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Renewable Energy System: Alternative Fuel Usage in the Energy Market of the US Public Transportation System

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Abstract The U.S. transportation sector is the second largest energy consumer in 2020 with about a 35% usage rate. However, the sector accounted for the largest proportion (29%) of the total greenhouse gas emissions in 2019. Compared with the use of personal automobiles, public transportation is believed to be cost-effective and provides low emissions, which tends to reduce the need to travel long distances and lower the carbon footprints of transit operations. This study examined the impact of alternative fuels (various blends of biodiesel, hydrogen, methanol, and ethanol) versus conventional fuels on greenhouse gas emissions in the U.S. public transit system. The research was anchored by three regression models to analyze the joint and individual impact of both conventional fuel and alternative fuel. Secondary data were extracted from the American Public Transit Association 2021 Fact Book, the U.S. Bureau of Transportation Statistics, and the Inventory of U.S. Greenhouse Gas Emissions and Sinks 1999-2019 (EPA 2021). The descriptive statistics, correlation, and stationarity tests were established on the variables, and the regression models were estimated using ordinary least squares. The findings revealed that while conventional fuel expands the flow of carbon emissions, alternative fuel is a drag on the total emissions from public transportation. However, it was concluded that the utilization of alternative fuels in the U.S. transportation industry is still very low, thus there is a need to put all machinery in motion to embrace this fuel type to reverse climate change issues, especially in the public transit system.

Keywords Alternative Fuels, GNG (Greenhouse Gas), Energy Efficiency, Conventional Fuels

1. Introduction

The global oil reserves as a source of energy might not be sustainable in the foreseeable future, necessitating the need for investment in other alternative sources of energy in many countries, including the United States. Boontome et al. [1] identified the major problem of fossil fuel was greenhouse gas emissions and the release of carbon particles which are injurious to human health and the environment. According to WEO [2], 26.6 billion tons of global CO_2 emissions were recorded in 2005 from fossil fuels. Total global emissions from fossil fuels can be said to be 65% in 2018 [3]. The concern for alternative fuel energy is being propelled by global air pollution, water pollution, and climate deterioration [4]. Diversifying the sources of energy for transportation has a direct impact on economic growth. Thailand and some parts of the developing world are currently promoting sustainability with renewable energy. The U.S. government is constantly making frantic efforts to reduce emissions released into the atmosphere.

The demand for renewable energy has been on the increase due to the need to reduce global carbon emissions. Renewable energy plays a major role in the energy mix of most countries of the world [4]. Sustainable development is a global priority to promote greater energy efficiency, and the use of renewable energy especially in reducing greenhouse gas emissions and adapting to a changing climate. In the United States, the transportation sector is the second-highest consumer of energy after the industrial sector because of its support in the development of the economy, thus there is a need to harmonize economic growth with land use planning and conservation of resources [5]. The U. S. transportation system still depends on 92.8% oil fuel as energy consumption (fig. 1), thereby increasing greenhouse gas emissions (GGE) [5].

Public transportation is a sustainable means of transportation that promotes reliability and accessibility, optimizing the use of resources while reducing emissions of pollutants and GGE, and promoting technological innovations [6]. Public transportation refers to all services that provide adequate, effective, and efficient mobility to the public by the use of buses, trains, ferries, etc. [6]. By current standards, alternative energy sources, which are independent of fossil fuel production, are in low use in the U.S. According to the 2021 report of the U.S. Energy Information Administration (Figure 1), the major transportation fuel in the United States is gasoline (56%), followed closely by diesel fuel (24%), and then jet fuel (9%), biofuel (5%), natural gas (4%), and other sources of fuel sum up to 2%. This study, therefore, investigates whether a switch from conventional energy to alternative energy can reduce GGE from buses used in the public transit system of the United States.

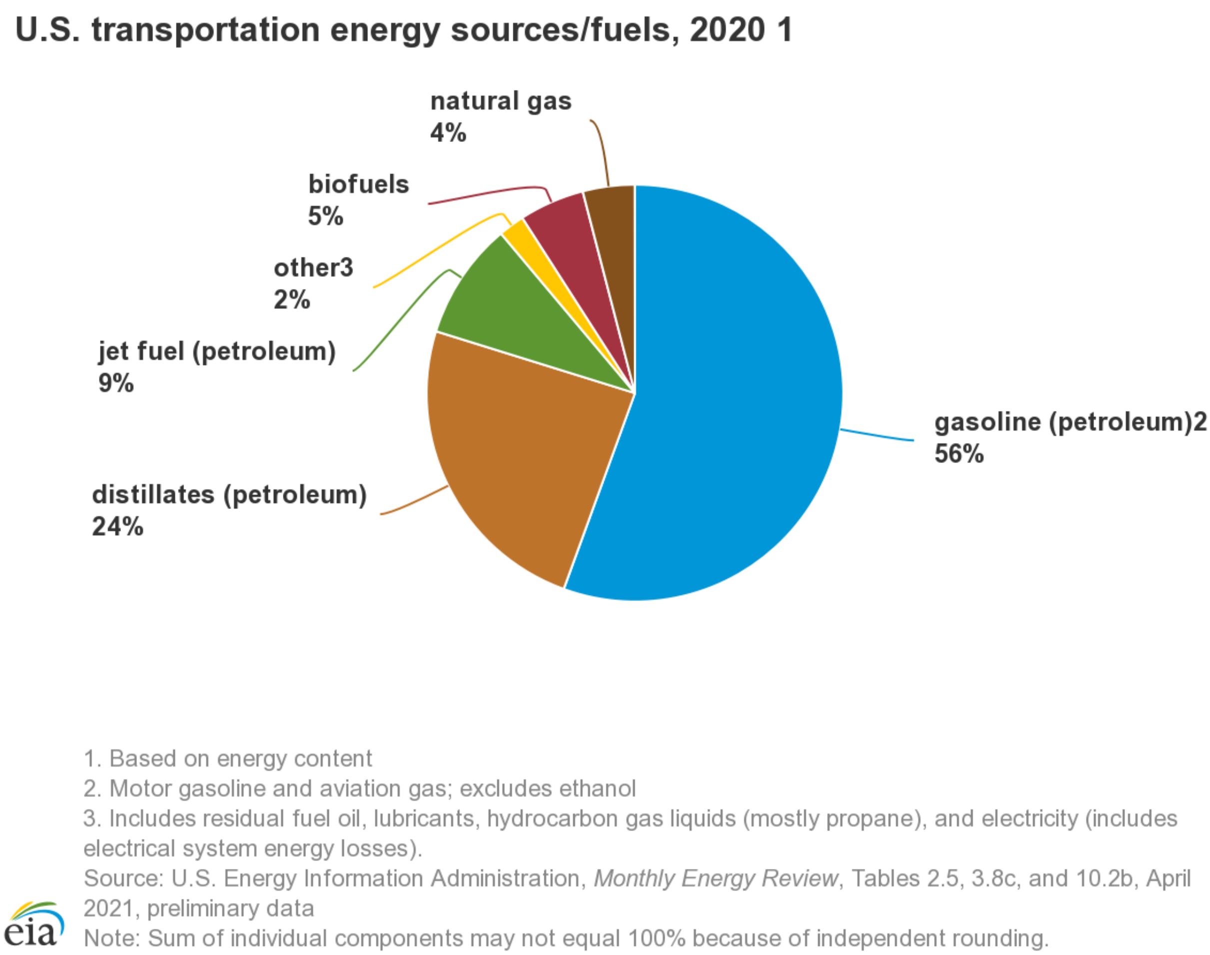

Figure 1. The United States Energy Sources / Fuels (2020)

2. Review of Literature

2.1. The Need for Alternative Energy

Energy is essential for human survival because of its usage in the production of goods, cooking of food, generation of electricity, and distribution of goods and services through transportation [7]. The energy sector has a spillover effect on the economy and the environment, moreover, several theories and tools are increasingly developed globally regarding environmental assessment [8]. Transportation has been noted to be a major source of carbon monoxides and the release is in relation to the proportion of fuel usage. Alvarsson et al. [9] discussed the release of CO_2 and its effects on the environment can be traced to acidification, tropospheric ozone, genetic effect, the nutrition of soil, and negative health effects.

The climate change issue has been the focus of the public policy energy debate in the last few years [10]. According to Cheng et al. [11] and Li and Su [12], the release of carbon emissions into the atmosphere is the leading cause of global warming and climate change. The work of Frey [13] stated that on-road vehicles are the major contributors to US national emissions due to the country's largest vehicle fleets. However, the introduction of new technologies and emission regulations has been effective in reducing these emissions, and many countries of the world are making frantic efforts to decarbonize to a net-zero emission [13].

On January 27, 2021, the current administration issued executive order 14008 with the focus of "tackling the climate change crisis at home and abroad". By placing climate crisis at the forefront of foreign policy and national security planning, energy efficiency, conservation, and fuel switching in transportation were recognized as the major pathways modeled by Laws for Deep Decarbonization in the United States (LPDD) to mitigate the effect of climate change in the transportation sector. According to Marcin et al. [14], public transportation is one of the major initiatives of urban sustainability in reducing the negative impact on the environment. Li et al. [15] also explained public transportation as a system that has an enhanced passenger capacity and a reduced environmental impact than personal automobiles. There is a high proportion of trips with personal automobiles, resulting in higher consumption of energy and greater emissions into the atmosphere.

Public transportation reduces pollution and eases congestion on the road as many transit fleets are switching over to cleaner, alternative fuels and technologies. This has led to calls for continuous usage of alternative fuels in the U.S. public transit system. Dyr et al. [16] explained sustainable development in transportation as the process of using the available alternative fuels or renewable energy sources to meet the current needs of people without compromising the ability of future generations to meet their own needs.

2.2. Characteristics of Alternative Energy

The world economy is embracing the use of alternative energy to reduce the effect of emissions and climate change issues. Alternative fuels as identified by Amrouche et al. [17] has the potential for reduced pollutant emissions as compared to gasoline or diesel fuel and are often classified as cleaner energy. Biodiesel, hydrogen, ethanol, electricity, and other biofuels are usually categorized as alternative energy sources. Alternative fuel continues to retain the forefront in cleanliness and cost-efficienc. Its use as a transportation fuel is receiving more attention because of the reduced exhaust emissions. Universal Technical Institute, for instance, defined Compressed Natural Gas (CNG) as an environmentally clean alternative fuel because the combustion process emits a lower percentage of greenhouse gases when compared to other conventional fuels. The volume of LNG is $1/600^{th}$ of its gaseous state which allows more flexibility in transportation and storage De-zhi et al. [18].

Hydrogen has been proposed as an energy carrier like oil and natural gas, and it could be used for land and marine transportation. Hydrogen produced and consumed on-site has 1.53 times more electricity embedded than its own Higher Heating Value (HHV) content [19]. It is a very good fuel mix for transportation because of its high efficiency and can further assist to mitigate climate change [20]. Alternative Fuels Data Center of the U.S. Department of Energy defined biodiesel as a renewable fuel manufactured domestically from vegetable oils, animal fats, or recycled restaurant grease. Biodiesel is a liquid fuel often referred to as B100 or neat biodiesel in its pure, unblended form. Like petroleum diesel, biodiesel is used to fuel compression-ignition engines.

Ethanol is a renewable biofuel made from biomass. The use of starch fermentation from corn, sugarcane, and sugar beet is essential for ethanol production. In the United States, fuel ethanol is made from biomass materials referred to as feedstocks. 40% of corn produced in the United States is converted into ethanol since the introduction of the Energy Independence and Security Act of 2007. Biofuels are fuels produced from renewable organic material. Biofuel has the potential to reduce some undesirable aspects of fossil fuel production and use, including conventional and greenhouse gas pollutant emissions, exhaustible resource depletion, and dependence on unstable foreign suppliers.

3. Methodology

The variables analyzed in this study are three: GGE from road transport, conventional energy sources, and alternative energy sources. The conventional sources are diesel fuel, compressed natural gas, gasoline, liquefied natural gas, and propane. These conventional sources are hence called conventional fuels. Alternative sources are various blends of biodiesel, bio/soil fuel, hydrogen, methanol, and ethanol. These alternative sources are referred to as alternative fuels. This study used aggregated data on these fuel types. Data on energy sources were extracted from the American. Public Transportation Fact Book (2021 edition) and data on GGE were obtained from the U.S. Bureau of Transportation Statistics (2021 edition). The database spanned from 1999 to 2019.

The general multiple regression model is specified as follows:

Where GGE is greenhouse emissions, COF is conventional fuel, while ALF is alternative fuel. This general model is further decomposed into three equations as follows:

$$GGE = f(COF, ALF)$$

$$GGE_t = \alpha_1 + \alpha_2 COF_t + \alpha_3 ALF_t + e_t \quad (1)$$

$$GGE_t = \beta_1 + \beta_2 COF_t + u_t \quad (2)$$

$$GGEt = \theta_1 + \theta_2 ALF_t + v_t \quad (3)$$

Where α's, β's, and θ's are coefficients to be estimated; **e,** $\boldsymbol{u}$ and $\boldsymbol{v}$ are error terms while **t** indicates the time period (year) at which the variables were measured.

While equation (1) aimed at establishing the joint effect of conventional and alternative fuels on GGE, equations (2) and (3) analyze the isolated effect of conventional fuels and alternative, respectively, on GGE. This analytical technique is targeted at exploring whether GGE can be controlled independently by either conventional fuel or alternative fuel. Having conducted descriptive, correlation, and stationarity tests on the variables, the equations were estimated using ordinary least squares.

4. Results and Discussion

4.1. Descriptive Analysis

Table 1 provides the summary of descriptive statistics of the three variables. The average GGE is 15.76 million metric tons with the standard deviation being 4.53; this shows a low level of volatiliy of the emissions. That the emissions are less prone to disruptions is further projected by their minimum and maximum values being not too distant from the mean value. Skewness is a measure of the asymmetry of the distribution of the series around its mean, and kurtosis measures the peak or flatness of the distribution of the series. Table 1 shows that GGE is negatively skewed, meaning that its distribution has a long-left tail. And with a threshold of 3, the series of GGE are platykurtic, indicating that the distributions are flat relative to the normal.

The mean conventional fuel is 307.6 million gallons compared to 38.57 million gallons for alternative fuel. This clearly demonstrates the high usage rate of fossil fuels in the U.S. relative to the low demand for less-polluting sources. Even with low patronage, alternative fuel is vulnerable to prolonged highs and lows, hence the standard deviation (27.34) being close to the mean value. On the other hand, the demand for conventional fuel seems to follow a stable trend with fewer fluctuations (the standard deviation is low relative to the mean value). Both fuel types are positively skewed and, finally, their distributions are platykurtic (not prone to extreme values).

4.2. Correlation Analysis

The correlation coefficients in Table 2 show the association between GGE and conventional fuel is positive and nearly perfect (0.96). This suggests that there is a direct, instant effect of conventional energy on GGE. However, alternative fuel is weakly and inversely correlated with GGE (-0.20). The correlation coefficient between conventional fuel and alternative fuel (-0.16) informs that the two energy types are strong substitutes: they are mutually exclusive in the baskets of energy sources of the consumers. It follows that both types of fuels cannot be simultaneously popular. In view of the above analysis, a decision to boost the environmental performance of U.S. public transit should support a switch from conventional to alternative fuels.

Table 1. Descriptive statistics of the variables

Variable(s)	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
Greenhouse gas emissions (million metric tons)	15.76	4.53	9.10	22.20	-0.19	1.57
Conventional fuel (million gallons)	307.60	139.99	90.40	468.97	-0.50	1.58
Alternative fuel (million gallons)	38.57	27.34	0.8	75.3	-0.36	1.61

Table 2. Correlation coefficients among the variables

	Greenhouse emissions	Conventional fuel	Alternative fuel
Greenhouse emissions	1		
Conventional fuel	0.96	1	
Alternative fuel	-0.20	-0.16	1

Table 3. ADF and PP Unit Root Test Results

Variables	Form of test	Constant		Constant and Linear Trend		Order of Integration
		Levels	First Differences	Levels	First Differences	
s emissions	ADF	-1.3455	-4.1893	-1.1109	-5.4589	I(1)
	PP	-0.6924	-5.2398	-1.2348	-5.1268	I(1)
Conventional fuel	ADF	-1.1242	-5.3429	-1.7688	-5.3544	I(1)
	PP	-1.1043	-5.1239	-1.7076	-5.3284	I(1)
Alternative Fuel	ADF	-0.1045	-5.1230	-2.3419	-5.5483	I(1)
	PP	-0.9213	-5.2394	-2.0047	-5.2871	I(1)
Asymptotic Critical Values						
1%	ADF	-3.6463	-3.6463	-4.2528	-4.2627	
	PP	-3.6394	-3.6463	-4.2529	-4.2627	
5%	ADF	-2.9540	-2.9540	-3.5485	-3.5530	
	PP	-2.9511	-2.9540	-3.5485	-3.5530	
10%	ADF	-2.6158	-2.6158	-3.2071	-3.2096	
	PP	-2.6143	-2.6158	-3.2071	-3.2096	

Table 4. Regression results

Dependent variable: Greenhouse emissions from buses			
	Model 1	Model 2	Model 3
Constant	(5.80) [7.25] *	(6.24) [7.87] *	(10.96) [8.56] *
Conventional fuel	(0.04) [8.71] *	(0.03) [13.13]*	
Alternative fuel	(-0.04) [-1.65]**		(-0.32) [4.55] *
R-squared	92.48%	91.51%	56.44%
F-stat	96.84*	172.49*	20.73*

Numbers in ( ) are coefficients; Numbers in [ ] are t-statistics

*Indicates significance at 5%; ** indicates no significance at 5%

Conventional fuel = diesel fuel, gasoline, liquefied/compressed natural gas, and propane

Alternative fuel = biodiesel, biofuel, hydrogen, methanol, and ethanol

4.3. Stationarity Analysis

Table 3 summarizes the stationarity analysis. The variable distributions were tested for stationarity to determine whether mean reversion occurs on them. For robustness purpose, this was achieved using two-unit root tests: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). The specifications used included constant only and then constant and trend only. The tests were conducted on levels and first differences. The test statistics obtained from the two techniques (ADF and PP) were then compared with their given critical values. The results showed that the three variables were not stationary at levels but became stationary at first differences. This made all the variables to be stationary, having been integrated at order 1. Since the variables have the same order of integration, we can conclude that the use of ordinary least squares is appropriate for the analysis.

4.4. Regression Analysis

Table 4 presents the regression results. Models 1-3 are the estimated versions that follow directly from equations 1-3 in Section 3. In models 1 and 2 featuring conventional fuel as an independent variable, its coefficients are positive. This implies that as people increase their consumption of conventional fuel, there are additions to atmospheric pollution. On the other hand, alternative fuel has negative coefficients, meaning that more usage of alternatives leads to a fall in GGE. This is the central argument of this study: using alternative fuels will save the earth from harmful emissions. More specifically, in model 1, increasing the consumption of alternative fuel by a million gallons reduces the emissions by 0.04 million metrics. Whereas scaling the conventional fuel by the same degree increases the emissions by the same 0.04 million metrics. In models 2 and 3, the explanatory effects of scaling both conventional and alternative fuels by the same unit are opposite (0.03 versus-0.32).

The coefficients of the constant term are also instructive of the notion that alternative fuel is yet to be fully utilized in the U.S. In model 1, the average emissions outside the influence of conventional and alternative fuels are 5.8 million metrics. This becomes 6.24 million metrics in model 2. However, the figure shoots to 10.96 million metrics in model 3, suggesting that a large fraction of GGE (from public transit) is sourced from non-alternative fuels. And the fact that the mean emissions were considerably low in models 1 and 2 emphasized the suspicion that conventional fuel is the primary polluter of air in the U.S. A more straightforward measure of the popularity of the independent variables towards affecting the variation in the dependent variable is the R-squared (also referred to as the coefficient of determination). In models 1 and 2, the R-squared is convincingly high at about 92% each, but it is only 56% in model 3. Statistical inference from this is that alternative fuel has not been established as an important element that tilts the variation in GGE which is traced to U.S. public transportation.

The t-statistics of conventional fuels are high enough to make the variable a significant factor accounting for changes in GGE, the significance is reported at 5%. Nevertheless, alternative fuel is not yet a significant determinant of emissions into the air. This explains the reason for its low value of t-statistics in model 1 when it is combined with the conventional fuel, making the coefficients not significant at 5%. In another vein, when the alternative fuel stands alone as the regressor in model 3, its t-statistic is high to make its coefficient significant. It is important to state that the low utilization of alternative fuels among Americans needs a prompt reversal to put the unfolding consequences of climate change under control. While the t-statistic measures the individual significance of the variable, the F-stat explains the joint significance of all the variables in the regression model. In model 1, both conventional and alternative fuels are jointly significant. In model 2, only conventional fuel features as the independent variable and the F-stat revalidates the significance that has been signaled by the t-stat. Again, the F-stat in model 3 is also significant, but the degree is not as high as what is obtained in models 1 and 2. The alternative fuel, as a regressor, could not be decomposed into its units (biodiesel, bio/soil fuel, hydrogen, methanol, ethanol, etc) because only its combined data were available until 2007.

5. Conclusions

The impact of climate change is already unfolding in the world, ranging from increased temperature, wildfires, and flooding to health challenges. World leaders have been showing interest in containing climate change, although concrete actions are yet to be ascertained from the major countries with a high record of pollution (the United States, China, and Europe). It is essential to state that talks and debates around the subject have never been very popular, while a common agenda on the solutions is yet to be established, there is consensus on the major cause of climate change; GGE. However, if the emissions to the atmosphere are contained, the world is in the mode of reversing climate change. The literature established that GGE is mostly sourced from fossil fuel exploration, transportation, and uses. Fossil fuels (petrol, diesel, natural gas, bitumen, etc.) discharge harmful emissions which trap heat in the atmosphere, causing the earth to be warmer beyond comfortable levels. In this study, fossil fuels are aggregated as conventional fuels. However, other sources of fuel (such as biofuel, biodiesel, hydrogen, methanol, etc.) do not eject emissions. They would rather protect the environment from risky pollutants. These other sources (such as biodiesel, bio/soil fuel, hydrogen, methanol, ethanol, etc.) are called alternative fuels. This study has therefore investigated whether alternative fuel has any tendency to reduce greenhouse emissions in the United States.

To achieve this objective, three regression models were specified and analyzed to establish both combined and individual effects of the two categories of fuels on greenhouse emissions. In the models, the coefficients of conventional fuel are positive. This echoes the general assertion that the fossil fuel industry is the major pollutant of the atmosphere. The more fossil fuel is used especially for public transit, the more the emissions are traceable to the transportation industry. The obtained coefficients are all statistically significant and the measures of R-squared and F-stat confirm the role of the fossil fuel industry as the major driver of the public transit system in the United States. On the other hand, the coefficients of alternative fuel are negative – the more the alternative fuel is used, the less the emissions released. This upholds the prior expectation that if U.S. public transit sector switches to alternative fuel as the main source of energy, greenhouse emissions associated with the transportation industry will reduce markedly. Unfortunately, the use of alternative energy remains unpopular in the U.S. transportation industry. This caused the negative coefficient to be statistically insignificant when it is combined with conventional fuel and becomes significant when it is isolated. Also, the isolated R-squared and F-stat are considerably lower.

Furthermore, the use of alternative fuels has been established in this study as a major tool for reducing GGE, reversing climate change, cooling off the earth, and returning to a more comfortable standard of living. The government needs to create prompt and consistent measures to make alternative fuels popular in the basket of goods bought by American consumers. Embracing this would project her commitment to curbing GGE (including the carbon footprints). By current standards, the fact that prices of fossil fuel energy seem to be consistently increasing (the aftermath of the Russian-Ukraine war) presents a vital opportunity to see alternative fuels as indeed an alternative.

6. Suggestions for Future Work

This study examined the relationship between conventional fuel and alternative fuel with GGE from buses. Future researchers may be interested in factors underlying the demand for these energy sources and the best techniques that can be helpful in seamlessly switching the attention of consumers from conventional to alternative energy.

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