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Research article

Energy consumption analysis of the transportation sector of Senegal

Bertrand Tchanche *

Deptartment of Physics, Universit é Alioune DIOP de Bambey, P.O. Box 30, Bambey, Senegal

*** Correspondence:** bertrand.tchanche@uadb.edu.sn; bf.tchanche@gmail.com; Tel: +22-177-423-6771; Fax: +221-973-3093.

Abstract: Although blessed with abundant energy resources, Africa is still far from providing total energy access to its population. The amount of energy per capita consumed across the continent is very low in comparison to that observed in other continents. Literature survey shows lack of knowledge on energy system's analysis of most countries. This study is aimed at analyzing the energy system of Senegal with focus on energy consumption in the transport sector. The analysis of the energy used in the transport sector in the period 2000–2013 shows an increasing energy demand in road transport, steady energy consumption in the maritime, and a dramatic shift in air transport. The calculated mean weighted energy efficiency of the transport sector is around 14.70%. This low performance is due to poor operating conditions surrounding the transport sector. Senegal is not an oil producing country and massive use of imported fossil fuels for electricity generation and transport raises many issues: energy security, economic vulnerability, health and pollution associated with combustion. Therefore, decarbonizing the transport system, increasing the energy independence and integrating renewable energies are major challenges for the near future.

Keywords: transport sector; energy consumption; developing economy; Africa; transport efficiency

1. Introduction

Africa is well known for its vast energy resources and the paradox of energy poverty. In North Africa, governments have made efforts to reach universal energy access, and electrification rate for instance is above 90% in most countries. In sub-Sahara Africa (SSA), many countries still have electrification rate below 50%: Central Africa Republic, Chad, Democratic Republic of Congo, Ethiopia, South Sudan, etc. [1]. The whole continent consumes very little energy in comparison with other continents, and the consequence is the low living standard observed. Literature on Africa shows a lot of research on renewable energies but little attention is given to other important topics, like resource assessment, energy policy, energy planning and analysis of energy consumption pattern. Analysis of energy systems is of particular interest as it takes into account all forms of energy used, integrates conversion systems and shows how energy is consumed in a country or region. Primary energy supply determines the level of energy security of any territory, and the ideal situation is when a state realizes 100% independence by producing all forms of energy needed in the country. But, this is hardly achieved. The worst scenario is when a country entirely depends on imports which bring the issue of energy security, and economic vulnerability. Final energy consumption analysis allows us to know how energy is utilized and to understand its dynamics in different sectors: residential, transport, industry, agriculture, services, etc. By monitoring an energy system, better understanding is reached and proper energy policy can be designed. It is only recently, after the energy crisis of 2000s that many countries in SSA set offices in charge of energy data collection and analysis. At the continent's level, the African Energy Commission (AFREC) was established in 2008 and first report released in 2012 [2].

Transport is based on energy utilization, whether it is motorized or not. Road transport mainly uses liquid fossil fuels, which are gasoline and diesel [3,4]. In some cases, gas or biogas are used. Hybrid and electrical vehicles are progressively being developed and commercially viable, and it is expected they will become popular. Hydrocarbons sold on the market should fulfil certain criteria, for maximum energy yield, engine protection and emission reduction. In view of reducing the emissions, some developed countries have introduced biofuels such as methanol, ethanol and biodiesel. This also has the advantages of reducing fossil fuels imports and offers an opportunity for recycling perished foods from farms, supermarkets and restaurants. However, there has been a debate about the necessity of the integration of biofuels in the transport sector as this could have serious drawbacks: food security, land competition, water overexploitation, and high food prices especially in developing countries. In aviation, propulsion systems are based on gas turbines which consume jet fuels [5]. In rail transport, high power diesel engines are largely used but this is the subsector of transport where coal, lignite and electricity also play significant role, think about trams, metro and high speed trains [6]. Maritime transport does utilize thermal engines which consume heavy fuels like bunker and fuel oil but some ships/boats do use diesel and gasoline [7]. The trend today is to integrate renewable electricity in the transport system. Some biofuels could serve as substitutes to kerosene. Solar powered boats have been designed and integration of renewable electricity in rail transport is being progressively adopted.

According to U.S. Energy Information Administration (EIA), the share of the transport sector in final energy consumption in the U.S. in 2016 was 29% [8]. In the European Union (EU), a similar figure was found: 31.6% in 2013. Transport sector energy mix whether in U.S., in E.U. or in Africa is dominated by fossil fuels (diesel, gasoline, kerosene, etc.) which are responsible for greenhouse gas emissions and climate change. Main modes of transport are air, rail, road and maritime and road is the dominating mode at the global scale, especially in cities. Reducing the energy consumption on roads has many advantages including air quality improvement, reduction of fuels imports and harmful emissions. Abundant literature on transport energy consumption in urban areas underlines different strategies to decrease energy use in cities: reducing the need to travel and travel length, increasing the efficiency of transport systems and modal shift towards more sustainable transport modes [9,10].

Energy analysis has been applied to the transportation sector for its performance evaluation. Konchou et al. [3], Badmus et al. [4], Dincer at al. [5], Jaber et al. [11], Mitra and Gautam [12], Ediger and Çamdali [6], Koroneos and Nanaki [13], Mohamadi [7], Sattar et al. [14] and Zhang et al. [15] are among authors who evaluated the energy efficiency of transportation sector in Cameroon, Nigeria, Saudi Arabia, Jordan, India, Turkey, Greece, Iran, Malaysia and China, respectively. They assessed the energy consumption of the entire transportation sector, of respective countries for precise time periods and found increasing energy demand and transport energy efficiency below 25%, what shows room for improvement and calls for further research.

Although, transport and mobility are acknowledged as important parts of economic activities in Senegal, requiring fuels and allowing people and goods to flow every day, literature shows that fuels consumption in the transport sector has not been investigated. This study aims at evaluating the energy consumption of the Senegalese transport sector and estimating its energy efficiency.

2. Energy Consumption in Senegal

Senegal is a West African country, with a total land area of 196,722 km^2. It shares borders with Mauritania in the North, Mali in the East, Guinea and Bissau Guinea in the south, and the Atlantic Sea in the West (500 km length of maritime façade). It is located in the Sahel region, between African savanna and Sahara desert. The climate is hot tropical with very little rainfall. It is home to about 15 million inhabitants unequally distributed across the country: densely populated areas are found in the coast while northern and eastern parts of the country are almost empty. The demography rate is close to 2.87% per year. Since 1971, the number of its inhabitants has been multiplied by 3.75, from 4 million up to 15 in 2017. The global population density is about 73 inhabitants per km^2. Senegal is divided into 14 regions and Dakar the capital city with 0.3% of total land area hosts 23% of the population (Table 1) [16]. The country is experiencing a high urbanization rate, which brings a number of challenges: energy access, insufficient supply of potable water, insufficient number of accommodation, access to adequate healthcare system, poverty, unemployment, and of course transport and mobility issues.

According to the Ministry of Energy and Renewable Energies Development [17], primary energy supply for the year 2013 reached 155.50 PJ. Fossil fuels represented 52% and renewables 47% (mainly biomass). The energy independency is defined as the fraction of national energy production. The independency rate in Senegal was 49% in 2013, but falls below 3% without biomass. This shows the importance of bioenergy, and any strategy in the energy sector should take this fact into account. Biomass is massively used in the residential sector, while industrial and transport sectors heavily depend on imported fuels. The electricity generation and the transport sector rely entirely on hydrocarbons. Some 1,687,316 tonnes of hydrocarbons were imported in 2013, for US$ 1.28 billion and represents 25% of total imports of the country. Total final energy consumption was about 107.16 PJ and dominated by fossil fuels and biomass (Figure 1). Final energy consumption is distributed as follows: 48% for residential, 30% for transport, 16% for the industry and 6% for other uses (Figure 2). The residential sector represents half of the total energy used in the country, 51.25 PJ (47.8%). Traditional biomass has the lion's share, 84% followed by fossil fuels 9% and electricity 7%.

Table 1. Administrative regions, land and demography distribution.

Regions	Land area		Demography (2015 data)		
	km^2	(%)	inhabitants	(%)	Density (inh./km^2)
Dakar	546	0.28	3,330,692	23.20	6100
Diourbel	4862	2.47	1,591,593	11.09	327
Fatick	7049	3.58	761,710	5.31	108
Kolda	13,721	6.97	703,774	4.90	51
Kaolack	5265	2.68	1,021,656	7.12	194
Louga	25,644	13.04	9,24,050	6.44	36
Matam	28,852	14.67	607,229	4.23	21
Saint Louis	18,981	9.65	957,602	6.67	50
Tambacounda	42,638	21.67	730,473	5.09	17
Thiès	6597	3.35	1,889,323	13.16	286
Ziguinchor	7355	3.74	583,528	4.06	79
Kaffrine	11,041	5.61	609,638	4.25	55
Sedhiou	7346	3.73	483,768	3.37	66
Kedougou	16,825	8.55	161,832	1.13	10
Total	196,722	100	14,356,868	100	73

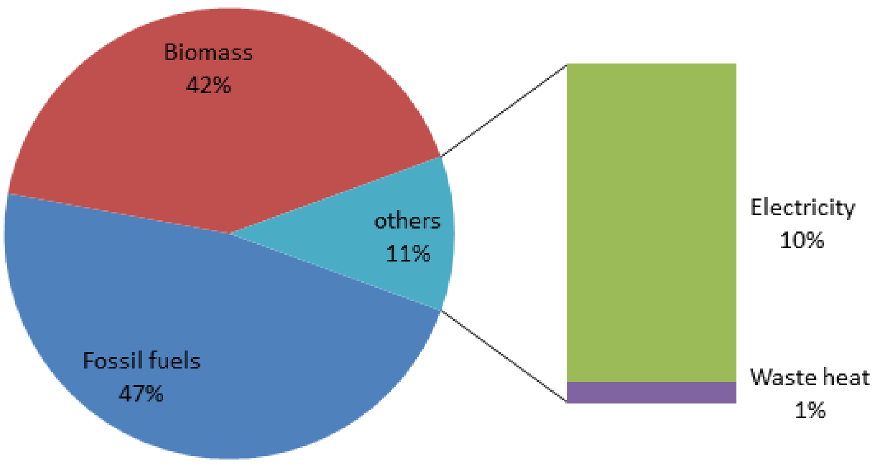

Figure 1. Final energy consumption distribution by energy type (2013).

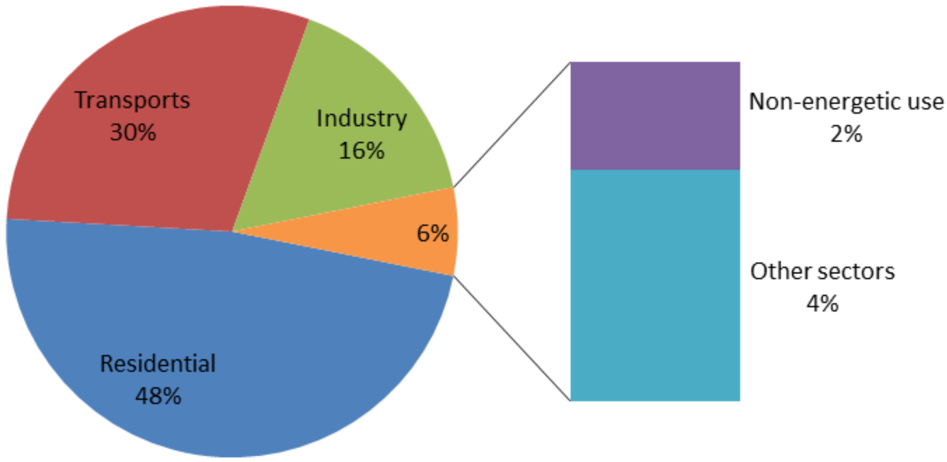

Figure 2. Final energy consumption distribution by sector (2013).

3. An Overview of the Transportion Sector of Senegal

Transport sector is an important part of the economy and provides mobility for people and goods. It includes air transport (cargo, passengers, freight), maritime (boats, ferries, tankers, cargo ships, etc.), rail transport (train, tramway) and road (walking, horse carriage, motorcycle, cars, buses, etc.) [18].

3.1. Road transport

Transport sector is dominated by the road sub-sector, and can be classed into motorized and non-motorized transportation. Non-motorized includes walking, cycling and animal driven systems such as horse/donkey carriage. Senegal is a developing country where the majority of people walk, in urban as well as in rural areas. Justifications for walking in rural and usually isolated areas are lack of infrastructure and poverty, which forces people to carry goods and other agricultural products on their heads, shoulders and back over long distances. In urban areas, poverty is the main driver for the adoption of walking [19,20]. In the largest city Dakar, people walk to reach different services: hospitals, schools, restaurants, marketplaces, etc. Despite the existing infrastructure, more than half of its dwellers walk long distances to reach their destination. Bikes are not very popular, and only a minority of youth use this means. Animal driven transport is very popular. It has many advantages: flexibility, oil-free, zero emission, built locally and cheap. A trip costs around US$ 0.10–0.20. It is used to carry out people and goods over long distances and provide income for owners. Motorcycles recently became an important part of public transport, due to their low cost; they are imported mostly from Asia. As in most African developing countries with high rate of unemployment, especially among youth, motorcycle taxi is seen as a way to keep them active [21,22]. Among motor-taxi drivers are some students and university graduates who after graduation could find no other employment. Despite many difficulties found such as frequent accidents, exposure to air pollution, lack of training, disorganization, and harassment from policemen, motorcycle taxi remains attractive.

Roads in Senegal are classed in five categories: national roads (link regions), regional roads (link divisions), divisional roads (link municipalities), tracks (link agricultural areas to urban zones), and urban roads (link different areas within the city). In 2007, total length of road network was estimated at 14,806 km, of which only 4805.4 km were paved (32.45%) [23]. 87% of national roads on a total of 3352 km were paved against 2.2% of total tracks (4198 km). In 2013, the national car fleet [24], was estimated at about 402,312 vehicles, and should be close to 500,000 in 2017. Geographical distribution (Figure 3) shows that 73% of vehicles are concentrated in Dakar region, 8% in Thiès, 5% in Diourbel, 3% in Kaolack and Louga.

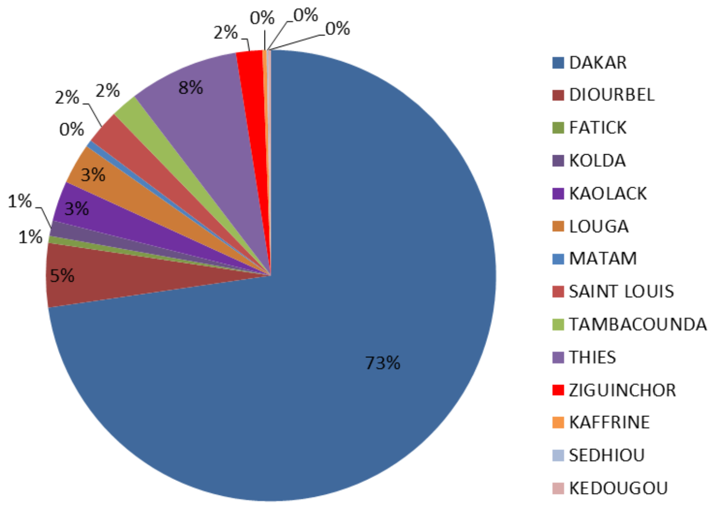

Figure 3. Geographical car fleet distribution (2013).

According to ANSD [24], most vehicles in the country are second hand imported vehicles and just 27.3% were bought new. Automotive sales have become an important activity, fueled by Senegalese diaspora established in Europe and America. Record shows brands present are Toyota, Renault, BMW, Peugeot, Hyundai, Volkswagen, Citroen, Ford, Mazda, Mercedes and Opel. There is no automotive manufacturing industry recorded in the country, and only one assembly line is reported, that of Senbus Industries established after an agreement with the Indian manufacturer Tata motors. Cars and spare parts imports were estimated at about US$ 400 million. The number of vehicles in a country is linked to the purchasing power of dwellers as shown by Figure 4 [25]. In developed countries, such as Canada, Greece, UK, Spain and Italy the per capita income is above US$ 15,000 and car ownership is above 400 vehicles per 1000 persons. In Senegal, per capita GDP (Gross Domestic Product) didn't grow significantly in the period 2000–2013, and was about US$ 2150 in 2013, that is 7 times lower than that of countries like Portugal and Greece. The number of road vehicles per inhabitants is low, and didn't vary that much past ten years. From 2005 where it was 26 it reached 30 vehicles per 1000 inhabitants in 2014 (Figure 5). These low figures can be explained by low development level of the country and low GDP.

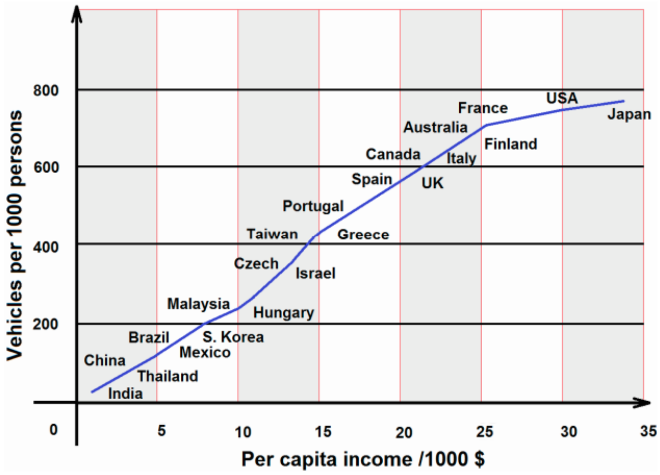

Figure 4. Correlation between the per capita income and the personal vehicles owned [25].

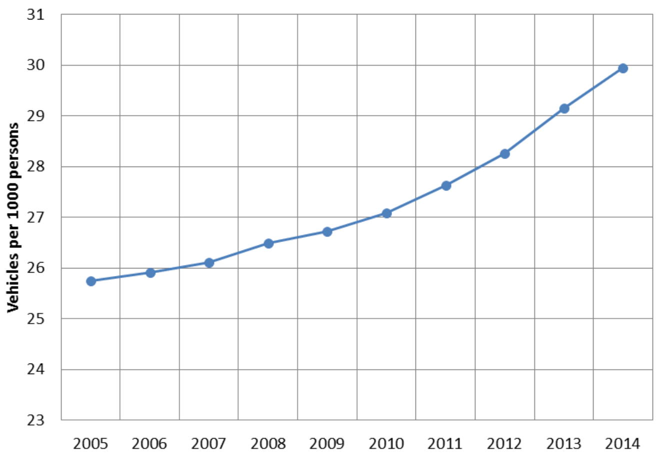

Figure 5. Number of vehicles per 1000 inhabitants, source: adapted from [26] and [16].

3.2. Air transport

Senegal has a dozen airports of which the main ones are L. Sedar Senghor of Dakar (LSSD), Saint Louis, Cap Skiring, Ziguinchor and Tambacounda. Dakar international airport represents more than 90% of air traffic with more than 2 million passengers and therefore plays and important role in the economy of the country [27]. Secondary airports with minor roles are [28]: Kaolack, Kédougou, Simenti, Richard Toll, Podor, Matam, Bakel, Linguere and Kolda. Amongst the large number of foreign airlines landing in Senegal are Kenya Airways, Tap, Air France, Corsair, Brussels Airlines, Air Algérie and South African Airways. Commercial planes identified are from ATR, Boeing and Airbus. The country does not have a national company after the close down of Air Afrique, Air Senegal International in 2009 and Senegal Airlines in 2016. A new company has been announced but is still awaited. In view of modernizing its infrastructure, the country is investing in the construction of a new airport: the AIBD (Blaise Diagne International Airport) located some 36 km from Dakar.

Table 2. Data for main Senegalese airports for the year 2015 [27].

Airports	Runway length (ft)	Aircraft movements		Passengers	
			(%)		(%)
Dakar	11,450	42,290	90.68	2,234,331	96.76
Saint Louis	6372	811	1.74	3202	0.14
Cap Skiring	4757	825	1.77	28,000	1.21
Ziguinchor	4413	2492	5.34	42,538	1.84
Tambacounda	6562	218	0.47	1102	0.05
Total		46,636	100	2,309,173	100

3.3. Rail transport

Rail was introduced into the country during the colonial period, but after independence in 1963, the activities in this subsector were dramatically reduced. At the beginning of the colonial period (1850s till 1960s), maritime transport on rivers was most used to travel from coastal areas to inner parts of the country. Rail became important when resources were to be transferred from West Africa to Europe (France). The railway was the most developed transport system till the independence of the country and the first line Dakar to Saint Louis was inaugurated in 1885. It was part of the strategy designed by France to connect several countries, including Mauritania, Niger, Mali and Senegal and for the transportation of goods and passengers, in what was called AOF (Afrique Occidentale Française). After the independence of Senegal in 1963, the first free government of late Leopod Sedar Senghor decided to change this strategy and to focus on national transport, and gave more emphasis on roads. And since that period rail progressively took less and less importance in the national transport policy, and received little attention. Now, two companies operate in the rail sub-sector, Transrail SA and Petit train de banlieue (PTB). Transrail operates on the main international line Dakar-Bamako and PTB assures the traffic between Dakar and its suburbs. The network is made up of 906 km distributed as follows [24]: 70 km two ways between Dakar and Thiès, 574 international line between Thiès and Kidira, 193 km between Thiès and Saint Louis and three short lines: Guinguinéo-Kaolack, Thiès-Taiba, and Diourbel-Touba. The international line Dakar-Bamako is close to 1287 km. The traffic as far as rail is concerned was dramatically reduced [24]. On the international line the traffic of goods was estimated by the National Statistics Bureau (ANSD) at 181,030 tonnes in 2013 lower compared to more than 250,000 tones in the period 2007–2011. PTB is experiencing a shift in the traffic of passengers also, from its level of 5,000,000 passengers in 2009, since 2011 it went down to half (2,380,664 in 2013).

3.4. Maritime transport

Senegal has four sea ports: Dakar (Port Autonome de Dakar, PAD), Saint Louis, Kaolack and Ziguinchor. Maritime transport is crucial for trading, and represents 95% of trade [24]. Traffic at the PAD amounted to 12.2 million tons of which 77.8% represented imported goods. The Ziguinchor sea port is the second port after Dakar. The main way of bridging Dakar, the capital city and the Casamance region is by sea, and the number of passengers in 2013 was 90,504, and total volume flow of goods 63,362 tonnes (only 12.22% exports). Kaolack sea port is dedicated to oil, oilcake and salt exports.

4. Energy Consumption and Efficiency Evaluation

4.1. Data and methods

Data related to transport and energy sectors were collected from various sources, Ministry of Energy and Renewable Energies Development of Senegal (MEDER), National Agency for Statistics and Demography (ANSD) and Ministry of Infrastructure and Land Transports for the period 2000–2013 [17,29–32]. Data obtained from MEDER were related to the energy sector for the period 2000–2013. These were collected by the Energy Statistics Bureau (SIE) which was set in 2000s with mission of monitoring the energy system of the country. ANSD provides statistical data for various sectors (education, health, water, transport, economy, etc.) available on its website and publishes annual reports. Personal contact was established with some employees at the Ministry of Infrastructure who were very kind of providing us with few reports and data sheets.

In the transportation sector, some efficiency indicators could be used such as [10]: passenger transport energy use [kWh/person], private individual mobility [passenger-km/capita], and energy use per transport vehicle-kilometer [kWh/passenger-km]. However, the evaluation of these indicators requires a large set of reliable data, usually scarce in developing countries. Moreover, most of these indicators do not take into account the type of energy consumed nor the quality of the transport system (impact of the infrastructure, transport system regulation, etc.). A new approach appeared recently in the literature and will be used in this study. It consists of determining the mean weighted energy efficiency of the transport sector by summing up the energy efficiency of different modes. The energy efficiency is the ratio of the energy contained in the useful products of a process to the energy contained in all input streams and is defined as

$$\eta = \frac{Energy\ in\ products}{Total\ energy\ inputs} \tag{1}$$

The mean weighted energy efficiency of the transportation sector is calculated on the basis of fuel's energy efficiency conversion [4,6,14]:

$$\eta_{tee} = \sum_i \eta_{f,i} . p_i \tag{2}$$

With p_i the fraction of fuel energy consumed by a specific type of engine with thermal efficiency, $\eta_{f,i}$.

$$p_i = \frac{E_{f,i}}{\sum_k E_{f,k}} \tag{3}$$

In transportation sector, work production processes using electricity and fossil fuel are taken to produce shaft work (W). The energy conversion efficiency for a specific type of fuel can be calculated from equation 4.

$$\eta_f = W/E_f \tag{4}$$

If m_f is the mass of a fuel, then the chemical energy it contains is given by the following relationship:

$$E_f = m_f . LHV \tag{5}$$

LHV is the energy content of a fuel also known as its lower heating value. Tables 3 and 4 give LHV and part load efficiencies for few fuels [6,33].

Table 3. LHV for few fuels (15 ℃, 1 atm).

Fuels	LHV (MJ/kg)	Fuels	LHV (MJ/kg)
Refinery gas	52.00	Coal	24.23
LPG	46.00	Coke	29.30
Gasoline	43.80	Waste	10.50
Fuel oil	42.70	Wood chips	9.30
Diesel	42.70	Wood pellets	17.50
Heavy fuel oil	40.65	Straw	14.90
Petroleum coke	31.40	Biogas	19.83
Natural gas	48.03	Bio oil	36.69

Table 4. Energy conversion efficiency for different modes of transport.

Modes	Fuels	Part load efficiency (%)
Railways	Electricity	28
	Hard coal	28
	Lignite	28
	Oil	28
Seaways	Oil	15
Airways	Air fuel	28
Highways	Gasoline and diesel	22
	Natural gas	22
Pipeline transport	Pipes	29

4.2. Results and discussion

4.2.1. Energy consumption distribution

Strong link between transport activities, economy and energy consumption is evident. Developed transport infrastructures, high household income, high level of mobility and fluidity, and competitiveness of the country are key drivers for energy consumption. Road sector alone, as shown on Figure 6 consumed 95% of total energy of the sector and the remainder for other modes. This shows how road is the dominant motorized mode of transport in Senegal. Navigation is very limited, and rail has been declining since independence in 1963. Motorized vehicles are of diesel and gasoline engines. Car fleet is dominated by diesel engines (59% in 2010) which consumed in 2013, 81% of energy and gasoline19% [17].

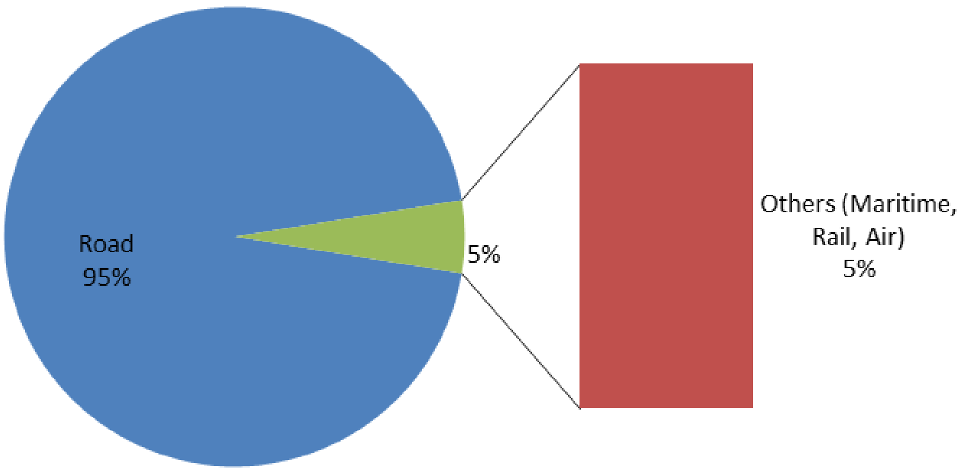

Figure 6. Distribution of energy consumption in the transport sector (2013).

4.2.2. Energy consumption dynamics

Air transport played a significant role as Figure 7 shows in the period 2000–2006, contrary to what is seen since 2008. Air transport has always been a difficult business in SSA. In 1961 former French colonies (11 countries including Senegal) set a panafrican company that was known as Air Afrique. By 2002, this company was no longer competitive and was forced to close down. While being part of Air Afrique, Senegal had its own company, Air Senegal, founded in 1971. Early in 2000, the company went bankrupt. Senegalese government then negotiated with Royal Air Maroc to create a new company. The new company called Air Senegal International (ASI) started operating in 2001. Mismanagement, financial deficits and frequent disagreements among partners didn't allow the company to prosper, and a progressive decline in activities was observed from 2006, leading to its closure in 2009. The same year, some local entrepreneurs decided to team up with the government to found a new company. Senegal Airlines was therefore created to replace ASI, and activities were lunched in 2011. This new company operated only in West Africa with a fleet of two planes and was not competitive. It also went bankrupt and was dissolved in 2015. The brief history of the Senegalese civil aviation given here is in agreement with the energy consumption evolution observed in Figure 7. The fall in air transport seems to have seen compensation in the road sub-sector. Maritime activities did not experience any significant development; the energy consumption looks steady across the same period. Rail transport was not taken into account because of lack of data. Figure 8 shows that diesel consumption is in constant increase, and especially since 2006 when air transport activities collapsed (reduction in kerosene consumption). The quantity of energy from gasoline remains relatively stable around 5 PJ. Broadly, the total energy consumed in the transport sector oscillates between 25 and 32.5 PJ.

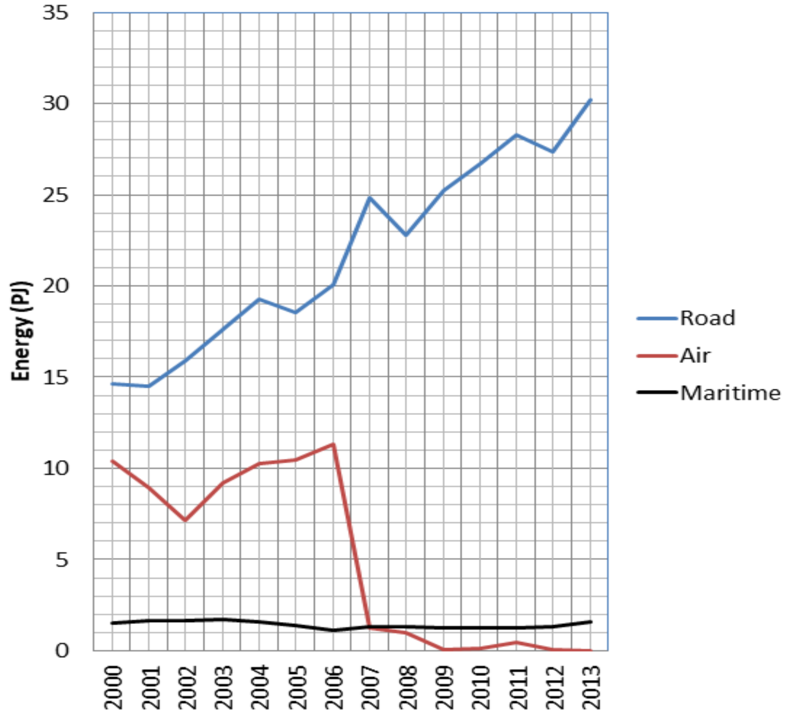

Figure 7. Energy consumption dynamics by sub-sectors.

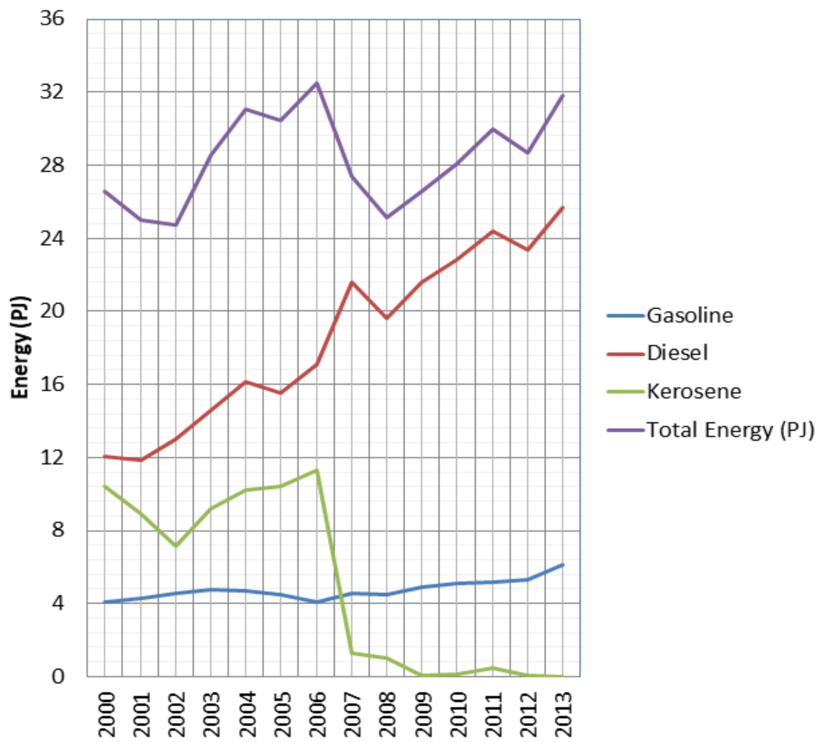

Figure 8. Fuels consumption dynamics.

4.2.3. Mean weighted energy efficiency

Heat engines used in the transport sector have different thermal performances due to their technology. Motors' efficiencies from manufacturers are around 28% for diesel and gasoline engines and 35% for propulsion systems [3,5]. However, these values do not remain constant during a car's life span period as the engine deteriorates with time. For some places, where the average age of the car fleet could be around ten years, 22% for gasoline and diesel vehicles, 28% for aircraft, and 15% for ships are values considered for thermal efficiencies [3,5]. Using equation 2, the mean overall energy efficiency of the transport sector in Senegal was calculated. Using data for the year 2013, a value of 21.65% is obtained. Figure 9 shows the variation of the weighted mean energy efficiency in the period 2000–2013. It is seen that the efficiency does not exceed 24% in that period, and a decrease is experienced in 2006, when air subsector started facing major crisis. Better efficiency would be obtained if the transport system was based on air and rail transport which are the most efficient modes. For the Senegalese case, it sounds that better performance would go with improvement of the air transport subsector.

Mean weighted energy efficiency calculations were carried out for some other countries. Structures of transport systems vary from one country to another. A transport system can bear two or more subsectors. For instance Jordan has only two modes while Greece has four modes. In some studies, rail and waterways are not taken into account, justification being the minor role played or the lack of data. Table 5 displays mean weighted energy efficiency for different countries and where Jordan appears as the most efficient place (23.09%) while India has the less efficient transportation system (21.12%). This value will hardly exceed 28%, which is the part load efficiency of rail and air devices. Seeking for high performance transportation systems planners should then integrate more of these devices and less road motors.

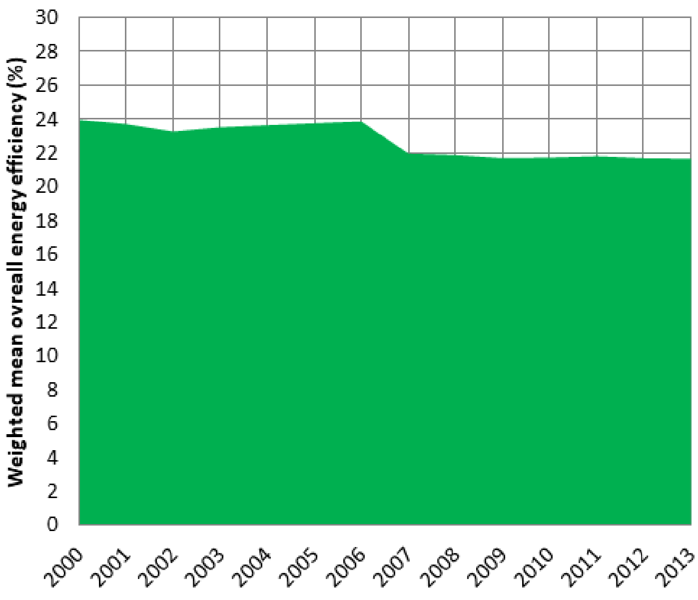

Figure 9. Mean weighted energy efficiency evolution of the transport sector of Senegal.

Table 5. Mean weighted overall energy efficiency comparison for several countries.

Country	η_{tee} (%)	Year	Reference
Saudi Arabia (Ro + Ai + Wa)	22.40	2000	Dincer et al. [5]
Turkey (Ro + Ai + Ra + Wa)	22.54	2000	Ediger and Çamdali [6]
Cameroon (Ai + Ro)	22.15	2010	Konchou et al. [3]
Jordan (Ro + Ai)	23.09	2006	Jaber et al. [11]
Greece (Ro + Ai + Ra + Wa)	22.69	2000	Koroneos and Nanaki [13]
Malaysia (Ro + Ai + Wa)	22.80	2003	Sattar et al. [14]
China (Ro + Ai + Ra + Wa + Pi)	21.63	2009	Zhang et al. [15]
Iran (Ro + Ai + Ra + Wa)	22.03	2011	Mahamadi [7]
Nigeria (Ro + Ai + Ra + Wa)	22.02	2010	Badmus et al. [4]
India (Ro + Ai + Ra + Wa)	21.12	2010	Mitra and Gautam [12]
Senegal (Ro + Ai)	21.65	2013	/

(Ro: road, Ra: railways, Ai: air, Wa: waterways, Pi: pipes)

The above calculation of mean energy efficiencies didn't take into account the quality of the transportation system. In fact, many factors can affect the engine's or mode's efficiency. Factors negatively affecting the transport sector in Senegal are poor infrastructures, lack of automotive industry, lack of skilled technicians and engineers, massive import of old equipment and spare parts, low household income and poor administrative organization. To illustrate the poor quality of the road transport subsector in Senegal, the average age of the car fleet is close to 20 (and in some categories the average age is around 30) while in developed countries, it is around 8 years [34]. A more realistic approach was proposed by Badmus et al. [4]. They used a part load efficiency of 14.68% for highway devices, justification being the poor operating conditions surrounding the road transport in Nigeria.

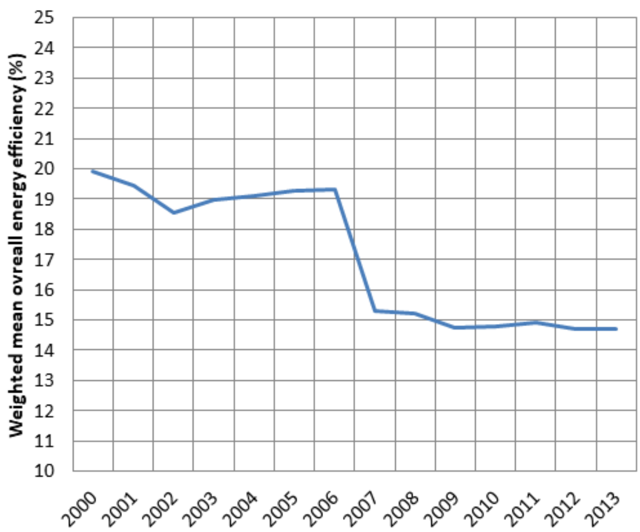

Figure 10. Mean weighted energy efficiency of the transport sector based on corrected highway part load efficiency.

The same approach can be applied to the transport sector of Senegal if we consider it operates in conditions similar to that of Nigeria (both are developing countries located in West Africa). New evaluation of the mean energy efficiency led to Figure 10. Mean weighted energy efficiency loses up to 6.95% in comparison with Figure 9: for the year 2000, 19.92% is obtained instead of 23.95% and while it was 21.65% in 2013 in the previous calculation it shifts down to 14.70%. Senegalese transport system clearly outperforms Nigerian's before 2006, and then from 2008 becomes less efficient (Figure 11). In 2010, both countries have very close transport efficiencies, 14.77% for Senegal and 14.91% for Nigeria.

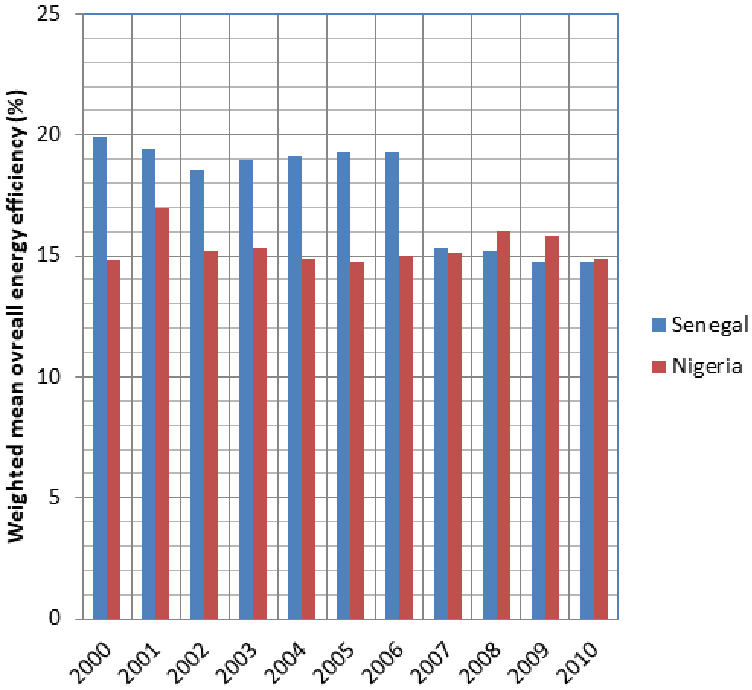

Figure 11. Mean weighted overall energy efficiency comparison between Senegal and Nigeria.

4.3. Policy implications and suggestions

Senegal till now is not an oil and gas producer and imports crude oil and oil products for its economy. Utilities and transport sector are based on these products. As noted, the country's energy independence is close to 50% and falls below 5% if biomass is omitted. The cost of these imports has been increasing over the years: in the period 2000–2008 it has been multiplied by 3.36, from US$ 370 million up to 1.24 billion [35]. This situation raises many concerns: energy security, economic vulnerability, exposure to oil shocks, and air pollution. Air transport as seen in the previous subsection hardly succeeds in Senegal; and this is common to sub-Saharan African countries. Internal navigation is scarce, and maritime activities are dedicated to international trade in coastal areas. Rail is less used and most infrastructure is old and out of date. This situation favors the road mode. A sustainable energy strategy to reach a carbon-free, sustainable and less vulnerable economy in Senegal should necessarily include the transport sector. Solutions already exist such as [36,37]:

- Replacement of fossil fuels by biofuels (ethanol, methanol, biodiesel, biogas, etc.) or a mix of them.
- Introduction of hybrid and electrical vehicles.
- Introducing hydrogen vehicles.
- Reorganization of transport systems by introduction of electrical trains and rapid bus transit.
- Development and modernization of animal driven systems.
- Development and modernization of pathways for pedestrians and other non-motorized systems.

These options require accurate studies and their implementation needs a clear policy for the transport sector. By the time the world is facing two major challenges namely climate change and fossil fuels depletion, the future of the transport sector in Senegal should be examined as it relies entirely on imported fossil fuels. Failure to seek for future solutions and strategies will put the weak local economy at risk.

5. Conclusions

An analysis of the energy system of Senegal was carried out. It showed massive use of traditional biomass in the residential sector, and importance of imported fossil fuels for transport and electricity sectors. Transport sector largely dependent on fossil fuels was investigated and showed constant increase of energy consumption since 2008. In 2013, 32 PJ were consumed in the transport sector. The mean weighted overall energy efficiency of the transport sector is estimated at around 14.70% if real conditions are applied. A deep analysis will be necessary to determine the efficiency of engines fleet in the country. It is absolutely necessary to totally assess the transport sector in view of understanding the challenges around mobility and its dynamics and reduce the fossil fuels consumption. Fossil fuels not only put the economy of the country at risk but are important sources of pollution. Technological solutions exist such as introducing electric motors in the transport sector, and in this perspective solar energy could play an important role. The present study, even though partial is an important step towards a better understanding of the energy system of Senegal.

Conflict of Interest

The author declares no conflicts of interest in this paper.

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