation of such approaches requires additional data about vehicular activities. The available statistical data for Nigeria does not allow for the use of such approaches. All the projections were based on historical data. The vehicle population in 2050 is projected at 38.5 million, which is about 94 cars per 1000 people[9], as compared to 60 in 2018 [50]. Energy consumption is expected to increase to about 30097.49 ktoe for petrol and 6550.96 ktoe for diesel for the same year.

The baseline scenario's projected road transport CO_2 emissions in 2050 are 113.545 Mtoe. This compares to the United Kingdom's 2018 value (113.20 Mtoe) [51]. Although Nigeria emits less than 1 % of the global emissions, an increase in economic activity and standard of living beyond the historical trend will result in higher emissions. The baseline scenario assumes that vehicle technology in the country is uncontrolled and older vehicles are imported into the country leading to higher

---

[9]Nigeria's population in 2018 was 198 million and is projected by the United Nations, Department of Economic and Social Affairs, Population Division to reach 411 million in 2050.
.

emission factors. There have been policies to curtail the import of these older vehicles. For instance, in 1993, Nigeria formulated a policy known as the Nigerian National Automotive Act to ensure the growth and development of the automotive industry using locally available materials [52]. In 2014, Nigeria announced the introduction of a new automotive policy, which was geared towards the same aim of discouraging the importation of automobiles and encouraging local manufacturing. The policy was intended to provide subsidies for the production and assembly of automobiles by local assembly plants and raise import duties on fully assembled cars from 10 percent to 35 percent [53]. However, several years later, this policy failed to achieve the desired outcome. Such a commitment towards the policy implementation may constitute a major impediment to adoption and reception of better measures and policies. On another level are the SO_2 emissions of the baseline scenario. Because of the higher level of sulphur in the fuel used in this scenario, the SO_2 emission stands at 94.24 ktoe in 2050, which is about 5.4 times the combined SO_2 emission for 3 other scenarios.

The improved fuel scenario records a CO_2 emission of 113.55 Mtoe and reduced SO_2 emission of 11.11 ktoe, a difference of 87.58 % from the baseline scenario. If the proposed ECOWAS Scenario is implemented by the adoption of EURO 4/IV vehicle emission standards, SO_2 emission will be reduced to 3.45 ktoe in 2050. In addition, if the fossil fuel-powered vehicles are gradually replaced by the EVs, the SO_2 emission would further drop to 2.90 ktoe.

Results from this study provide an insight into the growth pattern of the vehicle population, energy consumption and the resulting emissions. Several policy measures for curbing transportation emissions are country-specific due to differences in technology and transportation infrastructure. However, with the country's current transportation infrastructure, the adoption of the scenarios outlined herein is feasible. For instance, there should be strict adherence to the importation of vehicles (used and new) in conformity with EURO 4/IV vehicle emission standards. A vehicle emission policy to limit the fuel sulphur content to 50 ppm for both diesel and petrol, as well as limiting the age of used vehicles imported into the country to no more than 10 and 15 years, respectively, for the light and heavy-duty vehicles, can as well be adopted. The latter will come with current and improved vehicle technologies and fuel efficiency. An evaluation of these alternative scenarios reveals that there are several benefits to their adoption and subsequent implementation. Since the environmental effects of these emissions are an "all-affected" phenomenon, there is a need for an "all-inclusive" approach to tackle this challenge. The study provides decision-makers with a lens to frame the challenges of road transport and to set robust policies in the long run. The government should

not only stop at formulating policies but go through with their implementations, encouraging community compliance and participation and stakeholders' support.

As noted previously, the study's central hypothesis is that the current and projected patterns in vehicle population and energy consumption are, in proportion, reproducing prior historical trends and that there is not enough information to employ a more precise method of evaluating emissions. There may, however, be fundamental divergences in the future. For instance, higher Tier techniques, particularly Tier 3, should be explored if the precise data like vehicle age distribution, vehicle kilometres and mean travelling speed available per mode and vehicle technology are known.

Supplementary information

The paper includes the following supplementary resources, which may be available online at https://doi.org/10.5281/zenodo.6951467

Supporting information (SI)

Provides additional information to the paper.

Supplementary data

Excel sheets that contain data used for the analysis.

Acknowledgement

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] OTUOZE, S., HUNT, D., JEFFERSON, I. Neural network approach to modelling transport system resilience for major cities: case studies of Lagos and Kano (Nigeria). *Sustainability* [online]. 2021, **13**(3), 1371. eISSN 2071-1050. Available from: https://doi.org/10.3390/su13031371

[2] NWAFOR, M. E., ONYA, O. V. Road transportation service in Nigeria: problems and prospects. *Advance Journal of Economics and Marketing Research* [online]. 2019, **4**(3) p. 104-115. ISSN 2271-6239. Available from: https://aspjournals.org/ajemr/index.php/ajemr/article/view/1

[3] Energy Balance for Nigeria (2017). International Energy Agency (IEA), 2019.

[4] BADMUS, I., OSUNLEKE, A. S., FAGBENLE, R. O., OYEWOLA, M. O. Energy and exergy analyses of the Nigerian transportation sector from 1980 to 2010. *International Journal of Energy and Environmental Engineering* [online]. 2012, **3**(23). ISSN 2008-9163, eISSN 2251-6832. Available from: https://doi.org/10.1186/2251-6832-3-23

[5] DIOHA, M. O., KUMAR, A. Sustainable energy pathways for land transport in Nigeria. *Utilities Policy* [online]. 2020, **64**, 101034. ISSN 0957-1787. Available from: https://doi.org/10.1016/j.jup.2020.101034

[6] An infrastructure action plan for Nigeria: closing the infrastructure gap and accelerating economic transformation - African Development Bank Group [online] [accessed 2022-04-27]. 2013. Available from: https://www.afdb.org/en/documents/document/an-infrastructure-action-plan-for-nigeria-closing-the-infrastructure-gap-and-accelerating-economic-transformation-33031.

[7] EZENWA, A. O. Trends and characteristics of road traffic accidents in Nigeria. *Journal of the Royal Society of Health* [online]. 1986, **106**(1), p. 27-29. ISSN 1757-9139, eISSN 1757-9147. Available from: https://doi.org/10.1177/146642408610600111

[8] ADEPOJU, O. O. Analysis of road transportation infrastructure construction and maintenance for sustainable development in South-Western Nigeria. *Journal of Sustainable Development of Transport and Logistics* [online]. 2021, **6**(1), p. 49-58. ISSN 2520-2979. Available from: https://dx.doi.org/10.14254/jsdtl.2021.6-1.4

[9] OROLEYE, A. K. Appraisal of road transport policy reform in Nigeria: a case of infrastructural deficit. *Journal of Governance and Public Policy* [online]. 2019, **6**(3), p. 216-235. ISSN 2549-7669. Available from: https://doi.org/10.18196/jgpp.63110

[10] MILLER, J. Costs and benefits of soot-free road transport in Nigeria [online] [accessed 2022-04-29]. 2019. Available from: https://theicct.org/publication/costs-and-benefits-of-soot-free-road-transport-in-nigeria/

[11] MADUEKWE, M., AKPAN, U., ISIHAK, S. Road transport energy consumption and vehicular emissions in Lagos, Nigeria: an application of the LEAP model. *Transportation Research Interdisciplinary Perspectives* [online]. 2020, **6**, 100172. ISSN 2590-1982. Available from: http://dx.doi.org/10.1016/j.trip.2020.100172

[12] West African Ministers adopt cleaner fuels and vehicles standards - CCAC [online] [accessed 2022-05-20]. 2020. Available from: https://www.ccacoalition.org/en/news/west-african-ministers-adopt-cleaner-fuels-and-vehicles-standards

[13] OFIKHENUA, J. Vehicle dealers move against ECOWAS vehicle emission standard [online] [accessed 2022-05-23]. 2020 Available from: https://thenationonlineng.net/vehicle-dealers-move-against-ecowas-vehicle-emission-standards/amp/

[14] ALIOGO, U. Examining proposed ECOWAS vehicle emission policy [online] [accessed 2022-05-23]. 2020. Available from: https://www.thisdaylive.com/index.php/2020/12/31/examining-proposed-ecowas-vehicle-emission-policy/

[15] ABAM, F. I., EKWE, B. E., DIEMUODEKE, O. E., OFEM, M. I., OKON, B. B., KADURUMBA, C. H., ARCHIBONG-ESO, A., EFFIOM, S. O., EGBE, J., UKUEJE, W. E. Environmental sustainability of the Nigeria transport sector through decomposition and decoupling analysis with future framework for sustainable transport pathways. *Energy Reports* [online]. 2021, **7**, p. 3238-3248. ISSN 2352-4847. Available from: https://doi.org/10.1016/j.egyr.2021.05.044

[16] GUJBA, H., MULUGETTA, Y., AZAPAGIC, A. Passenger transport in Nigeria: environmental and economic analysis with policy recommendations. *Energy Policy* [online]. 2013, **55**, p. 353-361. ISSN 0301-4215. Available from: http://dx.doi.org/10.1016/j.enpol.2012.12.017

[17] UKONZE, F. I., NWACHUKWU, M. U., MBA, H. C., OKEKE, D. C. JIBURUM, U. Determinants of vehicle ownership in Nigeria. *SAGE Open* [online]. 2020, **10**(2). ISSN 2158-2440, eISSN 2158-2440. Available from: https://doi.org/10.1177/2158244020922970

[18] KOLLI, Z., DUPONT-KIEFFER, A., HIVERT, L. Car survival in a national fleet: a non-parametric approach based on French data. In: 12th World Conference on Transport Research: proceedings [online]. 2010. Available from: https://hal.archives-ouvertes.fr/hal-00614977

[19] HAMILTON, B., MACAULEY, M. Heredity or environment: why is automobile longevity increasing? *Journal of Industrial Economics* [online]. 1999, **47**(3), p. 251-261. ISSN 0022-1821. Available from: http://www.jstor.org/stable/117513

[20] CHOO, S., MOKHTARIAN, P. What type of vehicle do people drive? The role of attitude and lifestyle in influencing vehicle type choice. *Transportation Research Part A* [online]. 2004, **38**(3), p. 201-222. ISSN 0965-8564. Available from: https://doi.org/10.1016/j.tra.2003.10.005

[21] ZACHARIADIS, T., NTZIACHRISTOS, L., SAMARAS, Z. The effect of age and technological change on motor vehicle emissions. *Transportation Research Part D* [online]. 2001, **6**, p. 221-227. ISSN 1361-9209. Available from: https://doi.org/10.1016/S1361-9209(00)00025-0

[22] SHABBIR, R., AHMAD, S. Monitoring urban transport air pollution and energy demand in Rawalpindi and Islamabad using LEAP model. *Energy* [online]. 2010, **35**(5), p. 2323-2332. ISSN 0360-5442. Available from: https://doi.org/10.1016/j.energy.2010.02.025

[23] EMODI, N. V., EMODI, C., MURTHY, G. P., EMODI, A. S. A. Energy policy for low carbon development in Nigeria: a LEAP model application. *Renewable Energy and Sustainable Energy Reviews* [online]. 2017, **68**(1), p. 247-261. ISSN 1364-0321. Available from: https://doi.org/10.1016/j.rser.2016.09.118

[24] VAILLANCOURT, K., LABRIET, M., LOULOU, R., WAUB, J. The Role of nuclear energy in long-term climate scenarios: an analysis with the World-TIMES model. *Energy Policy* [online]. 2008, **36**(7), p. 2296-2307. ISSN 0301-4215. Available from: https://doi.org/10.1016/j.enpol.2008.01.015

[25] LIMANOND, T., JOMNONKWAO, S., SRIKAEW, A. Projection of future transport energy demand in Thailand. *Energy Policy* [online]. 2011, **39**, p. 2754-2763. ISSN 0301-4215. Available from: https://doi.org/10.1016/j.enpol.2011.02.045

[26] MURAT, Y. S., CEYLAN, H. Use of artificial neural networks for transport energy demand modelling. *Energy Policy* [online]. 2006, **34**(7), p. 3165-3172. ISSN 0301-4215. Available from: https://doi.org/10.1016/j.enpol.2005.02.010

[27] POLEMIS, M. L. Empirical assessment of the determinants of road energy demand in Greece. *Energy Economics* [online]. 2006, **28**, p. 385-403. ISSN 0140-9883. Available from: https://doi.org/10.1016/j.eneco.2006.01.007

[28] JU-LONG, D. Control problems of grey systems. *Systems and Control Letters* [online]. 1982, **1**(5), p. 288-294. ISSN 0167-6911. Available from: http://dx.doi.org/10.1016/S0167-6911(82)80025-X

[29] QIAO, Z., MENG, X., WU, L. Forecasting carbon dioxide emissions in APEC member countries by a new cumulative grey model. *Ecological Indicators* [online]. 2021, **125**, 107593. ISSN 1470-160X. Available from: https://doi.org/10.1016/j.ecolind.2021.107593

[30] ZHOU, W., WU, X., DING, S., PAN, J. Application of a novel discrete grey model for forecasting natural gas consumption. *Energy* [online]. 2020, **200**, 117443. ISSN 0360-5442. Available from: https://doi.org/10.1016/j.energy.2020.117443

[31] ANJUM, M., SHAHAB, S., UMAR, M. S. Application of modified grey forecasting model to predict the municipal solid waste generation using MLP and MLE. *International Journal of Mathematical, Engineering and Management Sciences* [online]. 2021 **6**(5), p. 1276-1296. Available from: https://doi.org/10.33889/IJMEMS.2021.6.5.077

[32] JAVED, S. A., ZHU, B., LIU, L. Forecast of biofuel production and consumption in top CO2 emitting countries using a novel grey model. *Journal of Cleaner Production* [online]. 2020, **276**, 123997. ISSN 0959-6526. Available from: https://doi.org/10.1016/j.jclepro.2020.123997

[33] LI, K., ZHANG, T. Forecasting electricity consumption using an improved grey prediction model. *Information* [online]. 2018, **9**(8), 204. Available from: https://doi.org/10.3390/info9080204

[34] DING, S., HIPEL, K. W., DANG, Y. Forecasting China's electricity consumption using a new grey prediction model. *Energy* [online]. 2018, **149**, p. 314-328. ISSN 0360-5442. Available from: https://doi.org/10.1016/j.energy.2018.01.169

[35] LI, S. H., WU, N. A., HUANG, R. Q., XU, Q. A new grey prediction model and its application in landslide displacement prediction. *Applied Soft Computing* [online]. 2020, **95**, 106543. ISSN 1568-4946. Available from: https://doi.org/10.1016/j.asoc.2020.106543

[36] ZHAO, X., LI, H., DING, L., WANG, W., XUE, Y. (2020). Forecasting direct economic losses of marine disasters in China based on a novel combined model. *International Journal of Disaster Risk Reduction* [online]. 2020, **51**, 101921. ISSN 2212-4209. Available from: https://doi.org/10.1016/j.ijdrr.2020.101921

[37] LIU, S., LIN, Y. Grey systems: theory and applications. In: Understanding complex systems. Berlin Heidelberg: Springer-Verlag, 2010. ISBN 978-3-642-16157-5.

[38] LI, S., CHEN, Y., DONG, R. A novel optimized grey model with quadratic polynomials term and its application. *Chaos, Solitons and Fractals: X* [online]. 2022, **8**, 100074. ISSN 2590-0544. Available from: https://doi.org/10.1016/j.csfx.2022.100074

[39] NTZIACHRISTOS, L., SAMARAS, Z. EMEP/EEA air pollutant emission inventory guidebook 2019 [online] [accessed 2022-05-22]. 2021.Available from: https://www.eea.europa.eu/themes/air/air-pollution-sources-1/emep-eea-air-pollutant-emission-inventory-guiedbook/emep

[40] LIU, S., LIN, Y. Grey information: theory and applications. In Advanced information and knowledge processing. JAIN, L., WU, X. (eds.). London: Springer-Verlag, 2006. ISBN 978-185233-995-1.

[41] LUND, H., THELLUFSEN, J. Z., OSTERGAARD, P. A., SORKNAES, P., SKOV, I. R., VAD MATHIESEN, B. EnergyPLAN - advanced analysis of smart energy systems. *Smart Energy* [online]. 2021, **1**, 100007. ISSN 2666-9552. Available from: https://doi.org/10.1016/j.segy.2021.100007

[42] OGUCHI, M., FUSE, M. Regional and longitudinal estimation of product lifespan distribution: a case study for automobiles and a simplified estimation method. *Environmental Science and Technology* [online]. 2015, **49**(3), p. 1738-1743. ISSN 0013-936X, eISSN 1520-5851. Available from: https//doi.org/10.1021/es505245q

[43] HELD, M., ROSAT, N., GEORGES, G., PENGG, H., BOULOUCHOS, K. Lifespans of passenger cars in Europe: empirical modelling of fleet turnover dynamics. *European Transport Research Review* [online]. 2021, **13**, 9. eISSN 1866-8887. Available from: https://doi.org/10.1186/s12544-020-00464-0

[44] Africa's next Automotive Hub - pwC Nigeria [online] [accessed 2022-06-24]. 2016. Available from: https://www.pwc.com/ng/en/publications/africas-next-automotive-hub.html

[45] CERVIGNI, R., ROGERS, J. A., DVORAK, I. (eds.). Assessing low-carbon development in Nigeria: an analysis of four sectors. World Bank study. Washington, DC: World Bank, 2013. ISBN 978-0-8213-9973-6.

[46] AGBONKHESE, O., YISA, G. L., AKANBI, D. O., AKA, E. O., MONDIGHA, E. B. Road traffic accidents in Nigeria: causes and preventive measures. *Civil and Environmental Research* [online]. 2013, **3**(13), p. 90-99. ISSN 2224-5790. Available from: https://www.iiste.org/Journals/index.php/CER/article/view/9369/9590

[47] Road transport data - National Bureau of Statistics [online] [accessed 2022-06-01]. 2022. Available from: https://nigerianstat.gov.ng/elibrary.

[48] Number and categories vehicles in Nigeria using number plates production data from 1993 to 2020. Federal Road Safety Corps (FRSC), Motor Vehicle Administration Department, 2022.

[49] ZAMBANG, M., JIANG, H., WAHAB, L. Determinants of vehicle ownership in Greater Tamale Area, Ghana. *Transport Research Record* [online]. 2020, **2674**(12). ISSN 0361-1981, eISSN 2169-4052. Available from: https://doi.org/10.1177/0361198120947714

[50] Road Transport Data (Q2 2018) - National Bureau of Statistics [online] [accessed 2022-07-04]. 2018. Available from: https://nigerianstat.gov.ng/elibrary/read/813

[51] TISEO, I. Road transportation carbon dioxide emissions worldwide in 2018, by country [online] [accessed 2022-06-18]. 2022. Available from: https://www.statista.com/statistics/1201189/road-transport-sector-co2-emissions-worldwide-by-country/

[52] AGBO, C. O. A. Policy and the quest for a viable automotive industry: a lesson for the developing economies. *Journal of Science and Technology Management Policy* [online]. 2020, **11**(4), p. 583-603. ISSN 2053-4620. Available from: https://www.doi.org/10.1108/JSTPM-07-2019-0073

[53] CHEN, Y. I. Y. S., UKAEJIOFO, R. U., XIAOYANG, T., BRAUTIGAM, D. Learning from China? Manufacturing, investment and technology transfer in Nigeria. Working paper 2. Washington, DC: China Africa Research Initiative, School of Advanced International Studies, Johns Hopkins University, 2016.