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Contribution of Road Transport to the Attainment of Ghana's Nationally Determined Contribution (NDC) through Biofuel Integration

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Abstract: Since the Paris Agreement in COP21, many countries around the world, including Ghana and Thailand, have established a Nationally Determined Contribution (NDC) to reduce greenhouse gas (GHG) emissions, with first update recently in COP26. With Ghana's ongoing effort at COP26 to change its baseline to 2019, this study established a detailed Ghana vehicle ownership model with necessary transport parameters to construct an energy demand model to provide insight for reducing GHG emission contributions from road transport through biofuel (both bioethanol and biodiesel) potential by recourse to a Low Emission Analysis Platform (LEAP), with two scenarios of development from Thailand's best practice for policy recommendation, which are alternative (ALT), with up to E20/B20, and extreme (EXT), with up to E85/B50, for new vehicles. In each case, energy demand and GHG emissions were analyzed from detailed data on Ghana's transport sector to show potential benefit from biofuel usages. From Ghana's transport sector contribution to NDC, 8.4% and 11.1% of GHG emission reduction in 2030 can be achieved with a 0.13% and 0.27% additional arable land requirement from ALT and EXT scenarios. Policy recommendation and implication were also discussed.

Keywords: greenhouse gas emissions; Ghana road transport; energy demand model; biofuel integration; arable land requirement

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Citation: Saisirirat, P.; Rushman, J.F.; Silva, K.; Chollacoop, N. Contribution of Road Transport to the Attainment of Ghana's Nationally Determined Contribution (NDC) through Biofuel Integration. *Energies* **2022**, *15*, 880. https://doi.org/10.3390/en15030880

Academic Editors: Dolf Gielen and Kun Mo Lee

Received: 21 November 2021
Accepted: 18 January 2022
Published: 26 January 2022

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1. Introduction

Global warming has become a one of the most important issues of all economies in the world. Greenhouse gas (GHG) emissions contributes to the increase of global average temperature and, hence, is life-threatening for a number of species [1]. This has alerted the world to managing emissions and the consequent global warming potential while maintaining the energy-dependent ongoing development. The 3rd Conference of the Parties (COP) in 1997 resulted in the Kyoto Protocol [2], which was superseded by the Paris Agreement [3] adopted in COP21. The Paris Agreement requires the countries to commit the Nationally Determined Contribution (NDC) and update it every five years. COP26 in the United Kingdom welcomed the first update of the NDC, where most countries announced an ambitious emission reduction target to keep the global temperature increase under 1.5 °C [4]. The majority of the developed countries committed to over 50% GHG emission reduction by 2030 (compared to the 2005 level) in order to pave the pathway toward climate neutrality by 2050. As for Ghana, the intended NDC announced in 2015 aimed to *unconditionally lower its GHG emissions by 15 percent* (11.1 $MtCO_{2e}$) *relative to a business-as-usual (BAU) scenario emission of 73.95 $MtCO_2e$ by 2030*, and to additionally reduce emissions by 30 percent (22.2 $MtCO_{2e}$) *on the condition that external support is made available* (Figure 1) [5]. These targets were replaced by more stringent ones in the updated NDC presented at COP26 [6]. Unconditional mitigation measures in all relevant sectors would result in 8.5 $MtCO_{2e}$ GHG reductions by 2025, and 24.6 $MtCO_{2e}$ by 2030. Additional conditional measures have the potential to achieve an increment of 16.7 $MtCO_{2e}$ by 2025, and 39.4 $MtCO_{2e}$ by 2030, if financial support is made available. The BAU scenario emission is being recalculated with 2019 as the base year.

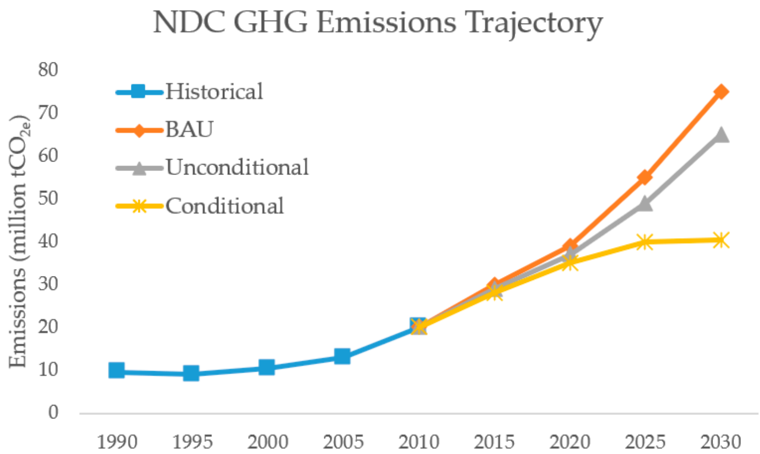

Figure 1. Ghana's GHG emission reduction trajectory in the NDCs [5].

The transportation sector makes a significant contribution to global GHG emissions and, thus, owns large potential for emission reduction. The transportation sector accounts for 14.3% of the total GHG emissions as of 2010, with 14% and 0.3% as direct and indirect emissions, respectively [7]. The statistics are similar in Ghana, where the transportation sector is the third largest contributor to the GHG emissions, making up to 17% of the total emissions [8]. Transportation in Ghana includes road, rail, marine, and aviation, and communication networks are centered in the southern region. The road transport contributes to 95% of freight and passenger carriers [9]. About 84% of passenger trips are made with public transport, mainly by low occupancy mini-buses and modified passenger vans, which are imported used cars. These vehicles have poor fuel economy and high GHG emissions [10]. This is projected to increase exponentially as a result of vehicle fleet accumulation that corresponds with the rapid GDP growth [11], as shown in Figure 2 [12]. Appropriate planning for GHG emission reduction for new and existing vehicles is inevitable to be able to achieve the updated NDC. In addition, even though Ghana has set ambitious targets to reduce GHG emissions by 4439.4 kTOE and 1338.4 kTOE by low carbon electricity generation and scale-up renewable energy penetration, there has been no plan on vehicle electrification, which could facilitate further decarbonization.

However, the only transportation-related policy action that appeared in the annex of the updated NDC is the *expansion of inter-and-intra-city transportation modes*, which contributes to 109.9 $ktCO_2e$ emission reduction. This aligns with *scaling up sustainable mass transportation*, which was mentioned as a policy action in the initial NDC. This policy must be coupled with public communication measures to incentivize people to use more efficient mass transport systems, rather than their own private cars or low occupancy vehicles. This action is supposed to involve the adoption of an urban mass transport system in terms of roads and rails to reduce vehicle traffic and cut down energy demand and, consequently, reduce GHG emissions [13,14]. There was no mention of policy actions contributing to alteration of fuel types to lessen GHG emissions.

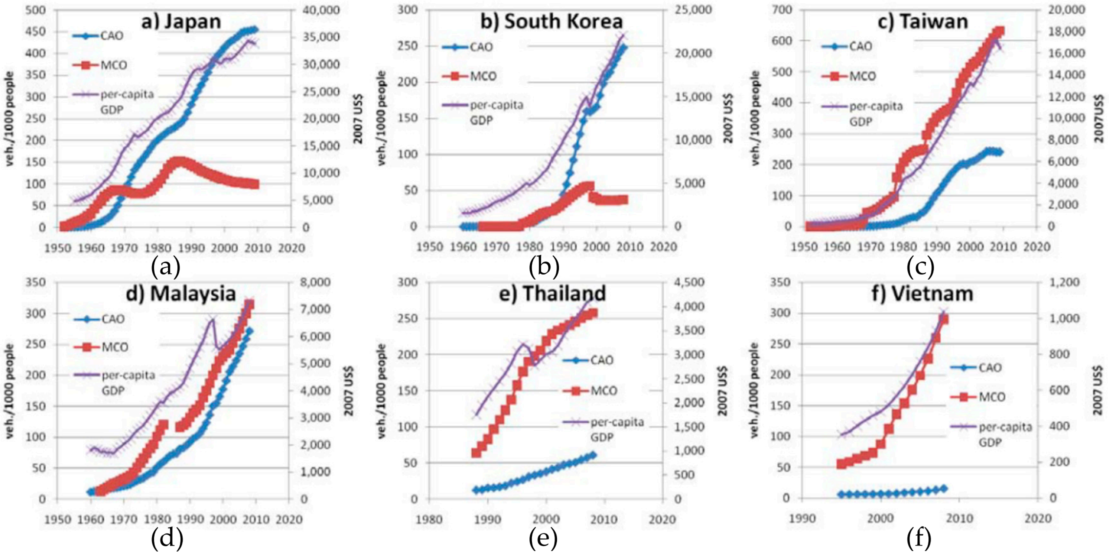

Figure 2. Historical ownership trends of car (CAO) and motorcycle (MCO) and GDP per capita [12] (**a**) Japan, (**b**) South Korea, (**c**) Taiwan, (**d**) Malaysia, (**e**) Thailand, and (**f**) Vietnam.

There have been various alternative fuels studied and used around the world. Biofuels, such as ethanol and biodiesel, are widely used to blend with gasoline and diesel in order to lower the reliance on fossil fuels. The United States [15] and the European Union [16] have various policy actions to accommodate biofuel substitution in the transportation sector in their territories. Usage of biofuels is primarily determined by biofuel crops available in the country. The United States and Brazil use corn and sugarcane to produce bioethanol [17], while China uses corn, wheat, and sweet sorghum [18]. In contrast, Malaysia relies heavily on palm-based biodiesel [19]. Sub-Saharan Africa also has large potential of biofuel usage in the region, though it needs a careful plan to balance between food production and GHG emission reduction [20]. Electrification can be another means for decarbonization, especially for non-agricultural-based countries. Battery electric vehicle is seen as a promising technology for a light duty vehicle in Europe, though it needs to be more competitive in terms of cost and social acceptance in order to achieve a large-scale penetration [21]. A study in the United States showed that government incentives are still needed to increase the market share of electric vehicles [22]. Similarly, China [23] and Japan [24] are also implementing sets of climate change-related policies to promote vehicle electrification. Though an electric vehicle may not be financially feasible at a first glance, which halts its penetration in most countries, it can be cheaper than an internal combustion engine vehicle with the consideration of GHG emissions throughout its life cycle, as well as carbon credit being implemented [25]. Apart from biofuel and electric vehicles, natural gas (NG) can be another alternative fuel with lower carbon emission, especially during transition to renewable fuels [26]. Since the initial investment on NG-based vehicles is not significantly different from oil-based vehicles, it can be easier to encourage the public to use them [27]. Appropriate policy and strategy to adopt these alternative fuels in Ghana will lead to far more reduction of GHG emissions from the transportation sector and, consequently, contribute to the targets committed in the NDC.

Thailand has been doing very well in promoting biofuel utilization in the transportation sector, in both ethanol in light duty vehicles and biodiesel in heavy duty vehicles [28]. This is due to its potential in cassava and molasses for ethanol production, and in palm oil for biodiesel production [29]. Electric vehicles have also been included in its Energy Efficiency Plan since 2015, as one of the measures to improve energy efficiency [30]. A study by the three electricity authorities revealed a goal to increase the number of electric vehicles up to 1.2 million by 2036 [31]. NG used as vehicle fuel has been successfully completed with government subsidies since 1993, sharing with major NG consumption in power sector [32]. Currently, NG consumption declines with NG price lifting to the actual market without government subsidies. Comparing between Thailand and Ghana, both countries have a similar tropical climate (located in tropical-equator zone, warm temperature, and high humidity of 26–27 °C and 70–85%RH) population density (about 750 thousand per square kilometer), and high ratio of arable area per capita (ranked at 61st and 82nd of 205 countries) [33,34]. Therefore, Thailand can serve as a good role model for biofuel integration and electrification in the transportation sector with an aim to reduce GHG emissions. Ghana's agro-ecological characteristics are suitable for planting biofuel crops, e.g., cassava, maize, sorghum [35], and a recent study showed potential of using the current energy surplus for electric vehicle charge [36]. As, in Ghana, new vehicles are generally imported used car from developed European countries, the number of electric vehicles can possibly expand following the European trend. NG vehicles are considered to have cleaner fuel [10], especially for large cities with traffic congestion issue, i.e., Accra, Kumasi. Ghana will have more NG potentials than Thailand as it has NG supported by the West Africa Gas Pipeline (WAGP). Ghana can refer to successful policy actions to promote these alternative fuels in Thailand to make use of its biofuel potential and excessive electricity production capacity. As both are developing countries, forecast in growth of vehicle fleet would also follow a similar trend, which is rather different from developed countries [37].

This study aims to indicate pathways to emission reduction in Ghana's transportation sector, particularly through biofuel integration, along with vehicle electrification and NG utilization, referring to good practices in transportation policy and planning of Thailand. Vehicle ownership models are developed to quantify and project the vehicular fleet until 2036 (from Thailand Integrated Energy Blueprint (TIEB)) and input to the Low Emission Analysis Platform (LEAP) [38] to assess the total energy demands and resulting GHG emissions. Two different scenarios, namely alternative scenario (ALT), which is based on the practices of Thailand, and extreme biofuel integration scenario (EXT), are used for the comparison with the business-as-usual (BAU) case. A policy recommendation is to be made following the outcome of the scenarios to promote additional contribution from the transportation sector to the updated NDC.

2. Methodology

The energy demand and GHG emissions were analyzed using the bottom-up approach due to its capability in indicating pathways of policy impacts. The calculation was performed based on the LEAP's algorithm, defined by a simple engineering relationship, as follows (1):

$$ED_{ij} = NV_i \times VKT_i \times SF_{ij} \times FE_{ij} \times HV_j, \quad (1)$$

where ED_{ij} is the energy demand (MJ) of vehicle category 'i' using fuel 'j', NV_i is the number of vehicle, VKT_j is the vehicle kilometer of travels (km), SF_{ij} is the fuel share (%), FE_{ij} is the fuel economy (liter or kg/km for fuel or kWh/km for electric vehicles), and HV_j is the fuel lower heating value (energy unit/physical unit of fuel). Then, the road transport energy demand can be integrated from all vehicle types and fuels, so that the considered measures or focusing policy can be analyzed and tracked. Afterward, GHG emissions can be calculated by multiplying the energy demand with the Emission Factor (EF), giving emission quantity per unit consumed energy. All analyses in this research were done using the Low Emission Analysis Platform (LEAP), a commercial software tool which is widely used for energy planning and climate change mitigation assessment [38].

2.1. Data Collection

Ghana's road transport is mainly made up of both public and private passenger vehicles and freight vehicles [39]. Private vehicles account for the majority of road vehicles, while public vehicles mostly belong to institutions. Historical data acquired from the Driver and Vehicle Licensing Authority (DVLA) of Ghana indicates that the majority of road transport is made up of private non-commercial vehicles. These include sedans, SUVs, and vans used for personal purposes. For data entry, vehicle data obtained from

DVLA were grouped into seven main categories, based on vehicle function and technical characteristics [16]. Table 1 shows vehicle categorization adopted for this research, and historical record of vehicle registration is shown in Figure 3.

Table 1. Categories of vehicles for road transport in Ghana.

Vehicle Category	Abbreviation	Description	Uses
Motorcycle and tricycle	MC	2- and 3-wheelers	Private passenger (lately tricycles) used for commercial purposes
Private Vehicles	PC	Include all sedan, SUVs, and Vans. Engine size up to 3.5 L	For personal/private passenger and freight non-commercial.
Taxi-Commercial vehicles up to 2 L	Taxi	All sedans with engine capacity up to 2 L	Used as Taxi for public commercial passenger transport
Mini-Buses and Vans-Commercial vehicles above 2 L	miniBus & Van	Smaller capacity vans and buses.	For commercial passenger and freight transport
Buses & Coaches	Bus & Coach	Larger capacity vehicles	Passenger and freight
Heavy-duty trucks	HD Truck	Without trailers (Capacity 16–22 tons)	For fright and construction purposes
Articulated trucks *	ARTICS	Mostly with trailers (Capacity from 24–32 tons)	Freight transport

Note: * Articulated trucks is a truck which has a permanent or semi-permanent joint in its construction, allowing the vehicle to turn more sharply.

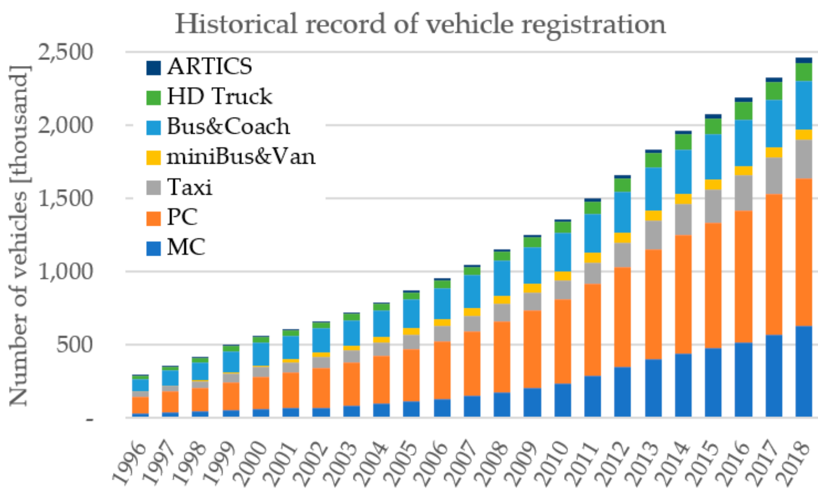

Figure 3. Historical record of vehicle registration [8].

Available historical data (1996–2018) in Figure 3 enables validation of a vehicle number model which is used to project vehicle number development between 2019–2036. The projected vehicle numbers are assembled with 'car survival' and vintage profile', to define vehicle stock-turnover rate in the LEAP program.

Besides, historical fuel consumption in Ghana which was reported from the National Petroleum Authority (NPA) of Ghana [40] was used as validation data for fuel demand calculation from LEAP. It must be emphasized that this data is the whole country's fuel demand. Nevertheless, the majority of Ghana's fuel consumption depends on the road transport sector, so it can be used to validate calculated results in this study. Other necessary data, such as Vehicle Kilometer Traveled (VKT) and Fuel Economy (FE), were collected from literature [13,14,39,41–43]. Note that the corrected averaged values of VKT and FE were assumed for all vehicles in each category, which can vary significantly, i.e., private vehicles include different vehicle segments: from small sedans up to large SUVs (with various engine size: 1.3–3.5 L), while commercial vehicles include small pickup-trucks and station wagons.

2.2. Model Development

Historically, economic development has been strongly associated with the transportation demand, particularly in the road vehicle numbers [11,37,44]. In this study, the vehicle ownership models are described in two functions, e.g., logistic and logarithmic, following literature [45,46]. In brief, the logistic vehicle-ownership (VO, vehicle number per capita) model is defined with maximum saturation level of car per capita (S), simplified from Button et al. [37], as follows Equation (2):

$$\ln\left(\frac{VO}{S - VO}\right) = B + \mathrm{a}.ln(GDPpCap), \tag{2}$$

where *GDPpCap* is gross domestic product per capita, and a and b are model coefficients. Otherwise, logarithmic function is used for the public low occupancy vehicles (miniBus & Van) and the heavy-duty trucks (HD Trucks and ARTICS). Logarithmic function was chosen because the number of these vehicles is not related to the saturation level (*S*), and the function will not over-predict in long-term projection, as used in References [45,46]. The developed models of vehicle population in vehicle categories according to Table 1 are shown with adjusted coefficient of determination (adjusted R-squared, R^2_{adj}) in Table 2.

Table 2. Developed models of vehicle population.

Vehicle Category	Model	R^2_{adj}
MC	$\ln\left(\frac{\mathrm{VO_{MC}}}{600-\mathrm{VO_{MC}}}\right) = 2.656\ln(\mathrm{GDPpCap}) - 23.450$	0.993
PC	$\ln\left(\frac{\mathrm{VO_{PC}}}{812-\mathrm{VO_{PC}}}\right) = 1.237\ln(\mathrm{GDPpCap}) - 12.477$	0.984
TAXI	$\ln\left(\frac{\mathrm{VO}_{TAXI}}{812-\mathrm{VO}_{TAXI}}\right) = 1.616\ln(\mathrm{GDPpCap}) - 16.671$	0.981
miniBus & Van	$\mathrm{VO_{miniBus\&Van}} = -0.349\ln(\mathrm{GDPpCap}) + 4.946$	0.873
Bus & Coach	$\ln\left(\frac{\mathrm{VO_{Bus\&Coach}}}{812-\mathrm{VO_{Bus\&Coach}}}\right) = 0.254\ln(\mathrm{GDPpCap}) - 6.171$	0.964
HD Truck	$\mathrm{VO}_{HD\ Truck} = 3.859\ln(\mathrm{GDPpCap}) - 24.884$	0.994
ARTICS	$\mathrm{VO}_{ARTICS} = 1.112\ln(\mathrm{GDPpCap}) - 7.308$	0.966

VKT and FE represent transport activity and energy intensity for energy demand and GHG emission calculations. Table 3 outlines the base year values for these two variables, equivalent for each considered scenario. The data was extracted from limited sources [39,43] and analyzed according to involved parameters, i.e., vehicle size, technology, emission regulation level. The fuel economy data of EV has not yet been surveyed in Ghana. Therefore, the energy consumption of EV is assumed to be equal to 30% of conventional vehicles. This is estimated from the relationship between fuel economy of conventional vehicles and that of the battery EV, found in Reference [47].

Table 3. Average VKT and FE for the base year [39,43].

Vehicle Category	Average VKT (km)	Average FE (Lge */100 km)		
		Gasoline	Diesel	NG
Motorcycle and tricycle	12,500	3.7	-	-
Private Vehicle	25,000	9.7	8.8	10.2
Taxi-Commercial vehicle	30,000	9.7	8.8	10.2
Mini-Bus and Van	30,000	9.8	9.2	11
Bus & Coach	15,000	-	30.1	-
Heavy-duty truck	15,000	-	33.1	-
Articulated truck	12,000	-	33.1	-

Note: * Lge means liter of gasoline equivalent.

2.3. Validations

The developed model was validated by comparing calculated results obtained from LEAP [38] with historical records for both vehicle population and energy demand. As mentioned above, vehicle registration and fuel demand records were taken from DVLA [14] and NPA [42], respectively. Calculated vehicle numbers from the logistic and logarithmic functions fit well with the historical data, as shown in Figure 4. On the other hand, the calculated energy demands are lower for both diesel and gasoline fuels, as shown in Figure 5. The calculated values tend to be higher than the historical records. Noticeable difference in diesel fuel indicates that some portion of diesel fuel is consumed by other vehicles and equipment, i.e., agricultural and industrial sectors, which is slightly different from the assumption that the entire fuel usage is attributed to transport sector. Yet, the transport sector remains the largest contributor to fossil fuel usage [48], and the model is adequately robust for the calculation. Better agreement between actual and calculated values in gasoline fuel indicates that gasoline fuel demand depends heavily on the road transport sector.

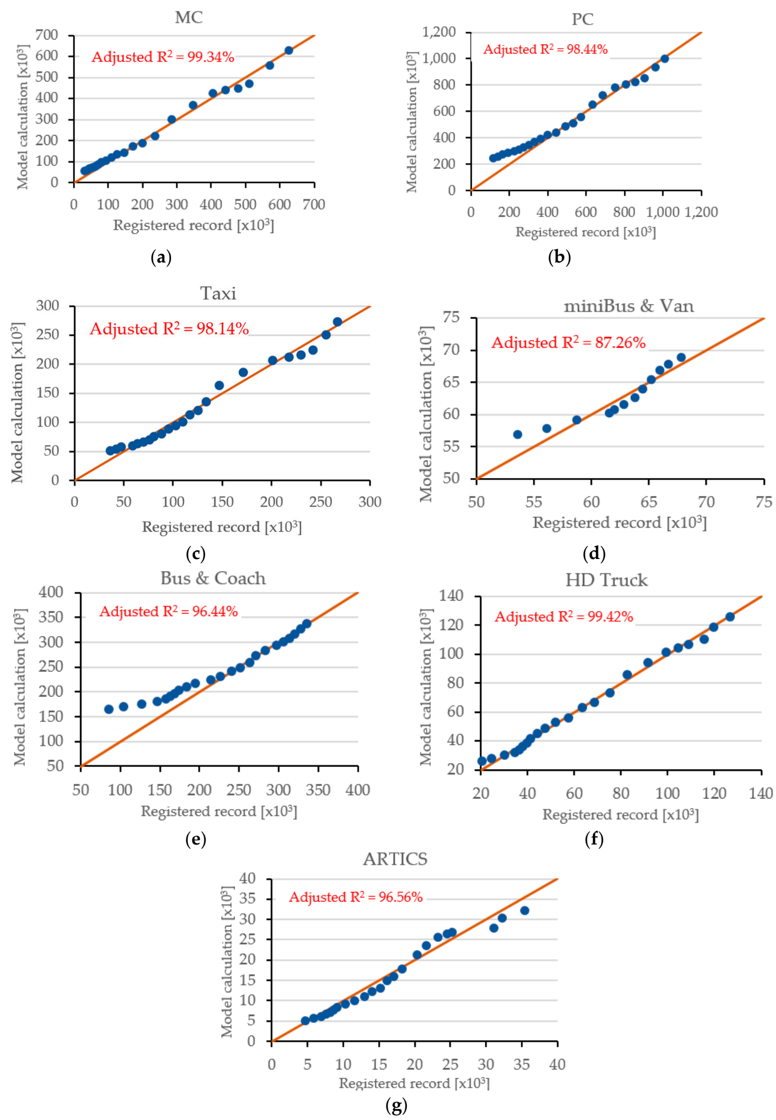

Figure 4. Validation of vehicle population models (**a**) Motorcycle, (**b**) Private vehicle, (**c**) Taxi, (**d**) Mini bus and Van, (**e**) Bus and Coach, (**f**) Heavy-duty truck, and (**g**) Articulated truck.

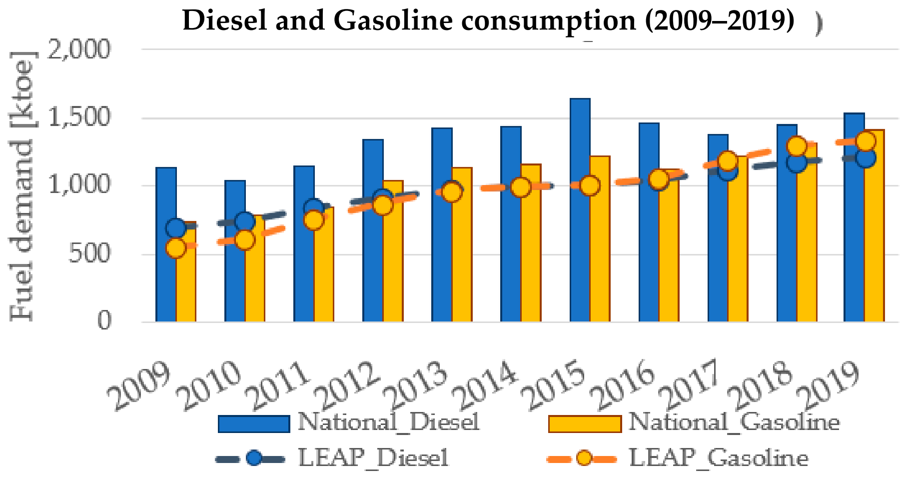

Figure 5. Validation of energy demand calculation.

2.4. Greenhouse Gas Emission Calculation

In this study, GHG emissions were calculated according to the Tier-I Intergovernmental Panel on Climate Change (IPCC) methodology [49]. This study focuses on the use phase GHG emission calculation (Tank-to-Wheel) to be comparable with the NDC target. Using the LEAP feature of Technology Environmental Database (TED), the amounts of GHG emissions can be calculated from the quantity of fuel consumption in Equation (1) by described vehicle technology level in various vehicle types and segments. The GHG emissions from consumed fuels are carbon-dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Non-CO_2 emissions were considered according to Ghana's NDC [6], as well as because a use of NG has its specific emission of methane. IPCC recommended that all GHG emissions should be reported in a mass unit of carbon dioxide equivalent (CO_{2e}), by multiplying the emission quantity with its Global Warming Potentials (GWP, equaled to 1 for CO_2 [49]). GHG emissions are calculated as followed Equation (3):

$$GHG_{ijk} = ED_{ij} \times EF_{ijk} \times GWP_k, \tag{3}$$

where GHG_{ijk} is the GHG emission type 'k' (kg CO_2-equivalent) produced from vehicle category 'i' using fuel 'j', EF_{ijk} the emission factor (kg/MJ), and GWP_k the global warming potentials (kg CO_{2e}/kg of emission 'k'). The GWP_k are shown in Table 4.

Table 4. Global warming potential of consumed fuel.

GHG Emission	GWP_k (kg CO_2-Equivalent/kg of Emission 'k')
CO_2	1
CH_4	25
N_2O	298

2.5. Scenario Definitions

There are three scenarios considered in this study. First, the Business as Usual (BAU) scenario was defined from the current situation, as a baseline trend of energy consumption and GHG emissions in the road transport sector. The other two scenarios were developed as the guideline measures for biofuel integration in two possible levels of GHG mitigation, namely the alternative (ALT) and extreme (EXT) scenarios. In both the ALT and EXT scenario, the share of NG vehicles was included for the transport sector in the same approach to increase more cleaner gaseous fuels as in the power generation sector [10,50]. On the other hand, electric vehicles were also included for motorcycles, private passenger cars, taxis, mini vans, and buses, followed the "Drive Electric Initiative (DEI)" supported by the Energy Commission, Ministry of Energy of Ghana [51]. Electric vehicle penetration will indicate the impact of vehicle fuel economy improvement. Gas vehicles and electric vehicles will each achieve 10% by 2030 in both ALT and EXT scenarios by replacing shares of gasoline and diesel vehicles, proportionally (Figure 6).

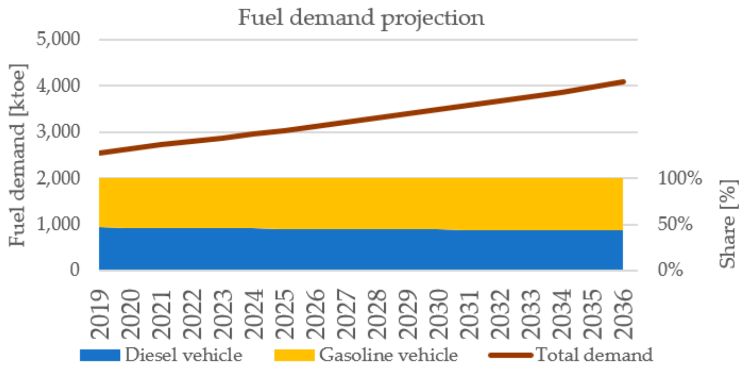

Figure 6. Fuel demand projection (BAU scenario).

Biofuel integration was described by considering the case study of Thailand. Anhydrous ethanol (less than 1% water) has been proven to replace some portion of gasoline in various blending fractions, namely gasohol E5, E10, E20, and E85. The descried numbers represent ethanol blending fraction in fuels, i.e., E20 is the blending of gasoline and ethanol fuels, with a fraction of 80% and 20%, respectively. In general, vehicles will have a maximum applicable limit of gasohol fuel specified in the vehicle handbook. Besides, the retrofit kits are widely available to increase this applicable limit, beyond the vehicle specification. However, the use of high blended gasohol, i.e., E20 and E85, is limited with ethanol production capacity; nevertheless, the Flex Fuel Vehicle (FFV), which can use wide types of gasohol fuels, is supported in many countries [52]. On the other hand, the methyl-ester of fatty acids, namely biodiesel, which is derived from vegetable oils or animal fats, is the fossil fuel replacement for a diesel vehicle. In the contrary, the limit of biodiesel blending fractions has stringent manufacturer's cautions in that the use of biodiesel without being essentially careful may cause severe damage on many vehicle parts. Currently, the biodiesel limit varies in different countries, depending on different national policies and available biodiesel resources, as well as regional weather. Biodiesel is not good in cold flow properties, so it is more favored in warm regions. Today, the maximum blending fraction of biodiesel B20 succeed as voluntary program in some tropical countries, e.g., Indonesia, Thailand, Brazil [53]. In contrast, there is an ambitious target to push forward biodiesel blending fraction, achieving B50 as a voluntary measure used in Indonesia [54,55].

According to the aforementioned, ALT and EXT scenarios were defined with probable and ambitious targets of new gasoline and diesel vehicles which will annually replace registered stock vehicles, according to a stock-turnover mechanism. Blending ratios of biofuel in both scenarios were adopted according to those that have been implemented in Thailand, i.e., gasohol E5, E10, E20, and E85 and biodiesel B5, B10, and B20. In addition, the biodiesel B50 was added for the ambitious measure in the EXT scenario. New vehicles were defined to gradually switch from fossil fuel to using biofuel every five years, starting from 2020 until 2031. The scenario starts from 2020, the same period as the Ghana's Strategic Program at COP26. Figure 7 and Table 5 show the scenario definitions and its timelines.

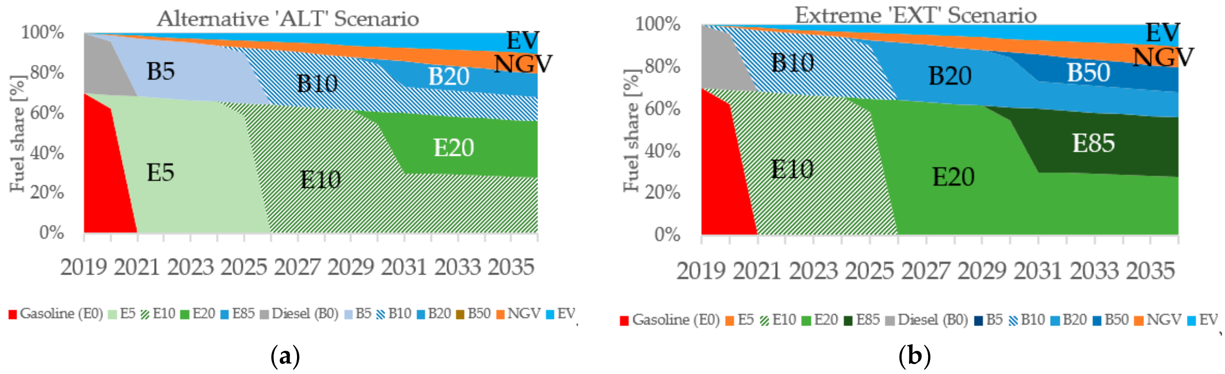

Figure 7. Graphical chart of biofuel integration in the considered scenarios for new light duty vehicles: (**a**) alternative scenario (ALT) and (**b**) extreme scenario (EXT).

Table 5. Scenario definitions for biofuel integration (Ethanol, EX; and Biodiesel, BX).

		2020 (Base-Year)	2021	2025	2026	2030	2031
BAU		There are no gasohol or biodiesel measures (E0 & B0).					
ALT	Ethanol (gasoline replacement)	E0: E5 = [90%:10%]	E5 [100%]	E5: E10 [90%:10%]	E10 [100%]	E10: E20 [90%:10%]	E10: E20 [50%:50%]
	Biodiesel (diesel replacement)	B0: B5 = [90%:10%]	B5 [100%]	B5: B10 [90%:10%]	B10 [100%]	B10: B20 [90%:10%]	B10: B20 [50%:50%]
EXT	Ethanol (gasoline replacement)	E0: E10 = [90%:10%]	E10 [100%]	E10: E20 [90%:10%]	E20 [100%]	E20: E85 [90%:10%]	E20: E85 [50%:50%]
	Biodiesel (diesel replacement)	B0: B10 = [90%:10%]	B10 [100%]	B10: B20 [90%:10%]	B20 [100%]	B20: B50 [90%:10%]	B20: B50 [50%:50%]

In the ALT scenario, new gasoline vehicles will switch to gasohol in the final share of E10 and E20, 50% each, and new diesel vehicles are defined to switch from using diesel fuel to the biodiesel share of B10 and B20, likewise with a shared 50% each. Besides, the ambitious target was defined in the EXT scenario. The final 50% share of new vehicles is specified for gasohol E20 and E85, on new gasoline vehicles, and biodiesel B20 and B50, on new diesel vehicles.

3. Results and Analyses

3.1. Impacts on Energy Demand

Figure 8 shows the impacts of biofuel integration, NG vehicle, and electric vehicle penetration on energy demand of the road transport sector. The calculated results show a contrast between BAU scenario and the two others. Besides, the total energy demands are similar in the ALT and EXT scenarios. This result indicates that the electric vehicle penetration can reduce total energy demand in road transport due to its higher energy conversion efficiency compared to all combustion engine vehicles. On the other hand, the biofuel integration and NG vehicles cannot help in reducing total energy demand but replaced conventional fossil fuel (gasoline and diesel fuels). Figure 9 shows the fuel switching comparing between conventional fossil fuels (gasoline and diesel) and alternative fuels (ethanol, biodiesel, electricity, and NG). By gradually increasing alternative fuels with better vehicle fuel economy, forecasted conventional fossil fuels will be reduced more than alternative fuel demand under the same assumption on number of vehicle and vehicle kilometer of travels, leading to net energy reduction from fuel switching.

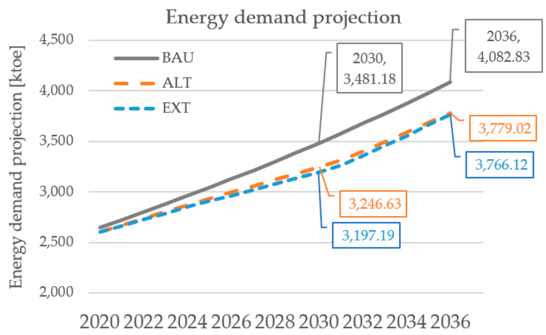

Figure 8. Energy demand projection.

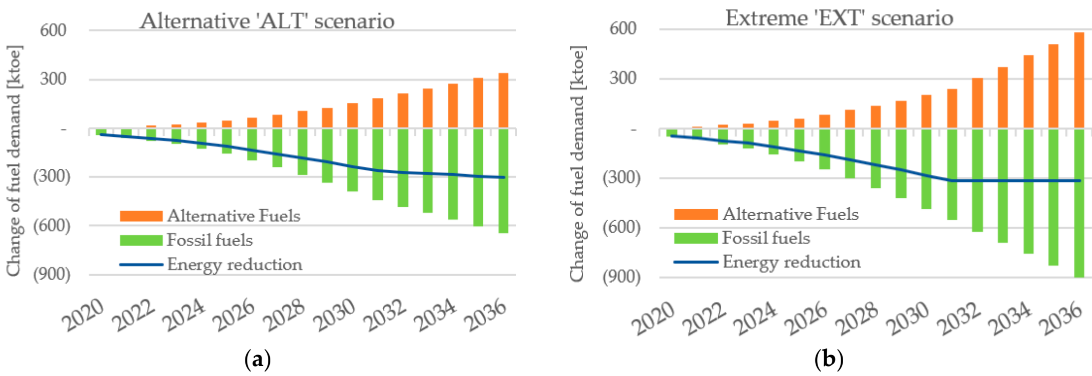

Figure 9. Fuel switching and energy reduction: (**a**) alternative scenario and (**b**) extreme scenario.

3.2. GHG Emission Mitigation

Figure 9 shows the projection of GHG emissions from the road transport sector. The results show that the road transport sector will contribute to 14.2% of the whole country's GHG emissions (Figure 10) in 2030. ALT and EXT scenarios can tear down the GHG emissions by introducing the electric vehicle technology (by improving fuel economy) and biofuel integration (apply carbon neutral fuels). GHG emission of ALT and EXT scenarios was lower than BAU scenario by 8.4% and 11.1% in 2030, and by 11.0% and 16.7% in 2036. The results show that biofuel integration measures offer only a moderate effect on GHG emission mitigation because the considered measures applied on new vehicles. The conventional vehicles in the road transport system require a period of replaced time. On the other hand, the calculated results confirm that GHG mitigation measures should be diversified. In addition, the results indicate that the impact of biofuel integration has higher potential on GHG mitigation than the impact on reducing energy demand.

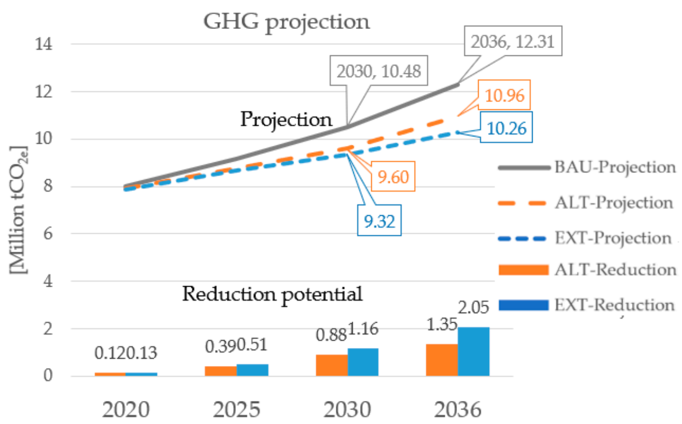

Figure 10. GHG emission projection.

3.3. Change in Biofuel Demand

This section indicates the calculated results of biofuel demand projection which must be prepared for sustainable biofuel development. Figure 11 shows the projection of ethanol and biodiesel demand according to ALT and EXT scenarios. The results indicate that ethanol demand will be higher than biodiesel demand for two reasons. First, the projection of energy demand from gasoline vehicle is higher than diesel vehicles, as shown in Figure 6. Otherwise, gasohol technology has more technology readiness than biodiesel in that the maximum blending fraction can be higher (85% of E85 compared to 50% of B50).

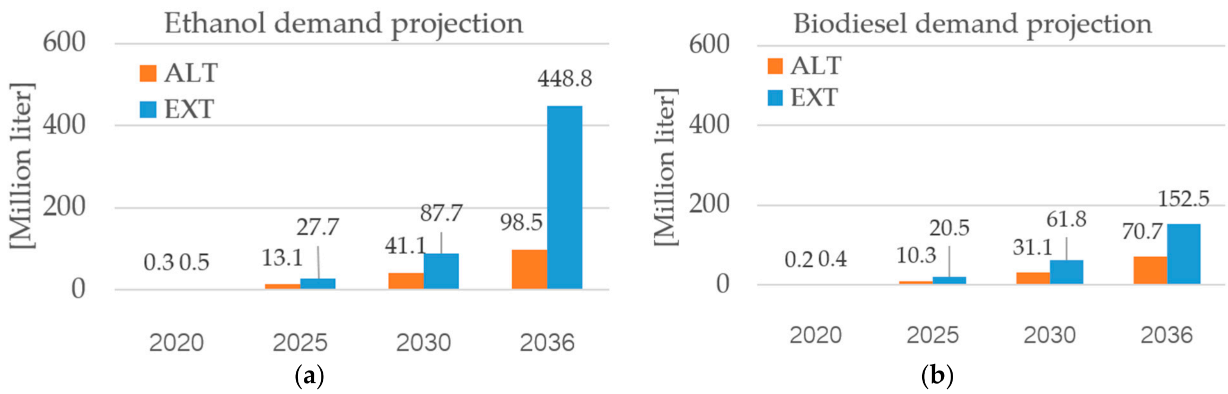

Figure 11. Projection of biofuel consumption in Alternative and Extreme scenario: (**a**) ethanol and (**b**) biodiesel.

On the other hand, the results show that biofuel demand has increased exponentially over the last five years. Biofuel promotion measures in this study are applied on the fuel share of new vehicle; therefore, biofuel demand will be gradually expanded. The stock vehicles which are not applicable for using biofuel will take a replacement period after endorsing measures. This behavior is good for the overall biofuel supply chain because the biofuel production can prepare to support the expansion of biofuel demand. This adjustment period includes preparation of farmland, growing periods of the biofuel crops, and construction periods for biofuel conversion industries, as well as the logistics of all biofuel supply chains.

4. Discussion

4.1. Land Preparation for Biofuel Crop Cultivation

Land preparation for biofuel crop cultivation is discussed in this section. The biofuel production yield by cultivation area (million liter/hectare, ML/ha) was taken from Ghana data surveyed by F. Kemausuor et al. [35]. Ethanol can be produced from cassava feedstock in the ratio to cultivation land of 18.75 ton/ha, or the ethanol yield is accounted for at 3000 L/ha. Besides, biodiesel can be produced from palm fruit feedstock in the ratio to cultivation land of 4.00 ton/ha, or biodiesel yield is accounted for at 6000 L/ha. Therefore, the cultivation area must be further prepared and give time for the biofuel crops to be ready for cultivation. The percentage of Ghana's arable lands are also determined by comparing to a total area of 147,827.40 ha [56]. Tables 6 and 7 show the biofuel resource preparation for ALT and EXT scenarios, respectively, up to about 1% arable land.

Table 6. Biofuel resource preparation for Alternative 'ALT' scenario.

	Ethanol			Biodiesel			Summary	
Year	**Demand [Million liter]**	**Feed Stock [Million ton]**	**Land Required [ha]**	**Demand [Million liter]**	**Feed Stock [Million ton]**	**Land Required [ha]**	**Required Arable Area [ha]**	**Percentage of Total Arable Land [%]**
2020	0.25	1562.5	83.3	0.20	133.3	33.3	116.66	0.00%
2025	13.13	82,062.5	4376.7	10.30	6866.0	1716.5	6093.16	0.04%
2030	41.12	257,000.0	13,706.7	31.09	20,724.6	5181.1	18,887.82	0.13%
2036	98.54	615,875.0	32,846.7	70.69	47,122.0	11,780.5	44,627.16	0.30%

Table 7. Biofuel resource preparation for Extreme 'EXT' scenario.

	Ethanol			Biodiesel			Summary	
Year	**Demand [Million liter]**	**Feed Stock [Million ton]**	**Land Required [ha]**	**Demand [Million liter]**	**Feed Stock [Million ton]**	**Land Required [ha]**	**Required Arable Area [ha]**	**Percentage of Total Arable Land [%]**
2020	0.52	3250.0	173.3	0.39	260.0	65.0	238.33	0.00%
2025	27.70	173,125.0	9233.3	20.53	13,685.3	3421.3	12,654.66	0.09%
2030	87.73	548,312.5	29,243.3	61.79	41,189.2	10,297.3	39,540.64	0.27%
2036	448.80	2,805,000.0	149,600.0	152.51	101,663.2	25,415.8	175,015.79	1.18%

4.2. Policy Considerations for Biofuel Integration

It can be seen from the results above that biofuel usage gradually increases with time until 2030 and sharply increases in 2036, in both ALT and EXT scenarios. This is due to the synergistic effects of large-scale replacement of vehicle fleets after 2030, and the increase in blending ratio of ethanol and biodiesel in gasoline and diesel, along with the increase in technology maturity of both fuels. In this study, rather than strictly follow the policy actions in Thailand by implementing the nationwide mandatory blending, obligation of biofuel usage was applied only to new vehicle fleets, even if it led to much slower penetration of biofuels in the country and, consequently, much less GHG emission reduction. There are two main reasons for this rather conservative assumption. One is that Ghana is a net fossil fuel exporter [40], where fossil fuels can be produced and used domestically, as well as exported to generate national income. Reduction in domestic production will affect the national economics, and it has to be done with caution. The other is the fact that the price of biofuel can be higher than gasoline or diesel, requiring adequate subsidy to gain public acceptance as the majority of the public will not be willing to pay significantly more for a cleaner fuel [57]. However, a preceding study showed that biofuel can be more economical than fossil fuels if its social benefits are taken into account [58]; hence, the two scenarios took into account the balance among national economic growth, public acceptance, and reduction of GHG emissions. This synchronizes well with the fact that, even though Ghana has made significant progress in reducing fossil fuel subsidies, it still continues to face public pressure to reinstate subsidies [59], especially when the international oil price is high [60]. Furthermore, as demonstrated above, that the land needed for biofuel crops is less than 0.3% and 1.2% of the total cultivation area in 2036 for ALT and EXT scenarios, respectively, competition between biofuel crops and food or feed crops would not happen. Farmers will be supported in the production of the biofuel feedstocks, and markets will be readily available. Since the availability of large continuous land has been identified as a barrier to the success of oil palm production in Ghana, small-holder plantations would be a better alternative. A good combination of policies for carbon-neutral fuel integration, management of fuel price structure, public communication, and good agricultural practices will result in gradual integration of biofuels, which can contribute to 11.0–16.7% of the *total* GHG emissions in the transportation sector compared to the BAU scenario within 15 years. Furthermore, additional national plan to decarbonize the entire transport system shall be considered, such as transport energy efficiency improvement (i.e., avoid-shift-improve measures) and scaling up the carbon-neutral fuel promotion, as well as the low emission electric vehicles.

4.3. Policy Considerations for NG Utilization and Vehicle Electrification

In both the ALT and EXT scenario, NG and electric vehicles are also planned to play significant roles in road transportation, with 10% share of all vehicles for NG, and 10% share of light duty vehicles for electric vehicles by 2036. Since Ghana has NG reserve and can import NG through the West Africa Gas Pipeline [61], the acquisition of NG should not be a big deal. The main issue would be regarding the technology acquisition and infrastructure development for NG vehicles. This issue is also applicable to the case of electric vehicles. The government could start developing infrastructure in urban area in the initial phase, and eventually expand to other areas. Another important concern regarding vehicle electrification is the energy sources for the electricity. At present, approximately 60% of the electricity is produced by thermal power plants. The government needs to gradually increase the share of renewable energy in electricity generation in order to ensure GHG emission reduction by shifting from an internal combustion engine vehicle to an electric vehicle.

5. Conclusions

This study indicated the two possible pathways, namely ALT and EXT scenarios, for GHG emission reduction in the transportation sector through biofuel integration, along with vehicle electrification and NG utilization, in order to achieve Ghana's updated NDC at COP26. The pathways were developed based on vehicular fleets projected by vehicle ownership models for developing countries, as well as energy demand and GHG emissions calculated by the Low Emission Analysis Platform (LEAP). The ALT scenario adopted the biofuel blending ratios implemented in Thailand, though it required biofuel blending with only a new vehicle fleet to maintain national economic competitiveness and to assure public acceptance. It also introduced NG and electric vehicles to follow the global trend. The EXT scenario maintained the assumptions of the ALT scenario, except for changes in blending ratios to the highest possible ones. Biofuel integration, along with the introduction of NG and electric vehicles, significantly reduced energy demand, though the difference between ALT and EXT scenarios was not notable. Energy demand of ALT and EXT scenarios was lower than the BAU scenario by 6.7% and 8.2% in 2030, and by 7.4% and 7.8% in 2036, respectively. On the other hand, it can be seen from the difference in GHG emissions in ALT and EXT scenarios that biofuel integration appreciably contributed to the reduction in GHG emissions. GHG emissions of ALT and EXT scenarios was lower than the BAU scenario by 8.4% and 11.1% in 2030, and by 11.0% and 16.7% in 2036, respectively. This amount of emission reduction could be achieved even if the biofuel mandates were only applied to new vehicle fleets due to the new vehicle technology compatibility with biofuel blends. The comparison between the land requirement for biofuel feedstock and the total cultivation area also indicated that the issue of land use competition with agricultural produces is unlikely to happen. NG would also play a significant role in both scenarios since Ghana has no challenge in NG acquisition, though the share of renewable energy in electricity generation would need to be carefully monitored. This is to ensure that electricity for charging EV will not emit significant GHG emissions when considering entire well-to-wheel emissions. The study demonstrated that a good combination of policy actions for clean fuel integration, management of fuel price structure, public communication, and good agricultural practices is necessary to achieve successful biofuel integration and, consequently, GHG emission reduction in Ghana's transportation sector. Furthermore, a transport decarbonization plan should be considered for the entire transport system, and the policy impact appraisal must be continuously updated, for effective GHG mitigation policy. These could be required to strengthen the GHG reduction capacity of the transport sector.

Author Contributions: Conceptualization, J.F.R. and N.C.; methodology, P.S.; software, J.F.R. and P.S.; validation, J.F.R., N.C., P.S. and K.S.; formal analysis, J.F.R. and P.S.; investigation, J.F.R.; resources, N.C. and K.S.; data curation, P.S.; writing—original draft preparation, J.F.R., P.S. and K.S.; writing—review and editing, N.C., P.S. and K.S.; visualization, P.S.; supervision, N.C.; project administration, N.C.; funding acquisition, N.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Science and Technology Development Agency (NSTDA) under the Postdoctoral Fellowship Program, contract number: NCR-MT-2563-10660-EN.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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