Exergy analysis and energy utilization in the transportation sector of the Philippines

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Abstract. This paper analysed the energy and exergy utilization of the four transportation sectors (road, rail, water, and air) in the Philippines during the years 1990 to 2016. The consumption per fuel was also considered in the analysis because each sector utilizes one or more type of fuel. The collected data showed that road transportation has the highest fuel utilization, and energy and exergy efficiency amongst the four followed by the aviation and marine subsectors which are both less significant than the results from the road transportation sector. Also, it was observed that diesel and gasoline are the ones commonly used in the road, rail, and marine subsectors compared to LPG, ethanol, biodiesel, and electricity. Comparing the overall energy and exergy efficiencies from 20 years ago, it was observed that the efficiencies are gradually increasing annually in small increments. The data presented in this research will be beneficial to the Philippine transportation sector to effectively reduce cost and improve the quality of transport in the country. It is also helpful to base future transportation designs on the energy and exergy efficiencies to better improve transportation and reduce the environmental impact which can both be practical for the economy and the ecosystem.

1. Introduction
Transportation eases mobility and enables industry and trade making it very important to human society. However, transportation also partakes in many environmental impacts making it critical to the extent that transportation planning should be carried out in a sustainable manner to promote environmental preservation and economic prosperity while meeting optimum travel needs.

In the Philippines, transport links population and economic center across the islands making a very important sector in its economy. The transport system in the Philippines comprises of land or road, water, air and rail transport. The road transport is the most dominant subsector accounting for 98% of passenger traffic and 58% of cargo traffic, however, water transport is also needed because the country is comprised of 7,107 islands[1].

As of 2015, the Philippine highway network has a total length of 19,162.72 kilometers (11,907.16 mi) of concrete roads, 9,756.45 kilometers (6,062.38 mi) of asphalt roads, 3,636.96 kilometers (2,259.90 mi) of gravel roads and 77.44 kilometers (47.99 mi) of earth roads [2]. The extent of the road network in the Philippines is comparable with or better than many neighboring developing countries, in fact, it showed modest improvement in transport services, but the quality in terms of intermodal integration and road networks lags far behind [1]. Another, efficient operation of the transport sector in the Philippines was impeded by poor sector governance.

Efficiency of transport operation in the Philippines affects the country’s fuel consumption. Cross-sector analysis showed that the rate of energy consumption of transport sector increased annually making it one of the fastest-growing energy user industries [3]. The rapid urbanization has resulted in growing levels of energy demand and consumption. The problem is that the Philippines do not have significant energy resources such as petroleum. Energy efficiency in the Philippine transportation sector merits special attention from the standpoint of energy security and the environment because this sector is almost solely dependent on petroleum fuels and the country heavily relies on importing energy from domestic provinces with fossil energy and mostly imported from oil-producing countries. Philippines suffers from energy shortage causing uncontrollable hike on fossil fuel cost periodically.
Thus, an investigation into energy performance of transportation sector will provide important information for the Filipino government, energy and policy makers. In the Philippines, there was about 33.1 million tons of oil equivalent (toe) demand for primary energy in 2016 while only 18.6 million toe in 1990. The largest single consumer among different sectors is the transport sector (37%), followed by residential (27%) and industry (23%); the rest being commercial and agriculture, fishery and forestry sectors. The high demand could be explained by the archipelagic geography of the country and reliance on diesel generation, inefficient and small generation, transmission and distribution systems in some areas, low investment in the sector, and inefficient energy conversion technology due to the use of old mass transport systems. The average growing annual rate of 3.2% in this sector will remain unchanged in the future if government’s strategies and policies will not be improved. The transport sector’s final energy consumption has increased by approximately 163% during the last 26 years, while the total energy demand has increased by 78% for the same span of years. The road transportation’s consumption of petroleum products has increased remarkably. In 2016, gasoline and diesel consumption were 3.1 and 2.4 times the rates in 1990, respectively.

Comparing the quality levels of energies from different sources requires determining the equivalents at a particular grade level which can be done through the concept of exergy which gives the true efficiency of engineering systems that is very useful to identify improvements in different processes. It is a potential tool for examining the negative effects of careless utilization and scarcity of energy resources on economics and ecology of the country [4]. It provides feasible approach for energy planning for a single sector and reveals real potential through internal irreversibility reflection of a system for technical improvement. Enhancement of the system tend to be realize easily with indication of the exact location and true magnitude of the waste of loss diagnosed through exergy analysis [5]. The concept of exergy analysis to identify losses and inefficiencies in transportation sector has been done in different countries such as Greece [5], Saudi Arabia [6], China [7], Jordan [8], and Canada [9], but there is no report found in the from the year 1990 to date and this paper will be the first detailed energy analysis report for the transportation sector in the Philippines.

The study aims to apply energy and exergy analysis to the Philippine transportation sector to examine the variations of energy and exergy efficiencies over the years. This study will present energy consumption and energy utilization efficiencies from 1990 to 2016 of the road, rail, water and air subsectors of the Philippine transportation sector, in order to address the development of its sustainability.

2. Methodology

2.1. Data Acquisition

The energy consumption data used for the analysis was provided by the Department of Energy for the years 1990 to 2016. The values for exergy grade function ($\gamma_f$), lower heating value ($H_f$), and chemical exergy ($\xi_f$) of energy source used in transportation sector in the Philippines are shown in Table 1.

2.2. Exergy Analysis

By definition, exergy is the maximum amount of work which can be obtained when the system moves from that particular state of equilibrium with the surroundings. The reference environment for evaluating exergy flows in a vehicle is the standard atmosphere [10].

| Fuel            | $H_f$ (kJ/kg) | $\xi_f$ (kJ/kg) | $\gamma_f$ |
|-----------------|---------------|-----------------|------------|
| Gasoline        | 47,849.00     | 47,394.00       | 0.99       |
| Diesel          | 39,500.00     | 42,265.00       | 1.07       |
| LPG             | 55,448.00     | 51,702.00       | 0.93       |
| Ethanol         | 29,700.00     | 30,389.57       | 1.02       |
| Electricity     | 3600.60       | 3600.60         | 1.00       |
| Aviation Fuel   | 46,117.00     | 45,897.00       | 1.00       |
Exergy of Fuel. The chemical exergy is the specific maximum work of a fuel produced upon equilibrium at environmental conditions [11]. Generally, it was derived by multiplying the exergy grade function and the lower heating value of the fuel as shown in Eq. (1). For fuels used in transportation, it was suggested that only the chemical exergy is significant [12].

$$\epsilon_f = \gamma_f H_f$$  (1)

Exergy of Work. The exergy of work is the physical work exergy, $E_W$, is equal to the mechanical work, $W$:

$$E_W = W$$  (2)

Energy and Exergy Efficiencies. The first law efficiency is called the energy efficiency which is equivalent to the ratio of energy contained in products of a certain process to the energy present in all input streams, is defined as:

$$\eta = \frac{\text{energy in products}}{\text{total energy input}} \times 100\%$$  (3)

On the other hand, the second law efficiency or the exergy efficiency is the ratio of exergy contained in products to the exergy present in all input streams, is defined as:

$$\psi = \frac{\text{exergy in products}}{\text{total exergy input}} \times 100\%$$  (4)

Shaft work energy, $W$, is produced from fossil fuel-driven kinetic production, $m_f$. The energy, $\eta_m$, and exergy, $\psi_m$,

$$\eta_m = \frac{W}{m_f H_f}$$  (5)

$$\psi_m = \frac{E_W}{m_f \epsilon_f} = \frac{W}{m_f \gamma_f H_f} = \eta_m \frac{\gamma_f}{\epsilon_f}$$  (6)

Mean and Overall Exergy and Energy Efficiency Calculations. The overall weighted mean energy efficiency ($\overline{\eta}_{\text{mp}}$) was obtained by getting the sum of the products of energy efficiency of each mode of transport ($\eta_f$) and energy fraction ($P_{\text{rel}_f}$). The energy efficiency of each mode of transport was taken as the part load efficiency. The rated and part load efficiencies for different vehicles provide different values, and for simplicity, the part load efficiencies for road, rail, water, and air was assumed to be 22%, 28%, 15%, and 28%, respectively [13].

3. Results and Discussions

3.1. Energy Consumption

The trend in Figure 1 shows that the energy consumption of the Philippine transportation sector is annually increasing. There is an average annual increase of 4.04% in the total energy consumed which incurred a total increase of 163% for a span of 27 years. This is due to certain factors such as the number of operating vehicles and activities. Though there was a plateau of energy consumption from 1996 up to 2010, the consumption rose steadily until 2014 to which a significant increase occurred afterwards. This sudden increase happened because the annual surge in number of vehicles before 2014 jumped from 360,000 to 585,000 for years 2014 to 2016 [14]. Air transportation also contributed
to the increasing demand of aviation fuel from the years 2010 onwards at which the number of foreign tourists increased drastically [15,16].

Figure 1. Annual energy consumption of Philippine Transportation sector for 1990 to 2010.

Figure 2 presents the energy consumption distribution for each subsector for the period of 1990 to 2016. For the years 1990 to 2016 the road subsector plays the top energy consumer among the different subsectors. During 1990, it incurred a total energy consumption share of 83.26% followed by air, water and rail with 10.48%, 6.21% and 0.04% energy consumption shares, respectively. During 2016, the same trend was observed with road subsector having a share of 81.37%, followed by air, water and rail with 13.66%, 4.88% and 0.09% energy consumption shares, respectively. The rail subsector was always the lowest energy consumer because there are only three main railroad systems in the Philippines, while the air subsector ranks second because of the increased tourism activities in the country and the opening of international airports.

The annual energy consumptions by fuel type for road, rail, water and air are shown in Figure 3. Data showed that for the road subsector, there was a steady increase of fuel consumption for biodiesel, gasoline and diesel for the whole duration, the latter being more popular with an average overall consumption that is 1.7 times higher than gasoline. This can be attributed to the better fuel economy and lower CO₂ emissions that diesel can provide [17]. It was also observed that the consumption for ethanol drastically increase from year 2006 to 2016. The demand for ethanol is expected to increase due to environmental and economic reasons. Moreover, this effect was also caused by the creation of gasoline-powered vehicle that uses gasoline with certain percentage of ethanol [9]. In 2007, the continuous increase in the price of gasoline led to the widespread use of LPG as alternative fuel for commercial taxis in the Philippines [18]. However, based on the data presented, there is an observable decline on its consumption due to its less efficiency. For the railway subsector, it can be observed that the trend is also increasing and it is mainly due to electricity. Diesel consumption was observed to fluctuate throughout the duration of data. It was found to increase at the year 2009, when the Philippines bought new units of diesel-powered trains for the Philippine National Railway (PNR) [19]. The start of decline in 2014 was attributed to the shift of diesel units to electrical units in PNR. For the water transportation subsector, the energy consumption for diesel and gasoline are fluctuating from time to time, while for the air subsector, the use of aviation fuel was found to increase starting from year 1990 to 2016. This can be attributed to the increase in tourism activities in the Philippines.
3.2. Energy and exergy Efficiencies

Based on Figure 4, the road subsector was the most energy and exergy efficient transportation subsector because of the range of fuel type it uses and the performance of the vehicles traveling in this subsector. Similarly, in Canada [9] and Malaysia [8], the road subsector was also the most energetically and exergetically efficient but it was in a far more higher degree as compared to the Philippines. Moreover, it can be seen that exergy and energy efficiencies of air and water transportations are almost the same. This is because the only difference between these two efficiencies is the exergy grade function ($\gamma_f$) specific for the fuel type used. If $\gamma_f = 1$, then the exergy and energy efficiencies will be equal. Air transportation uses aviation fuel, while water transportation uses gasoline, diesel and biodiesel.

In 2016, the highest portion of energy consumed was incurred from the consumption diesel in the road subsector. Although, the energy diesel in the country was higher than other fuels the loss was also the greatest as compared with others. Furthermore, it can be observed that the efficiency of the rail transport subsector was negligible. This means that almost all the input of fuel was transformed into losses. It only shows that the railroad transport in the Philippines was not given focus in terms of energy and exergy efficiency. This can be attributed to the fluctuating energy consumption and the scope of this sector. Moreover, the huge loss of energy in this sector can mean a decrease in economy.

The overall energy and exergy efficiencies in the transportation sector in the Philippines in Figure 5 show a fluctuating trend. The fluctuations in the efficiencies are simply due to the ignorance of the effect of certain technologies and the assumption that the part load efficiencies for each sector are constants. From 1990 to 1999, there is a decreasing trend in efficiencies while starting from years 1999 to 2013, the efficiencies are increasing. During 2014 and 2015, efficiencies dropped while during 2016 there is an improvement. Furthermore, the least efficiency is clearly seen during 1998 while the highest is during 2013. The overall mean energy and exergy efficiencies are 22.22% and 21.52%, respectively. It is also observed that energy efficiencies are higher than exergy efficiencies which supports the fact that exergy accounts losses due to irreversibilities. The basis of energy utilization policies should be the exergy because it considers irreversibilities. The efficiency decrease from 1990...
Figure 3. Annual fuel type consumption of (a) road, (b) rail, (c) water and (d) aviation transportation during 1990-2016.
to 1999 can be attributed to the Second World War in the Middle East. Fuels being used in the Philippines are imported from the Middle East. During this time, export markets were unstable that the oil commodity prices hiked, thus it caused less consumption of fuels. The increasing trend during 1999 to 2013 is generally attributed in the development of transportation sector which are stimulated by improvements and growth in economy. Moreover, during these years the tourism in the Philippines had flourished which help peak the efficiencies through air transportation subsector.

**Figure 4.** Overall energy and exergy efficiencies of the transportation subsectors in the Philippines.

**Figure 5.** Overall energy and exergy efficiencies in the transportation sector in the Philippines during 1990-2016.

4. **Conclusion**

The exergy and energy efficiencies of the Philippine transport sector for period from 1990 to 2016 were determined. An average annual increase of 4.04% in the total energy consumed which incurred a total increase of 163% was also calculated which shows that the transport sector was flourishing in the context of energy consumption. In the Philippines, the largest energy consumer was the road subsector with 81.37% total energy consumption in 2016. Nevertheless, it appears to have the highest exergy
and energy efficiency as compared with other subsectors. Moreover, the results have shown that all energy inputs in the rail subsector were converted to losses which suggest that this subsector was highly inefficient. The energy and exergy efficiencies showed a fluctuating trend. A decreasing trend was found during 1990 to 1999 while starting from years 1999 to 2016. It was found out that the overall mean energy and exergy efficiencies are 22.22% and 21.52%, respectively, which could be an important tool to attain insights regarding the improvements on the performance of this sector. This low value of energy and exergy efficiencies shows that there are a lot of rooms for improvement. Furthermore, when compared to other countries such as Canada and Malaysia, the Philippines, although possess the same energy and exergy efficient sector (road), has fared low in terms of efficiency. It means that more efficient energy utilization policies are needed.

The data presented in this paper can be used to develop policies that can make improvements in the Philippine transport sector. The proponents recommend that there should be more strategies and fiscal policies in improving the rail transport sector of the Philippines so that when this sector improve it will also show great improvement in the country’s economy. Moreover, keeping the pace of development in air transport was advisable as its efficiency is improving through the years. In order to conclude for more complete suggestions for improvement, further study involving each mode of transportation is required. Furthermore, economic factors, environmental effects and raw materials used must also be taken into consideration.

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