Badmus et al. International Journal of Energy and Environmental Engineering 2012, 3:23
http://www.journal-ijeee.com/content/3/1/23

International Journal of
Energy and Environmental Engineering
a SpringerOpen Journal

ORIGINAL RESEARCH Open Access

Energy and exergy analyses of the Nigerian transportation sector from 1980 to 2010

Ismaila Badmus[1*], Ajiboye Saheeb Osunleke[2], Richard Olayiwola Fagbenle[3] and Miracle Olanrewaju Oyewola[3]

Abstract

This paper analyses energy utilisation in the transportation sector of Nigeria using exergy methods. The sector is dominated by the road subsector, with a share ranging from 70.65% in 1990 to 97.51% in the year 2005 and a mean of 88.44%. The road subsector is still the most efficient, with energy efficiency values that range from 9.93% in 1990 to 19.19% in 1986. The corresponding exergy values are 9.28% and 17.93%, respectively. Following the road subsector is the aviation subsector with its least energy consumption share of 0.10% in 2005 and biggest share of 26.25% in 1990. The subsector energy efficiency values range from 0.03% in 2005 to 7.35% in 1990, with corresponding exergy values of 0.026% and 6.87%, respectively. The overall mean energy efficiency in the Nigerian transportation sector for the three decades is 17.11%, while the overall mean exergy efficiency is 15.97%. The road subsector performance has been adversely affected by the massive importation of used vehicles into the country.

Keywords: Energy analysis, Exergy efficiency, Nigerian transportation sector

Background

Nigeria's transport system consists of rail, road, water, and air subsectors. Ninety-six per cent of the total quantity of premium motor spirit (gasoline) consumed and 40% of the automotive gas oil (diesel oil) consumed go to road transportation. Twenty-four per cent of the dual purpose kerosene consumed goes to aviation, and it is the sole fuel. Ten per cent of the fuel oil consumed and 6% of the automotive gas oil consumed go to water transportation [1].

Road transport is the most commonly used mode of transportation in Nigeria today. Road traffic depends on the pattern of human settlements, accounting for more than 90% of the subsector's contribution to the gross domestic product (GDP). Road transport activities involve the en-masse conveyance of passengers or in small numbers, the transportation of animals, farm products and merchandise and the rendering of mobile services (clinics, libraries and banks). The optional use of motor cars for pleasure, which can be distinguished from the three uses listed above, also contributes tremendously to the importance of road transport in Nigeria. This is more predominant in Nigeria than in most other African countries because of the poor state of alternative means of transportation by which journeys could have been made and also due to the psychological satisfaction offered by the possession of a car. According to Obih [2], the Nigerian vehicle fleet size is 2.2 million, gasoline engines represent 60% of vehicle fleet and road transportation is the main transportation mode, accounting for 90% of passenger/freight movements. There are also low turnover rates for replacement of older cars with newer models. Nearly, all vehicles are imported from overseas, often used cars and trucks. Potential savings are achievable using roadworthy vehicles and changing policies. Vehicles tend to have low fuel efficiency. The average fuel efficiency in Nigeria is estimated to be about 18 l of gasoline/100 km [3].

Water transport occupies a distant second position to road transport, with an average share of about 1.6% of Nigeria's gross domestic product. Water transport is slow and, therefore, unsuitable for passenger movement, except for holiday and tourist traffic where time is not a constraint or where other forms of transport are not available. Water transport has the following three components: ocean, coastal water and inland water transports. Inland water transport is only advantageous in terms of costs of moving heavy traffic, especially

* Correspondence: ismail.badmus@gmail.com
[1]Mechanical Engineering Department, Yaba College of Technology, Yaba, Lagos, 6457, Nigeria
Full list of author information is available at the end of the article

Table 1 Lower heating value, chemical exergy and exergy factor for different fuels (at 25 °C and 1 atm)

Fuel	Lower heating value (kJ/kg)	Exergy factor, φ_f	Fuel chemical exergy, ε_f (kJ/kg)
Motor gasoline	44,300	1.07	47,401
Aviation kerosene	44,100	1.07	47,187
Diesel oil	43,000	1.07	46,010
Fuel oil	40,400	1.07	43,228

where speed is less important than cost. Water transport parameters are at present dominated by port statistics, statistics of inland water transport and the operations of ferries in ocean and coastal waters especially in Lagos and Niger delta areas of the country. The Petroleum Products Marketing Company, a subsidiary of the Nigerian government owned Nigerian National Petroleum Corporation, also keeps a fleet of chartered marine vessels which are used to transport products from the refineries to water-fed facilities [4].

Air transport has a unique advantage over all other modes of transport if speed, time and distance are major considerations. Air transport is of high value in relation to weight. It is also preferred where accessibility by other modes is a problem. Its share of the GDP is, however, still negligible in Nigeria [5].

Rail transport is usually the most suitable mode of transportation for heavy traffic flows when speed is also an advantage because of the lower cost per person per load as the train load increases. Nigeria's single-narrow-gauge railway line constructed in the colonial period was, for many years, the only mode of freight movement between the northern and southern parts of the country.

Contribution of rail transport to the gross domestic products of the transport sector is less than a half per cent. Although rail has always contributed a tiny proportion of value added in transportation, its share of value added continues to decline because road transport (freight and passenger) has virtually taken over all the traffic previously conveyed by rail. The relegated status of the Nigerian Railways is a classic illustration of a transportation policy which has sidelined an important

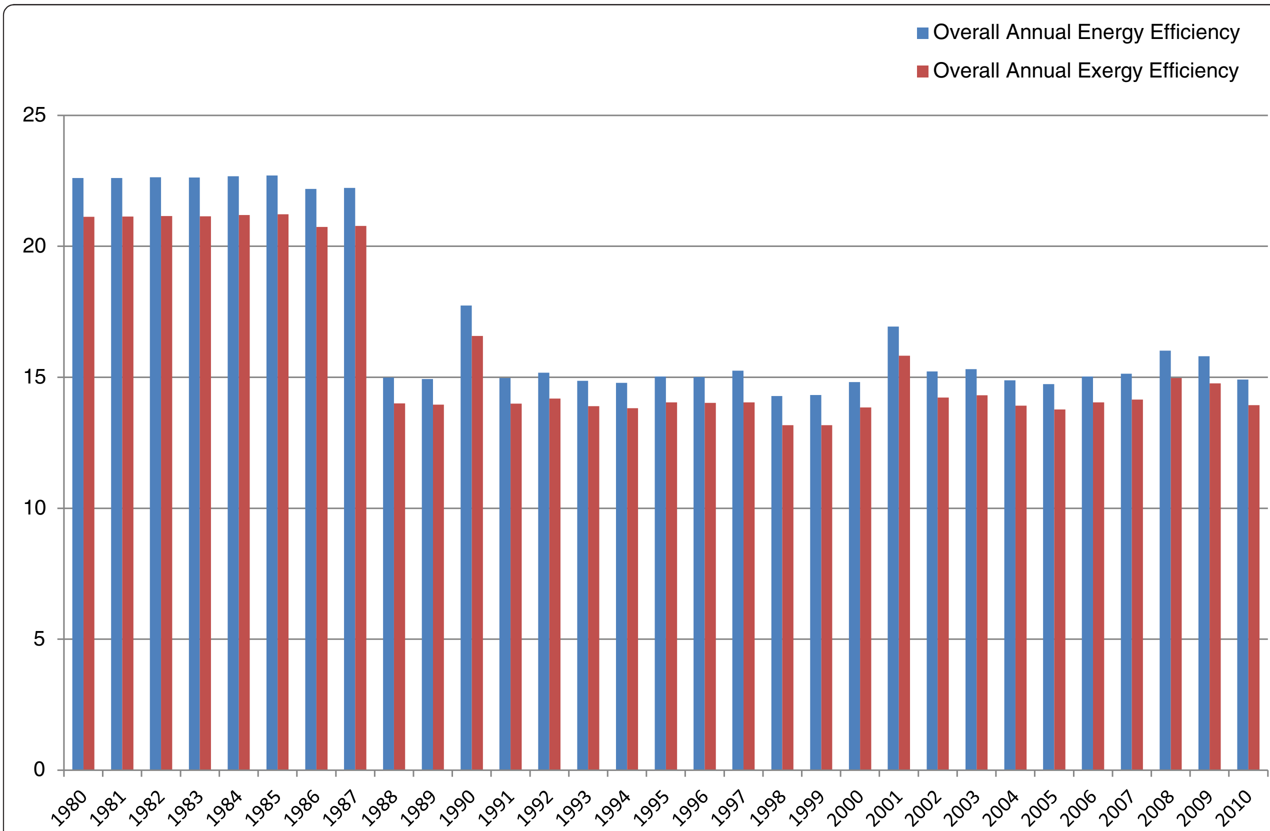

Figure 1 Overall energy and exergy efficiencies of the Nigerian transportation sector (1980 to 2010).

Table 2 Energy consumption values in the Nigerian transportation sector from 1980 to 2010

Year	Land transportation PMS (PJ)	Percentage of TEC	Land transportation AGO (PJ)	Percentage of TEC	Total land transportation (%)	Aviation turbine kerosene (PJ)	Percentage of TEC	Marine transportation FO (PJ)	Percentage of TEC	Marine transportation AGO (PJ)	Percentage of TEC	Total marine transportation (%)	Railway AGO (PJ)	Percentage of TEC	Annual total (PJ)
1980	121.7725	63.24	33.43869	17.37	80.60	29.09347	15.11	3.240969	1.68	5.015804	2.60	4.29	N/A	N/A	192.5615
1981	152.9379	63.93	39.31714	16.44	80.37	36.53939	15.27	4.530618	1.89	5.89757	2.47	4.36	N/A	N/A	239.2226
1982	171.9794	64.63	41.96783	15.77	80.40	41.08871	15.44	4.77431	1.79	6.295174	2.37	4.16	N/A	N/A	266.1054
1983	177.8283	64.61	43.31493	15.74	80.35	42.48611	15.44	5.1045	1.85	6.49724	2.36	4.22	N/A	N/A	275.2311
1984	169.3456	65.19	40.37992	15.54	80.74	40.45947	15.58	3.526152	1.36	6.056989	2.33	3.69	N/A	N/A	259.7682
1985	169.1236	66.22	37.06686	14.51	80.74	40.40643	15.82	3.225455	1.26	5.560029	2.18	3.44	N/A	N/A	255.3824
1986	154.016	72.29	31.8384	14.94	87.23	17.81905	8.36	4.618205	2.17	4.775761	2.24	4.41	N/A	N/A	213.0674
1987	155.5185	72.63	29.60361	13.83	86.45	19.4459	9.08	5.122074	2.39	4.440541	2.07	4.47	N/A	N/A	214.1306
1988	165.428	74.30	32.69032	14.68	88.98	14.26591	6.41	5.371018	2.41	4.903548	2.20	4.61	N/A	N/A	222.6588
1989	187.5791	76.18	34.40722	13.97	90.16	14.86699	6.04	4.209882	1.71	5.161084	2.10	3.81	N/A	N/A	246.2243
1990	185.69	57.87	40.98399	12.77	70.65	84.22042	26.25	3.8117	1.19	6.147598	1.92	3.10	N/A	N/A	320.8537
1991	185.7925	73.50	41.00136	16.22	89.72	16.03079	6.34	3.8117	1.51	6.150204	2.43	3.94	N/A	N/A	252.7866
1992	187.1253	75.83	32.13304	13.02	88.85	19.40576	7.86	3.287308	1.33	4.819956	1.95	3.29	N/A	N/A	246.7714
1993	226.9443	72.15	57.92496	18.42	90.57	17.59855	5.60	3.372632	1.07	8.688743	2.76	3.83	N/A	N/A	314.5292
1994	239.8583	78.83	39.73802	13.06	91.89	15.43368	5.07	3.277086	1.08	5.960703	1.96	3.04	N/A	N/A	304.2678
1995	175.6138	72.42	38.98208	16.08	88.49	16.21381	6.69	5.843981	2.41	5.847312	2.41	4.82	N/A	N/A	242.501
1996	169.48	71.48	38.95989	16.43	87.91	15.32255	6.46	7.501553	3.16	5.843984	2.46	5.63	N/A	N/A	237.108
1997	168.4867	67.00	45.59488	18.13	85.13	18.51314	7.36	10.00649	3.98	6.839232	2.72	6.70	2.021	0.80	251.4614
1998	150.1318	77.07	31.13056	15.98	93.05	1.154097	0.59	6.385382	3.28	4.669583	2.40	5.67	1.333	0.68	194.8045
1999	134.116	78.12	27.371	15.94	94.07	1.430163	0.83	3.273578	1.91	4.10565	2.39	4.30	1.376	0.80	171.6724
2000	190.2686	80.11	38.30822	16.13	96.23	0.434826	0.18	0.959548	0.40	5.746234	2.42	2.82	1.806	0.76	237.5235
2001	250.76	68.41	46.13529	12.59	81.00	59.91069	16.34	0.93609	0.26	6.920293	1.89	2.14	1.892	0.52	366.5544
2002	275.4001	81.56	41.35251	12.25	93.81	12.09123	3.58	1.062656	0.31	6.202876	1.84	2.15	1.548	0.46	337.6574
2003	271.5041	80.02	39.35402	11.60	91.62	14.31883	4.22	6.722852	1.98	5.903103	1.74	3.72	1.505	0.44	339.3079
2004	258.2866	88.05	24.72426	8.43	96.47	3.17961	1.08	2.252768	0.77	3.708639	1.26	2.03	1.204	0.41	293.3559
2005	307.2292	87.55	34.92473	9.95	97.51	0.345229	0.10	2.22513	0.63	5.23871	1.49	2.13	0.946	0.27	350.909
2006	376.2422	90.69	23.36103	5.63	96.32	10.71834	2.58	1.032407	0.25	3.504154	0.84	1.09	N/A	N/A	414.8581
2007	328.5612	92.89	10.77207	3.05	95.93	12.11762	3.43	0.647006	0.18	1.61581	0.46	0.64	N/A	N/A	353.7137
2008	306.4878	82.64	21.89909	5.90	88.54	37.05917	9.99	2.143436	0.58	3.284864	0.89	1.46	N/A	N/A	370.8743
2009	292.4471	87.29	11.15277	3.33	90.62	28.11002	8.39	1.630987	0.49	1.672915	0.50	0.99	N/A	N/A	335.0138
2010	386.5995	91.77	22.98541	5.46	97.23	7.251688	1.72	0.967965	0.23	3.447812	0.82	1.05	N/A	N/A	421.2524

AGO, automotive gas oil; FO, fuel oil; N/A, not applicable; PMS, premium motor spirit; TEC, total energy consumed.

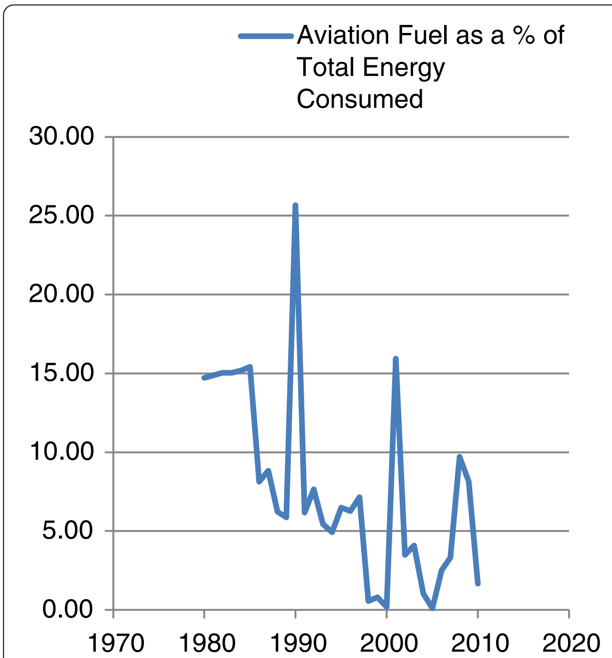

Figure 2 **Trend in annual aviation fuel consumption in the Nigerian transportation sector.**

and cheap means of transport to foster the growth of privately owned long haulage transport services. This policy has engendered the following:

(a) the Nigerian Railway Corporation (NRC) which has become a lame duck with total reliance on the government for subvention and
(b) a disorganised, unregulated private sector-owned road transport system providing freight and passenger services.

The effects of these are as follows:

(a) traffic congestion on urban roads,
(b) increasing rate of fatal road accidents emanating from bad roads, poorly maintained vehicles and careless driving, and
(c) worsening environmental pollution.

The sharp devaluation of the Nigerian local currency has also aggravated the situation as an increasing number of private car owners who would have travelled in their cars now have to join the pool of public transport commuters. The most comprehensive items of data on rail transport are published in the Annual Report issued by the Nigerian Railway Corporation. It contains a detailed account of all the activities of the corporation in the year covered. In one of the tables captioned 'General Statistical Returns', the corporation publishes time-series data of 54 observed and derived variables on the following items: receipts and expenditure, passenger statistics, freight statistics and combined passenger and freight train and engine statistics. Most of these publications have been discontinued in recent years.

Hence, from the foregoing, railway is a very small division of Nigeria's transport subsector. It once had the most comprehensive set of data which described its activities, but unfortunately, the Nigeria Railway Corporation (which is the sole authority in charge of rail transport) is just undergoing resuscitation and general overhaul presently. During the years of operation within the period covered by this work, the corporation only had functional diesel engines.

While countries like Turkey [6-8], China [9,10], Norway [11,12], Saudi Arabia [13] and Malaysia [14] have their transportation sectors analysed from the exergetic point of view in the open literature, there seems to be none analysing that of Nigeria, despite its importance in sub-Saharan Africa. Besides, the country transportation sector typifies a peculiar one, dominated by used and ill-maintained motor vehicles.

Methods

Device efficiencies

Virtually, all authors who have worked on this topic (like [9,14,15]) assume device efficiencies used by Reistad [16] to evaluate energy and exergy utilisation efficiencies. This work differs from theirs for one main reason: the present work is on a developing African country where cars and trucks that have been used elsewhere before being imported into the country and brand new ones compete for dominance. For instance, according to the Nigerian Customs and Excise sources, in 2005, 18,391 new vehicles and 33,134 used vehicles were imported into the country, while in 2006, 31,010 new vehicles of all types were imported as against 43,606 used vehicles of all types [17]. According to Oritse [18], for December 2011, out of the 3,725 vehicles arriving or expected at Lagos ports, about 1,000 were new while the remaining 2,725 are used vehicles. Specifically, more than 85% of motor vehicles being imported into the country annually are used vehicles [19].

In fact, the average vehicle fuel efficiency in the early 90s was 13.07 mpg [2] at a time when the average fuel efficiency in the US was 24.09 mpg for light duty vehicles [20]. In fact, the average new car in 2005 worldwide had a fuel economy level of about 29.4 mpg [21]. Fuel efficiency is low in Nigeria because the vehicle fleet is old and poorly maintained, there is traffic congestion in most urban centres and the driving habits are bad [22]. However, according to Ajayi and Dosunmu [23], there were no records of importation of used vehicles into the country prior to 1988. Hence, from 1980 to 1987, this work will be based on the assumptions of previous

Table 3 Nigerian transportation subsector's energy and exergy efficiencies

Year	Overall highway energy efficiency	Airway energy efficiency	Overall waterway energy efficiency	Railway energy efficiency	Overall highway exergy efficiency	Airway exergy efficiency	Overall waterway exergy efficiency	Railway exergy efficiency
1980	17.73	4.23	0.64	N/A	16.57	3.95	0.60	N/A
1981	17.68	4.28	0.65	N/A	16.52	4.00	0.61	N/A
1982	17.69	4.32	0.62	N/A	16.53	4.04	0.58	N/A
1983	17.68	4.32	0.63	N/A	16.52	4.04	0.59	N/A
1984	17.76	4.36	0.55	N/A	16.60	4.08	0.52	N/A
1985	17.76	4.43	0.52	N/A	16.60	4.14	0.48	N/A
1986	19.19	2.34	0.66	N/A	17.93	2.19	0.62	N/A
1987	19.02	2.54	0.67	N/A	17.78	2.38	0.63	N/A
1988	12.50	1.79	0.69	N/A	11.68	1.68	0.65	N/A
1989	12.67	1.69	0.57	N/A	11.84	1.58	0.53	N/A
1990	9.93	7.35	0.47	N/A	9.28	6.87	0.44	N/A
1991	12.61	1.78	0.59	N/A	11.78	1.66	0.55	N/A
1992	12.48	2.20	0.49	N/A	11.67	2.06	0.46	N/A
1993	12.73	1.57	0.58	N/A	11.89	1.46	0.54	N/A
1994	12.91	1.42	0.46	N/A	12.07	1.33	0.43	N/A
1995	12.43	1.87	0.72	N/A	11.62	1.75	0.68	N/A
1996	12.35	1.81	0.84	N/A	11.54	1.69	0.79	N/A
1997	11.96	2.06	1.00	0.23	11.18	1.93	0.94	0.21
1998	13.07	0.17	0.85	0.19	12.22	0.16	0.80	0.18
1999	13.22	0.23	0.64	0.22	12.35	0.22	0.60	0.21
2000	14.13	0.05	0.42	0.21	13.20	0.05	0.40	0.20
2001	11.89	4.58	0.32	0.14	11.11	4.28	0.30	0.14
2002	13.77	1.00	0.32	0.13	12.87	0.94	0.30	0.12
2003	13.45	1.18	0.56	0.12	12.57	1.10	0.52	0.12
2004	14.16	0.30	0.30	0.11	13.24	0.28	0.28	0.11
2005	14.31	0.03	0.32	0.08	13.38	0.03	0.30	0.07
2006	14.14	0.72	0.16	N/A	13.22	0.68	0.15	N/A
2007	14.08	0.96	0.10	N/A	13.16	0.90	0.09	N/A
2008	13.00	2.80	0.22	N/A	12.15	2.61	0.21	N/A
2009	13.30	2.35	0.15	N/A	12.43	2.20	0.14	N/A
2010	14.27	0.48	0.16	N/A	13.34	0.45	0.15	N/A

N/A, not applicable.

Table 4 Energy and exergy efficiencies of the transportation sector of some countries in the year 2000

Country	Energy efficiency	Exergy efficiency	Reference
Greece	22.69	21.23	Koroneos and Nanaki [26]
Jordan	22.83	22.45	Jaber et al. [15]
Turkey	23.71	23.65	Utlu and Hepbasli [7,8]
Saudi Arabia	22.24	22.24	Dincer et al. [13]
Malaysia	22.78	22.44	Saidur et al. [14]
Nigeria	14.81	13.85	This work

authors for land transportation engine efficiencies (22%), while the thermal efficiencies for subsequent years will be evaluated as in Equation 1:

$$\eta_{\mathrm{th,Nigeria}} = \frac{\eta_{\mathrm{fuel,Nigeria}}}{\eta_{\mathrm{fuel,US}}} \times \eta_{\mathrm{th,US}} \tag{1}$$

For the remaining modes of transportation, we rely on the values used by Reistad [16] as used by several other authors. These are 28%, 15% and 28% for railways, waterways and airways, respectively. Equation 1 yields 14.05% from 1988 up to the end of the 90s and 14.68% for the year 2000 to 2010.

Energy and exergy analyses

The expressions for energy efficiency (η) and exergy efficiency (ψ) for the processes in this paper are as follows:

$$\eta = \frac{\text{Energy in products}}{\text{Total energy input}} \tag{2}$$

$$\psi = \frac{\text{Exergy in products}}{\text{Total exergy input}}. \tag{3}$$

Exergy of a hydrocarbon fuel

The specific exergy of the fuel (ϵ_f) at environmental conditions reduces to chemical exergy, which can be written as follows:

$$\varepsilon_f = \phi_f \text{LHV}. \tag{4}$$

LHV is the lower heating value of the fuel and ϕ_f is the exergy factor of Szargut and Styrylska as enunciated in Szargut et al. [24]. The fuels and the liquid fuel exergy factor used in this work are in Table 1.

All the heating values have been taken from Garg et al. [25]. The exergy factor for liquid fuels has been taken from Table 3.4 of Szargut et al. [24].

Exergy of work

From the definition of exergy, mechanical work, W, is identical to the physical work exergy, E^W. Hence,

$$E^W = W. \tag{5}$$

From Equations 2, 3, 4 and 5, the energy η_m and exergy ψ_m efficiencies for the fossil fuel-driven kinetic energy production process which produces shaft work, W, from fuel mass m_f, can be expressed as follows:

$$\eta_m = \frac{W}{m_f \text{LHV}} \tag{6}$$

$$\psi_m = \frac{E^W}{m_f \phi_f \text{LHV}} = \frac{\eta_m}{\phi_f} \tag{7}$$

The weighted mean overall energy and exergy efficiencies for the transportation sector in each year are calculated following the method explained in Dincer et al. [13].

Results and discussion

The overall consumption efficiencies are generally between 22.19% and 22.71% for energy and between 20.74% and 21.22% for exergy before 1988, when mass importation of used vehicles into the country started. From 1988 to 2010, the efficiencies are generally around 15% and below (Figure 1). This is because the transportation sector has been dominated by land transportation (Table 2). The only exceptions to this general trend are prominently the years 1990 and 2001 with energy and exergy efficiencies 17.74% and 16.58% as well as 16.93% and 15.82%, respectively, and mildly the years 2008 and 2009 with energy and exergy efficiencies 16.02% and 14.97% as well as 15.80% and 14.77%, respectively. These are years with comparatively high annual percentages of aviation energy utilisation (Figure 2). They are also years of comparatively high aviation subsectoral annual efficiencies (Table 3). This positive influence is expected since aviation has a device part load thermal efficiency of 28% compared with that of land, which is 22%. A comparison of the overall sectoral efficiencies of various countries is shown in Table 4 where it is seen that Nigeria has the least values of energy utilisation efficiencies for the year 2000.

Conclusions

The overall mean energy efficiency in the Nigerian transportation sector for the three decades is 17.11%, while the overall mean exergy efficiency is 15.97%. This study also shows that airway transportation contribution should be increased to improve the overall energy and exergy efficiencies of the Nigerian transport sector. It is very necessary in the light of the results of this work that Nigerian policy makers review the issue of mass importation of used vehicles into the country. All efforts should also be made to ease air transportation and make it affordable for Nigerians. The Nigerian railway system should also be resuscitated for cheap and affordable transportation of goods and passengers.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

IB carried out the preliminary studies and data survey and prepared the draft of the manuscript. ASO together with IB did the data analysis. ROF and MOO both provided technical guide and review of the manuscript. All authors read and approved the final manuscript.

Authors' information

IB is a principal lecturer in the Department of Mechanical Engineering, Yaba College of Technology, Yaba, Lagos, Nigeria. He received his B.Sc. (Hons.) and M.Sc. in Mechanical Engineering from the University of Lagos in 1988 and 1996, respectively. He is a corporate member of both the Nigerian Society of Engineers and Nigerian Institution of Mechanical Engineers as well as a registered mechanical engineer of the Council for the Regulation of Engineering in Nigeria. His area of research is energy integration and exergy analysis. He has several publications in peer-reviewed international and local journals.

ASO holds B.Sc. and M.Sc. (Hons.) in Chemical Engineering from the Department of Chemical Engineering, Obafemi Awolowo University (OAU), Ile-Ife, Nigeria. He obtained his Ph.D. degree in Intelligent Adaptive Systems from the Division of Industrial Innovation Sciences, Okayama University, Japan. He is a prominent member of PSE Research group and an academic member of the Faculty of Technology, OAU, Nigeria. His areas of research include process modeling and simulation, linear and nonlinear intelligent adaptive control. He is a member of the Nigerian Society of Chemical Engineers (NSChE) and a registered engineer of the Council for the Regulation of Engineering in Nigeria (COREN) among others. He has published a number of research articles in journals and conference proceedings.

ROF is a retired professor and former head of the Mechanical Engineering Department at the University of Ibadan, Nigeria and is currently a contract

professor of Mechanical Engineering at the Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. Among other schools in which he has taught engineering courses are the University of Illinois (Urbana-Champaign, IL, USA), Iowa State University (Ames, IA, USA), Kwame Nkrumah University of Science and Technology (Kumasi, Ghana), South Bank University (London, UK) and Covenant University (Ota, Ogun State, Nigeria). As lead consultant on the 6.4 kW Solar PV street lighting and Central Administration lighting project of the University of Ibadan in 2008, he designed and supervised the entire project, the first of its type in Nigeria and Africa. He has been and is still involved in several national and international energy sector activities. He has consulted for numerous international agencies, and he was a key member of the consulting team, which developed the Niger State Renewable Energy Policy in 2010. He was also the chair of the Infrastructure Working Group of the National Adaptation Strategy and Plan of Action (NASPA) Project and on the Nigerian Environmental Study Action Team's (NEST) Building Nigeria's Resilience to Climate Change (BNRCC) from 2010 to 2011, and technology transfer lead researcher on the HBF-funded COP-17 Nigeria's National Position Paper (September/November 2011). Prof. ROF has about 50 publications in peer-reviewed international and local journals, and he has supervised many students at both the undergraduate, master's and doctoral levels. He continues to mentor students at the postgraduate level at the University of Ibadan, Obafemi Awolowo University and Covenant University, Nigeria, and has recently supervised students at Johns Hopkins University, MD, USA (2012) and Brandenburg University of Technology, Cottbus, Germany (2011). He is a fellow of both Nigerian Society of Engineers and Solar Energy Society of Nigeria.
MOO obtained B.Sc. (First Class Honours) in Mechanical Engineering from the OAU, Ile-Ife in 1997 and Ph.D. in Mechanical Engineering from the University of Newcastle, NSW, Australia in 2004. He is an editorial board member of several engineering journals. He has been a member of the American Society of Engineers (ASME) since 2003. He has been a reviewer of Experiments in Fluid Journal, since 2005, ASME Heat Transfer/Fluids Engineering Summer Conference, USA, 2004 and Mini-symposium on Energy and Thermal-Fluid Systems of CANCAM Conference, Canada, 2007. He was an invited visiting faculty in the Department of Mechanical Engineering, Howard University, USA, 2010. Currently, Dr. MOO is a reader in the Mechanical Engineering Department, University of Ibadan, Nigeria as well as the acting head of the department. He specialises in energy analyses and thermofluids. He has scores of publications in learned journals and conference proceedings.

Acknowledgements
The authors wish to acknowledge the Corporate Planning and Development Division of the Nigerian National Petroleum Corporation for providing information on the fuel consumption over the years. This work has been partly funded by the Education Trust Fund grant for researchers in Nigerian tertiary institutions.

Author details
[1]Mechanical Engineering Department, Yaba College of Technology, Yaba, Lagos, 6457, Nigeria. [2]Chemical Engineering Department, Obafemi Awolowo University, Ile-Ife, 220005, Nigeria. [3]Mechanical Engineering Department, University of Ibadan, Ibadan, 200284, Nigeria.

Received: 27 June 2012 Accepted: 3 September 2012
Published: 18 September 2012

References

1. Oniwon, A: Oil and gas in Nigeria's national development: an assessment. A presentation at the National Defence College, Abuja (2011)
2. Obih, H: Fuel distribution and logistics. Sub-regional conference on the phase-out of leaded gasoline in Nigeria and neighbouring countries, Abuja, Nigeria (2001)
3. Adegbulugbe, AO: The energy-environment nexus: the role of energy efficiency. In: Energy issues in Nigeria: today and tomorrow. Proceedings of a conference held by the Nigerian National Committee of The World Energy Council at the Nigerian Institute of International Affairs, Victoria Island, Lagos (1991)
4. Adenikinju, AF, Falobi, N: Macroeconomic and distributional consequences of energy supply shocks in Nigeria. AERC Research Paper 162. African Economic Research Consortium, Nairobi (2006)
5. Nigerian Bureau of Statistics (NBS): Transport and Communications. Office of the Director, Abuja, Nigeria (2008)
6. Ediger, VS, Camdali, U: Energy and exergy efficiencies in Turkish transportation sector, 1988–2004. En. Pol. **35**, 1238–1244 (2007)
7. Utlu, Z, Hepbasli, A: Turkey's sectoral energy and exergy analysis between 1999 and 2000. Int. J. En. Res. **28**(13), 1177–1196 (2004). doi:10.1002/er.1023
8. Utlu, Z, Hepbasli, A: Assessment of the energy utilization efficiency in the Turkish transportation sector between 2000 and 2020 using energy and exergy analysis method. En. Pol. **34**, 1611–1618 (2006)
9. Ji, X, Chen, GQ: Exergy analysis of energy utilization in the transportation sector in China. En. Pol. **34**, 1709–1719 (2006)
10. Zhang, M, Li, G, Mu, HL, Ning, YD: Energy and exergy efficiencies in the Chinese transportation sector. 1980–2009. En **36**(2), 770–776 (2011). 10.1016/j.energy.2010.12.044
11. Ertesva°g, IS, Mielnik, M: Exergy analysis of the Norwegian society. En **25**, 957–973 (2000)
12. Ertesva°g, IS: Energy, exergy, and extended-exergy analysis of the Norwegian society 2000. En **30**, 649–675 (2005)
13. Dincer, I, Hussain, MM, Al-Zaharnah, I: Energy and exergy utilization in the transportation sector of Saudi Arabia. Appl. Therm. Engn. **24**, 525–538 (2004)
14. Saidur, R, Sattar, MA, Masjuki, HH, Ahmed, S, Hashim, U: An estimation of the energy and exergy efficiencies for the energy resources consumption in the transportation sector in Malaysia. En. Pol. **35**, 4018–4026 (2007)
15. Jaber, JO, Al-Ghandoor, A, Sawalha, SA: Energy analysis and exergy utilization in the transportation sector of Jordan. En. Pol. **36**(8), 2995–3000 (2008)
16. Reistad, G: Available energy conversion and utilization in the United States. J. Engn. Power. **97**, 429–434 (1975)
17. Ochonma, M: Vehicle importation. BusinessDay., (2012). www.businessdayonline.com (2007). Accessed 1 April
18. Oritse, G: Fuel, vehicles top Nigeria's import for month of December. Sweetcrude Newspaper, (2012). www.sweetcrudereporters.com (2011). Accessed 1 April
19. Agbo, COA: A critical evaluation of motor vehicle manufacturing in Nigeria. Nig. J. Tech. **30**(1), 8–16 (2011)
20. Research and Innovative Technology Administration Bureau of Transportation Statistics (RITA/BTS): Average fuel efficiency of US light duty vehicles. http: www.bts.gov (2011). Accessed 26 February 2012
21. Elzinga, D, Fulton, L, Heinen, S, Wasilik, O: Advantage energy: emerging economies, developing countries and the private-public sector interface. Information paper prepared by the International Energy Agency in support of the United Nations private sector forum 2011. International Energy Agency, Paris, France (2011)
22. Jochem, E: Energy end-use efficiency. In: Jochem, E (ed.) World energy assessment: energy and the challenge of sustainability, pp. 174–217. United Nations Development Programme, New York (2000)
23. Ajayi, AB, Dosunmu, OO: Environmental hazards of importing used vehicles into Nigeria. In: Proceedings of international symposium on environmental pollution control and waste management, pp. 521–532. EPCOWM'2002, Tunis (2002)
24. Szargut, J, Morris, DR, Steward, FR: Exergy analysis of thermal, chemical, and metallurgical processes. Hemisphere Publishing Corporation, Washington DC, USA (1988)
25. Garg, A, Kazunari, K, Pulles, T: Volume 2: energy. In: IPCC guidelines for national greenhouse gas inventories. IGES, Japan (2006)
26. Koroneos, CJ, Nanaki, EA: Energy and exergy utilization assessment of the Greek transport sector. Res. Cons. & Recyc. **52**, 700–706 (2008)

doi:10.1186/2251-6832-3-23
Cite this article as: Badmus *et al.*: **Energy and exergy analyses of the Nigerian transportation sector from 1980 to 2010.** *International Journal of Energy and Environmental Engineering* 2012 **3**:23.