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Abstract

This paper seeks to analyze the evolution of the Bolivian vehicle stock in the mid-term and its policy implications. First, we analyze the relationship between income and vehicle ownership in the country during the period 1970 - 2017 through robust econometric techniques. Based on these results, we use an energy-mix accounting model programmed in General Algebraic Modelling System (GAMS) to analyze how the vehicle fleet and the derived demand of gasoline, natural gas and diesel oil evolved over time. Finally, we observe the trajectory of CO2eq in the transport sector for different types of vehicle categories. Our results prove that the relationship between vehicle ownership and per capita income is highly non-linear and we observe an excessive increase in the vehicle fleet during the last decade. Both of these results will speed up the saturation level of the vehicle fleet in Bolivia. With more equivalented vehicles (EV) on the roads, we expect that the consumption of derivatives will increase over the next years. Hence, we assume imbalances in diesel oil and gasoline production and a lower decarbonization path. Without an energy policy in the transport sector or any energy efficiency measures, the consumption of derivatives would grow 6.9 times and the total emissions of CO2eq would increase 7.93 times in the 2000-2035 period.

JEL Classification : H23, C25, L62, L9, O3, Q47, Q5, R4.
Keywords: Car ownership, integrated energy-transport modelling, energy-mix, emissions.

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Resumen

El presente estudio busca analizar la evolución del parque vehicular boliviano en el mediano plazo y sus implicaciones en políticas públicas. En primer lugar, se analiza la relación entre los ingresos y la propiedad de vehículos durante el período 1970 - 2017 mediante técnicas econométricas robustas. Con base en estos resultados, se utiliza un modelo contable de planificación energética programado en el Sistema de Modelaje Algebraico General (GAMS) para analizar cómo evolucionó la flota de vehículos y la demanda derivada de gasolina, gas natural y diésel en el tiempo. Finalmente, se observa la trayectoria del CO2eq en el sector transporte para diferentes tipos de categorías de vehículos. Los resultados muestran que la relación entre la propiedad de vehículos y el ingreso per cápita es altamente no lineal y que hubo un aumento excesivo de la flota de vehículos durante la última década; ambos factores acelerarán el nivel de saturación de la flota de vehículos en Bolivia. Con más vehículos equivalentes (EV) en las carreteras, se espera que el consumo de derivados aumente en los próximos años. Por lo tanto, se asume desequilibrios en la producción de diésel y gasolina junto a una trayectoria lenta de descarbonización. Sin la aplicación de una política energética en el sector transporte, ni medidas de eficiencia energética, el consumo de derivados se multiplicaría por 6,9 y las emisiones totales de CO2eq por 7,93 entre 2000 y 2035.

Códigos JEL: H23, C25, L62, L9, O3, Q47, Q5, R4.
Palabras Clave: Propiedad de automóviles, modelaje integrado de transporte de energía, combinación de energía, emisiones.

1. INTRODUCTION

During the last decades, economic growth in developing economies fostered growth of their transport sectors, resulting in larger vehicles stocks (World Bank, 2002; Bouachera and Mazraati, 2007) with higher demand for fuel and services around the world. Due to rapid urbanization, this scenario has been particularly noteworthy in cities (Button *et al*., 1993), with diverse and severe implications in the transport networks.

Since vehicles are the largest consumers of fuel and the growth of their fleet has a robust and positive correlation with economic growth, we expect to see an increase in the number of vehicles in developing countries. This framework opens up several dimensions for energy planning: i) pressure across the transport network; ii) degree of energy security and autarky; iii) energy price in the context of greater electromobility penetration; iv) emission of pollutants (Storchmann, 2005).

Increase in income has been historically correlated with increase in the demand for transport and for motorized vehicles (Dargay *et al*., 2007). When income increases, the share people destine to subsistence falls as they seek to increase their living standards. With regards to this, the present paper seeks to explore the paths of the first two dimensions defined, over close to fifty years in Bolivia. Our motivation is the economic boom the country has experienced in the last decade.

In addition, there is lack of research in this topic for countries of Latin America and the Caribbean. Most of the literature deals with developed countries and Asian developing countries (Dargay, 2001). Only a few studies and reports such as that of Dargay *et al*. (1999) and IMF (2005), consider countries around the world. The main results on transport networks research suggest that saturation levels (maximum level of vehicles per 1,000 people) in developing countries are lower than in developed countries, but the pressure on fuel demand is higher in the former.

This document examines trends of the vehicle fleet and ownership in Bolivia and projects their growth for the year 2035. To make a more precise analysis we first estimate the equivalent vehicle fleet[1]; then we estimate a Gompertz function and long-term elasticities to verify the non-linear effects of per capita income patterns on evolution of vehicle stock. Finally, we simulate vehicle fleets and derived demand for fuels over the coming 15 years.

The paper also discusses the assumption of response symmetry of demand and use of vehicles against an increase or decrease in per capita income. An increase in income could be expected to generate an increase in the demand for vehicles; however, a decrease in income would not have an influence of the same magnitude (Dargay *et al*., 2007). For these reasons it is important to consider the asymmetry that may exist in this relationship. This is a feature that will be dealt with in future research using a demand function allowing the response to a change in income to be different depending on whether income increases or decreases in the short-term.

[1] The different types of vehicles are transformed to be equivalent to a car.

In the second section, the document reviews the literature of previous studies that focus on the transport sector. The third section describes the historical patterns of vehicle demand and per capita income growth in Bolivia. The fourth section explains how to econometrically model the long-term relationship between income and vehicle ownership as a non-linear or log-linear function and presents the Energy Accounting Model programed in GAMS. In the fifth and sixth sections, we describe and analyze the results and state the major conclusions.

2. LITERATURE REVIEW

Research in developed countries focuses on the household level, with microsimulation [(Mannering *et al*., 1985; Meurs, 2003; Bjørner and Leth-Petersen, 2005; Woldeamanuel *et al*. (2009); Akay and Tümsel (2015)]. However, in developing countries, due to the lack of recent and disaggregated data, the studies are mostly at the aggregated level (Ogut, 2004).

Button *et al*. (1993) examine the factors of income, price of fuel, urbanization, and degree of industrialization that influence vehicle ownership in low-income countries using a quasi-logistic function. The document characterized a sigmoid-shaped path of vehicle ownership to evaluate the correlation of countries becoming wealthier and hence demanding more cars. The authors examine the increasing trends of car ownership – especially of commercial vehicles – for emerging countries.

Dargay, J., and Gately, D. (1997) examine the growth of car ownership to the year 2015 for OECD countries and some Asian economies to investigate the implications in energy demand and emissions. The authors relate car stock to income, population, prices, and technical characteristics – instead of estimating energy demand and fuel emissions directly – to derive the transport fuel demand.

Dargay and Gately (1999) observe the growth of cars and total vehicle stock to the year 2015 for OECD countries and several developing countries (*i.e.* China, India and Pakistan) during the 1960-1992 period for 26 countries. The model estimates the short- and long-run elasticities and the long-run relationship between car ownership and per capita income. As expected, the growth of vehicle ownership is highly explained as a function of per capita income and is defined by and S-shaped function.

Romilly *et al*. (2001) contribute by addressing new techniques to avoid uncertainties caused by some methods in car ownership modeling and forecasting. The authors model car ownership for Britain for 1953-1996 and forecast it to 2031. They propose five alternative methods by considering relationships between car ownership, income, motoring costs, and bus fares.

Medlock and Soligo (2002) modelled private motor vehicle ownership by considering related data from 28 countries with a wide range of incomes. The authors found that saturation varies across countries and that user costs are significant to explain car ownership. Contrary to regular literature, they found that income elasticity fell when countries became increasingly developed.

Dargay *et al.* (2007) built a model for vehicle saturation level as a function of observable characteristics for 45 countries worldwide. The pooled time series model considers the period 1960-2002 and makes projections of the vehicle stock to 2030. The authors also investigated the implications for future transportation oil demand and considered the assumption of symmetry[2] in the response of vehicle ownership to rising and falling income. This research is interesting, since they previously examine the hypothesis of hysteresis or asymmetry, showing that car ownership responded more strongly to rising than to falling income – Dargay (2001).

Bouchera and Mazraati (2007) model car ownership in India and its implications for fuel demand projections. This paper compares the use of logistic, quasi-logistic and Gompertz functions, using pooled data of seven Asian countries. Based on the latter, the authors determine a set of fuel consumption scenarios to make projections to 2030 for India. One of the main conclusions of this research is that the preference to choose one form over another for the functional form of the S-shaped function has no theoretical basis, so the preference must be based how well the data fits[3].

Finally, Ceylan, Baskan and Ozan (2018) deal with modelling and forecasting car ownership to 2035 in Turkey using multiple non-linear regressions. The model considers socio-economic and demographic indicators: income, gasoline price, car price, and number of employees. The document forecasts car ownership across four scenarios related to per capita income and gasoline prices.

3. THE PATTERNS OF VEHICLE OWNERSHIP

Table 1 summarizes the historical data of the transport sector in Bolivia for the period 1970-2017. The historical data of the vehicle stock in terms of the number of vehicles is compiled from the National Institute of Statistics of Bolivia (INE). Data on saturation levels, per capita GDP, population density, urbanization, and stock of vehicles (1970-2017), was obtained from the World Bank.

The first column shows the years included in the study. The following columns show the stock of vehicles, car ownership levels (the number of vehicles divided by population) and per capita GDP (in 2010 US dollars), as well as the average annual percentage change of these last the variables over the period. Table 1 also shows urbanization, expressed in percentage terms and used as a normalized variable (by taking the deviations from its mean). On the other hand, population density (which is also standardized) is calculated by dividing the total population in a certain area; square kilometers are used in this case. The next columns show saturation levels and the maximum saturation, with the latter determined by the maximum saturation rate of Dominican Republic. Bolivia is yet far from reaching its saturation levels, unlike other developing countries shown in the literature.
The historical data presented in this section aims to do an analysis of the sizable growth of Bolivia's automobile fleet in the entire 1970-2017 period, and especially the late 2000s. The section analyzes the speed of this growth and the variables related to it.

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[2] Which is well documented in Dargay, J. M. (2001). The effect of income on car ownership: evidence of asymmetry. Transportation Research Part A: Policy and Practice, 35(9), 807-821.

[3] Dargay et al. (2007) this document demonstrates the usefulness of the Gompertz function for simulating car stock, showing its flexibility. Also, the document shows that the quasi-logistic function underestimates car ownership compared to the Gompertz function, and that the logistic model usually estimates unrealistic car stock growth.

Table 1. *Historical data on income, vehicle ownership saturation, and population, 1970-2017*

Year	Car stock	% average growth (car stock)	Car stock/1,000	% Average annual change (car stock/1,000)	Urbanization (%)	Population density	Population	Per capita GDP
1970	32,000.00	-	7.10	-	21.24	4.07	4,505,778	1,393
1972	37,822.48	8.72%	8.05	6.47%	22.02	4.34	4,698,083	1,515
1977	57,444.71	8.72%	10.98	6.40%	24.09	4.83	5,233,677	1,745
1982	87,246.91	8.72%	14.95	6.38%	26.45	5.39	5,835,182	1,519
1987	132,510.43	8.72%	20.50	6.51%	29.42	5.97	6,464,732	1,289
1989	156,621.03	3.40%	23.30	2.59%	30.81	6.21	6,723,046	1,324
1990	170,274.68	1.69%	24.83	1.29%	31.54	6.33	6,856,244	1,358
1991	185,118.61	1.69%	26.47	1.29%	32.3	6.45	6,992,521	1,402
1992	201,256.58	1.69%	28.22	1.29%	33.08	6.58	7,131,707	1,397
1997	308,224.26	8.90%	39.16	6.77%	36.53	7.27	7,870,855	1,584
2002	433,915.00	7.08%	50.14	5.07%	39	7.99	8,653,345	1,624
2007	711,649.04	10.40%	75.38	8.49%	42.13	8.72	9,441,444	1,822
2012	1,358,700.94	13.81%	132.70	11.98%	45.97	9.45	10,239,004	2,122
2017	2,042,940.39	8.50%	184.85	6.85%	48.98	10.2	11,051,600	2,523

Source: Own preparation based on data from the World Bank and INE.

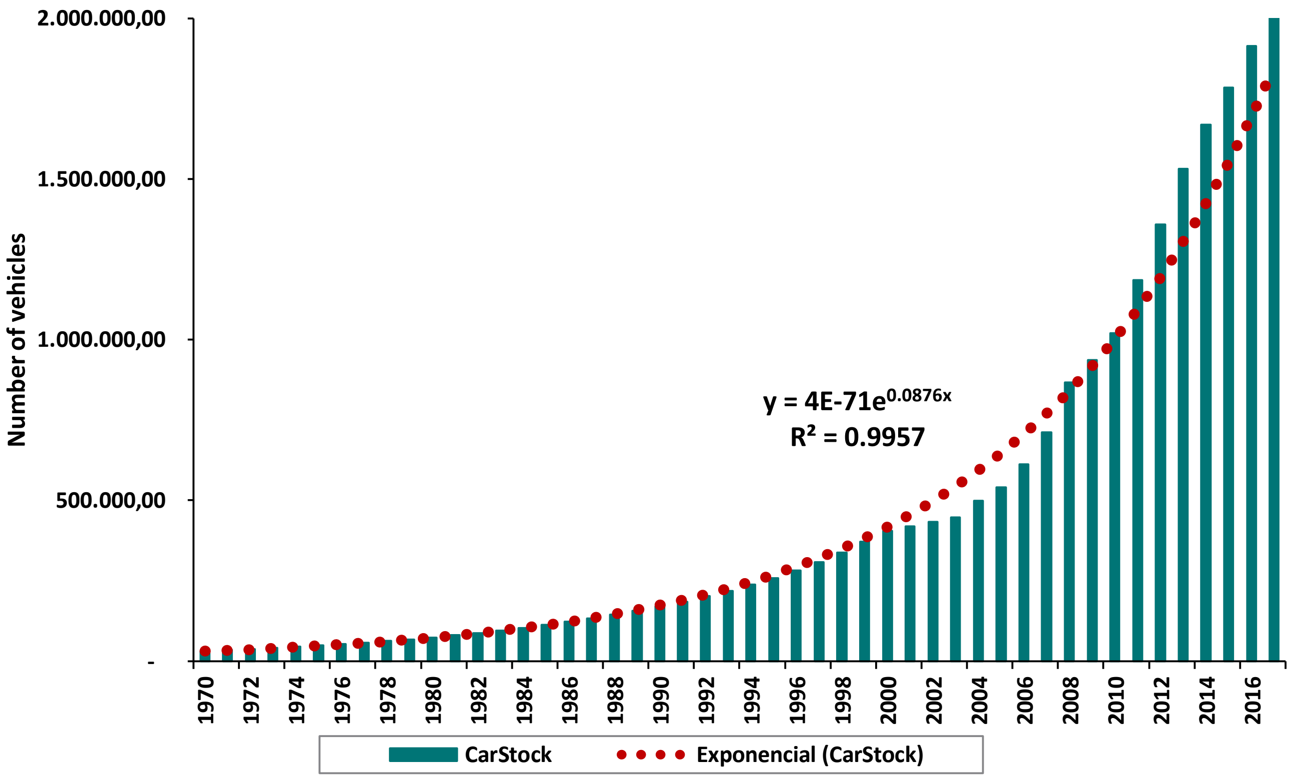
The historical trend of the car stock is a high rate of growth until the year 2017. In 2017, the total number of vehicles in Bolivia reached 2,042,940.39 vehicles, a vehicle fleet 63 times bigger than the one observed in 1970. The annual compound growth rate was about 9.20% in the 1970-2017 period, representing the average speed at which the stock grew throughout the period.

Table 1 also shows the growth occurring every 5 years, which is above the average in the late 2000s, a period in which growth in the vehicle stock was strong compared to other periods. The foregoing can also be seen in Figure 1, showing that growth in the number of cars in Bolivia has an exponential form and that car stock grows significantly since 2004.

Clearly, the same trend is to be observed in the car stock/1,000 indicator, which shows very low levels in the first years of the period: 7.10 vehicles per thousand people in 1970. This indicator increased to approximately 185 vehicles per thousand people for 2017. Such a phenomenon is to be expected given rapid economic growth and changes in demographics such as rapid urbanization and population growth. This situation has also occurred in other parts of the world (especially in developing countries), as the literature shows.

Behind such exponential growth in the vehicle stock, wealth is normally the main determinant. Economic growth and, therefore, household income increases are the most important reasons for the demand for cars to increase. If a household's income grows, it is very likely that it will demand having its own vehicle, and therefore save money to finally buy one (mainly for private use).

Figure 1. *Car stock evolution, 1970-2017*



Source*:* Own preparation based on World Bank data.

However, over time it is observed that GDP in Bolivia has been quite cyclical, and therefore, also GDP per capita (**see Table 1**). In this regard, the literature asserts that normally the stock of vehicles has a strong and positive relationship with increases in income, but when income falls, the demand for automobiles will not normally fall in the same magnitude. When income decreases, it does not mean that the demand for cars will go down as well and in the same proportion. People will continue to depend on the cars to move about, as cars become a necessity, and people are resistant to change (Dargay *et al*., 2007). In this sense, although there have been times when per capita income has decreased, the demand for vehicle ownership seems to have grown over time despite these falls. This fact shows that an asymmetry in demand can in some way be observed. It should be mentioned that growth of the vehicle stock has been higher since 2000 (coinciding with a period of significant growth in Bolivia), showing a strong positive relation with per capita income when it increases.

Additionally, the data reveal indications that the relationship between per capita income and vehicle ownership is not linear. Growth of the car stock occurs slowly with low levels of income and shoots up more quickly when the income is higher. This depicts the central relationship of this paper: the influence of per capita income growth on vehicle ownership. This graph plots the 1970-2017 growth in car (vehicle) ownership against the 1970-2017 growth in per capita income. We can observe the clear relationship between ownership and income levels: as income levels increase, car and vehicle ownership increase.

According to the literature, changes in the population, meaning total population or the urbanization rate, are other important causes for car ownership growth. **Table 1** shows the evolution of urbanization in Bolivia. The trend of the indicator grew at a moderate rate (1.7% calculating the compound growth rate). The indicator shows that by 2017, urbanization in Bolivia was 49% of the population, compared to a much lower level in 1970 (21.2%).

In terms of population, Table 1 shows a considerable increase, with a rate of growth of approximately 2%[4]. To have an idea of the magnitude of this growth, the population in 2017 reached 11,051,600: 2.5 times the population of 1970. Population growth has an impact on the population density indicator, which shows significant growth over time as the Bolivian population increased. Population density has more than doubled in the period of analysis (1970-2017). It is worth mentioning that the trend has continued moving upwards throughout the period of analysis, at a growth rate equal to that of population growth.

4. THE TRANSPORT MODEL

In order to model the relationship between vehicle ownership and income growth, we try to follow the paper developed by Dargay *et al*. (2007). The literature on the subject highlights that the relationship between income and vehicle ownership is non-linear or log-linear, usually represented by an S-shaped curve. Our model tries to capture the long-term relationship between vehicle demand and per capita income with a sigmoid "S" function – vehicle ownership increases slowly at lower income levels, and then more rapidly as income increases – and the saturation levels of ownership[5].

There are different functions models to represent this relationship (*e.g.* the cumulative logistic function, the logarithmic logistic function and the Gompertz function). In this paper we test both the Gompertz function and the log-linear function because of the greater flexibility of the latter, allowing different curvatures at low- and high-income levels, this characteristic being necessary to represent diverse structures of vehicle fleets and the logistic specification (Ogut, 2004).

To formalize the model, let us define C^*as the long-term equilibrium of vehicle ownership per 1,000 people and PCGDP as per capita GDP expressed in real dollars; γ is the saturation level (measured in number of vehicles per 1,000 people) and α and β are negative parameters that define the shape and curvature of the function [see equation (1)].

[4] This rate is calculated using the compound growth rate.

[5] The saturation levels can be treated in three different ways: i) the maximum level of cars for a population group; ii) the maximum level of cars for a population group given certain restrictions and conditions; iii) a parameter of long-run evolution of vehicle ownership. This document adheres to the first form.

$$C^* = \gamma e^{\alpha e^{\beta * GDPt}} \quad (1)$$

Equation (2) represents the linearized form of the Gompertz function, where S is the equivalent of the saturation level and C is the equivalent of the possession of vehicles per thousand people, which is the form used when running the regression.

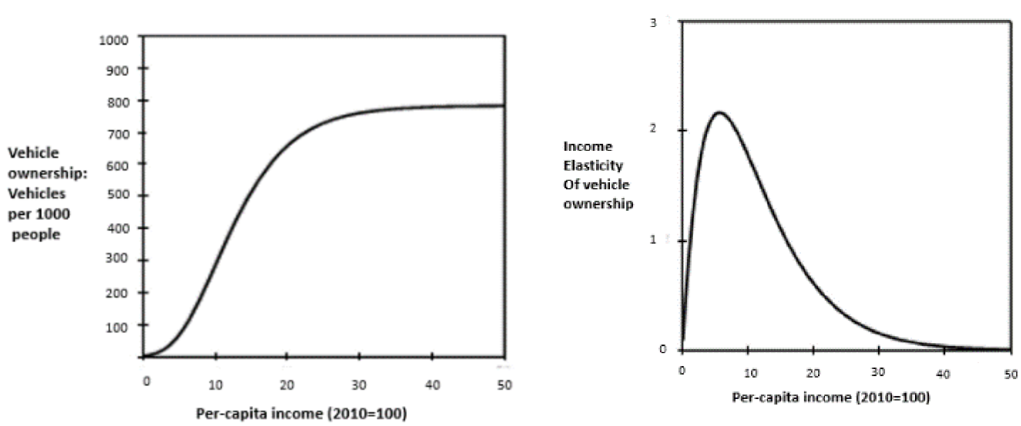
$$\ln\left(\ln\left(\frac{\gamma}{C}\right)\right) = \ln(-\alpha) + \beta * GDP \quad (2)$$

Note that the implicit long-term elasticity of the vehicle/population ratio with respect to per capita income is not constant, due to the nature of its functional form: it varies with income, hence the long-term income elasticity is calculated as follows:

$$\eta_t^{LP} = \alpha * \beta * GDP_t e^{\beta * GDP_t} \quad (3)$$

Elasticity is positive for all income levels because α and β are always negative values. Elasticity increases from zero in $PCGDP$ = 0 to a maximum in $PCGDP = 1/\beta$ and then declines to zero in an asymptotic way as the maximum saturation level is reached. This is how β determines the level of per capita income in which the demand for vehicles is saturated and α shows us the curvature at the beginning of the function. The larger β is in absolute value, the lower the level at which the demand for vehicles flattens out (see Figure 2).

Figure 2. *The Gompertz function for the vehicle fleet and income elasticity of vehicle holding*



Source: Dargay *et al*. (2007)

We assume that the Gompertz function describes a long-term relationship between vehicle ownership and per capita income. The parameters α[6] and β were calculated for Bolivia including the saturation level γ, and θ was calculated using a varied rate of growth (see **section 5**). The saturation levels are defined as follows:

$$\gamma_{it} = \gamma_{max} + \lambda\overline{D_{it}} + \varphi\overline{U_{it}} \text{ (4)}$$

Where:

$$\overline{D_{it}} = D_{it} - D_{Bol,t} \; if \; D_{it} > D_{Bol,t} \text{ (5)}$$
$$= 0 \; otherwise$$

and

$$\overline{U_{it}} = U_{it} - U_{Bol,t} \; si \; U_{it} > U_{Bol,t} \text{ (6)}$$
$$= 0 \; otherwise$$

where λ and φ are negative, D_{it} represents population density, and U_{it} denotes the urbanization of the country in question at a given time t.

For simplicity, our model assumes that the response to a decrease in income is equal but not equivalent to the response to an increase in income (the function is symmetric). According to Dargay *et al.* (2001) it is necessary to consider asymmetries: i) the reduction of income in the short-term; and ii) the long-term positive trend of income. The asymmetry of a fall in income will be considered in a future paper on Bolivia following the model in Appendix 1. Following this we estimated the described model for Bolivia during the period 1970-2017 with the iterative Robust Nonlinear Least Squares method

Then we simulated using an energy accounting model (EMA) programmed in GAMS, the stock evolution model – BAU scenario – with passenger equivalence (see **Appendices 2 and 3**) up to the year 2035. Then we followed an accounting energy-mix model and then derived the requirements of fuels and CO2 emissions for the transport sector.

$$EC_{t,y,v} = SD_{t,y,v} * EI_{t,y,v} \text{ (8)}$$

Where:

$EC_{t,y,v} = \; energy \; consumption \; for \; a \; given \; stock$

$$TEC = TS * annual \; vehicle \; mileage * fuel \; economy \text{ (8.1)}$$

[6] This parameter determines maximum income elasticity.

$TEC = \ total\ energy\ equivalent\ consumption\ in\ the\ transport\ sector$

$TS = \ total\ equivalent\ stock\ of\ vehicles$

$$SD_t = \frac{Saturation}{1+\alpha * e^{\beta * GDP}} \ (9)$$

Where

$SD_t = stock\ of\ vehicle\ ownership\ level\ at\ a\ moment\ ''t''$

$GDP = real\ gross\ domestic\ product\ per\ capita$

$Saturation = vehicle\ breakpoint$

$\alpha, \beta = negative\ parameters$

Note that to estimate annual millage we use the Modified Decomposition of Energy Consumption variation produced by Aliaga (2014). We applied this approach, since disaggregated information about millage and specific fuel consumption is not available. The variation in energy demand can be explained by three factors:

- A fleet effect, showing the influence of road fleet variation on energy consumption
- A structural effect, reflecting the impact of variation in the fleet composition on demand
- A unit consumption effect, reflecting the impact of changes in the yearly consumption millage

The first two can be considered effects of changes in the economy. The last one corresponds to energy policy or technical effects [see equation (10)].

$$TED = Q \sum_i \left(\frac{Q_i}{U_i}\right) / Q \ = Q \sum_i (S_i U_i) \quad (10)$$

5. THE RESULTS

First, we disaggregated energy consumption for the transport sector by mode and type of vehicle for our base year 2007. Based on annual average routes and specific consumption, our estimations were adjusted to harmonize with the corresponding Energy Balances of 2007-2014. **Table 2** shows the baseline consumption structure: road 89%; air 8% and railway 3%. Within the highway mode, the consumption proportions were 61% cargo and 39% passenger transport. Finally, disaggregation by source of consumption was diesel (DO) 46%; gasoline (GM) 38% and CNG 15%.

Table 2. *Vehicle fleets and consumption in the base year (2007)*

Vehicle mode and type	Vehicle units	Distance Km	Performance		Consumption	
			Value	Unit	KBOE	%
HIGHWAY						
Car	158,846	6,000	9.00	km/m³	600.8	6.0%
CNG	23,959	6,000	9.00	km/L	95.5	
GM	134,887				505.3	
Taxi	14,256	25,000	9.00	km/m³	234.0	2.3%
CNG	11,405	25,000	9.00	km/L	189.5	
GM	2,851				44.5	
Wagon and jeep	271,352				1,432.6	14.3%
CNG	9,530	7,500	8.00	km/m³	53.4	
GM	259,273	7,500	8.00	km/L	1,365.8	
DO	2,549	7,500	9.00	km/L	13.4	
Microbus and minibus	56,682				1,210.4	12.1%
CNG	11,853	18,000	4.80	km/m³	265.8	
GM	44,829	18,000	4.80	km/L	944.6	
Bus	6,263				397.5	4.0%
CNG	3,165	20,000	2.50	km/m³	151.4	
GM	1,319	20,000	2.50	km/L	59.3	
DO	1,779	50,000	3.00	km/L	186.8	
Motorcycle	35,024				19.7	0.2%
CNG	35,024	2,000	20.00	km/L	19.7	
Van	78,372				719.2	7.2%
CNG	11,786	10,000	6.87	km/m³	102.6	
GM	57,067	10,000	6.87	km/L	466.7	
DO	9,520	20,000	8.00	km/L	149.9	
Truck	78,847				5,424.3	54.0%
CNG	14,015	20,000	2.52	km/m³	665.7	
GM	10,248	20,000	2.52	km/L	457.4	
DO	54,584	42,000	3.36	km/L	4,301.2	
TOTAL HIGHWAY	699,642				10,038.5	100.0%
CNG	85,712				1,524.0	15.2%
GM	545,498				3,863.2	38.5%
DO	68,432				4,651.3	46.3%
RAILWAY					281.9	
DO					281.9	
AIR TRANSPORT					906.1	
GA					27.2	
JF					878.8	
TOTAL TRANSPORT					11,226.4	

Source: Own preparation based on data from INE and RUAT.
Note: KBOE: Kilo Barrel of Equivalent Oil

Secondly, we transformed different types of vehicles with their estimated equivalence factors to analyze the standardized evolution of the vehicle fleet. This procedure is known as Passenger Car Equivalent (PCE). For further details see **Appendix 3**. Table 3 presents our PCE estimations for Bolivia with a multiple linear regression. Cars in this case are the unitary vehicles; trucks are equivalent to 3 cars; minibuses and pick-up trucks are equal to 2 cars; wagons are 1.5 cars; and motorcycles are 0.25 cars.

Table 3. *Bolivian equivalence factors, PCE and ECS*

Nomalized Passenger Car	Coef.	Sig.	Nomalized coef. ECS	Sig.
Car	1.00	***	1.00	**
Truck	2.50	***	4.25	**
Van	1.25	***	1.85	**
Pick-up truck	2.00	***	1.85	*
Jeep	1.26	***	2.00	**
Microbus	2.00	***	1.10	**
Minibus	3.00	***	1.25	**
Motorcycle	0.25	***	0.10	***
Omnibus	5.00	***	3.85	**
Quadra Truck	0.25	***	0.35	**
Wagon	1.50	***	2.50	**

Source: Own preparation; estimated in Gretl.

Car ownership is driven by income and population growth; hence we need to define a baseline scenario and socioeconomic drivers for our energy-mix accounting bottom-up model in GAMS. Based on assumptions concerning energy production, energy consumption, GDP evolution, population, and urbanization, etc., the model forecasts the number of vehicles, consumption and production for the Bolivian transport sector up to 2035. In **Table 4** we present the evolution of the car stock with the equivalence factors and without them.

From 2003 to 2017, the fleet growth rate was 8.7%[7], and for the rest of the period we expect a growth rate of 4.7%. The vehicle fleet changed from about 700,000 equivalent cars to 6,029,290.40 during the 2000-2035 period, which is equivalent to 6.8%. According to our projections, by 2035, the composition of the vehicle fleet in Bolivia will be 91.0% private vehicles, 7.6% public vehicles and 1.6% official vehicles. Note that private vehicles are the largest part of the distribution and their growth rate has accelerated during the last decade due to higher income – households can now afford to buy their own cars. This behavior has implications for fuel consumption, production and imports. In this matter, it is well reported that transport is one of the major contributors to environmental and congestion problems, especially passenger transport with private cars (Dargay, 1997; World Bank, 2002).

[7] To obtain annual average growth, a compound growth rate is used: $\left(\left(\frac{X_F}{X_0}\right)^{\frac{1}{t_F-t_0}}\right)-1$.

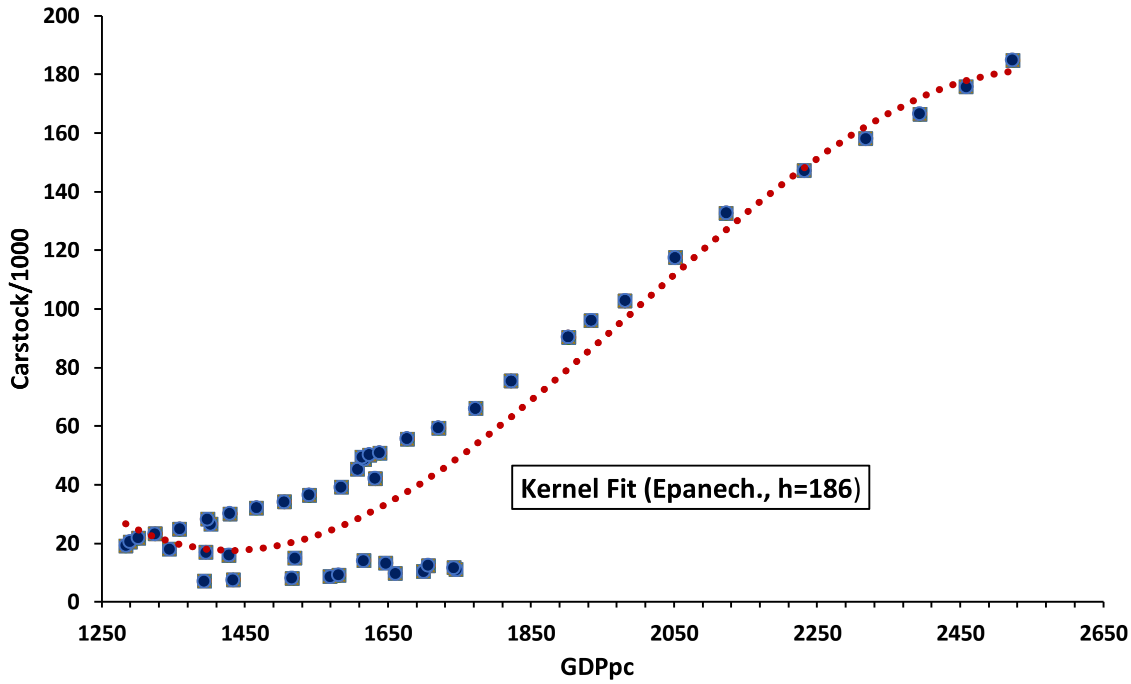
Table 4. *Number of vehicles for Bolivia, 2003-2035 PCU*

Years	2003	2005	2010	2015	2020	2025	2030	2035
Number of vehicles with Equivalence Factors								
Car	127,222.00	147,940.00	205,959.00	283,690.00	398,329.45	525,945.70	653,696.01	781,428.66
Truck	165,048.00	188,895.00	276,423.00	348,387.00	472,728.62	615,507.30	758,522.89	901,507.29
Wagon	91,780.50	103,708.50	147,888.00	237,850.50	344,209.12	452,883.95	561,595.30	670,301.83
Pickup truck	1,204.00	1,868.00	3,774.00	19,372.00	31,498.30	41,834.52	52,176.37	62,517.48
Jeep	40,103.75	46,220.00	60,813.75	73,025.00	96,840.72	127,182.55	157,531.47	187,879.46
Microbus	24,670.80	26,886.75	30,767.55	31,894.50	35,982.90	41,751.12	47,533.21	53,313.47
Minibus	47,090.00	59,528.00	112,966.00	170,248.00	246,612.90	324,349.26	402,120.32	479,886.81
Motorcycle	3,866.75	5,853.00	18,246.50	84,056.00	138,557.61	182,422.43	226,294.00	270,164.69
Omnibus	2,744.00	3,624.00	7,890.00	11,520.00	16,589.15	22,138.33	27,689.61	33,240.62
Quadra Track	946.25	1,010.50	997.50	1,957.25	3,125.65	4,159.13	5,194.48	6,229.58
Torpedo	27.00	66.00	291.00	273.00	327.69	426.35	525.00	623.66
Tracto-Truck	1,059.00	3,291.00	17,961.00	28,710.00	40,436.15	53,345.15	66,255.61	79,165.88
Trimovil-Truck	1,149.00	2,394.00	12,840.00	35,124.00	48,785.31	62,887.72	76,932.57	90,985.00
Van	215,824.00	282,758.00	695,184.00	944,848.00	1,257,821.96	1,642,565.77	2,027,305.61	2,412,045.97
Total	722,735.05	874,042.75	1,592,001.30	2,270,955.25	3,131,845.53	4,097,399.28	5,063,372.46	6,029,290.41
Number of vehicles without Equivalence Factors								
Car	127,222.00	147,940.00	205,959.00	283,690.00	398,329.45	525,945.70	653,696.01	781,428.66
Truck	55,016.00	62,965.00	92,141.00	116,129.00	157,576.21	205,169.10	252,840.96	300,502.43
Wagon	61,187.00	69,139.00	98,592.00	158,567.00	229,472.75	301,922.64	374,396.86	446,867.89
Pickup truck	602.00	934.00	1,887.00	9,686.00	15,749.15	20,917.26	26,088.19	31,258.74
Jeep	32,083.00	36,976.00	48,651.00	58,420.00	77,472.57	101,746.04	126,025.18	150,303.56
Microbus	14,952.00	16,295.00	18,647.00	19,330.00	21,807.82	25,303.71	28,808.00	32,311.19
Minibus	23,545.00	29,764.00	56,483.00	85,124.00	123,306.45	162,174.63	201,060.16	239,943.41
Motorcycle	15,467.00	23,412.00	72,986.00	336,224.00	554,230.44	729,689.70	905,176.02	1,080,658.77
Omnibus	1,372.00	1,812.00	3,945.00	5,760.00	8,294.57	11,069.16	13,844.81	16,620.31
Quadra Track	3,785.00	4,042.00	3,990.00	7,829.00	12,502.59	16,636.53	20,777.93	24,918.34
Torpedo	9.00	22.00	97.00	91.00	109.23	142.12	175.00	207.89
Tracto-Truck	353.00	1,097.00	5,987.00	9,570.00	13,478.72	17,781.72	22,085.20	26,388.63
Trimovil-Truck	383.00	798.00	4,280.00	11,708.00	16,261.77	20,962.57	25,644.19	30,328.33
Van	107,912.00	141,379.00	347,592.00	472,424.00	628,910.98	821,282.88	1,013,652.80	1,206,022.98
Total	443,888.00	536,575.00	961,237.00	1,574,552.00	2,257,502.70	2,960,743.77	3,664,271.31	4,367,761.13

Source: Own preparation based on PCE estimation and data from INE and RUAT.

Now we want to link fleet evolution to income. **Figure 3** shows that the relationship between the increase in the car stock and income of the population is highly non-linear in Bolivia. There are two traces of non-linearities. At the beginning, the curve grows slowly as per capita income increases to around 1,700 dollars and we verify a significant increase in car stock. Then the speed is maintained until income levels reach 2,000 dollars. For the highest per capita income levels, growth has a lower speed compared to data in the medium range, but vehicle ownership continues to increase until it reaches its maximum.

Figure 3. *Non-linear function of Vehicle fleet 1970-2017*



Source: Own estimation in Gretl with data from INE and the World Bank.

This curve is S-shaped and is characterized by its upper curve that flattens when it reaches the maximum point of saturation, where the speed of the demand for vehicles decreases. Low and middle-income countries such as Bolivia reach a high ratio with low incomes; the curves tend to be more flattened, suggesting that the levels of saturation (maximum level of vehicles per 1,000 inhabitants) in developing countries are lower than in richer countries.

Next, we estimate the vehicle ownership function with Robust Least Squares – S-estimation[8] (**Table 5**) because we verify the presence of innovational and level shift outliers[9] in the regressor. The model specification is logistic with a dependent variable defined as LOG[LOG(S/C)], where C is car ownership and S is the saturation level. All the coefficients have the expected sign and are statistically significant with R^2 equaling 82%.

[8] A robust regression is a method less sensitive to the presence of outliers and heteroscedasticity. S-estimation focuses on outliers in the regressors, finding a line (flat or hyperplane) that minimizes a robust estimate of the scale (from which the method obtains the S in its name) of the residues.

[9] An innovational outlier is characterized by an initial impact with effects lingering across subsequent observations. The influence of the outliers may increase as time advances. For a level shift, all observations appearing after the outlier move to a new level. In contrast to additive outliers, a level shift outlier affects many observations and has a permanent effect.

Table 5. *Robust S-estimation of the vehicle ownership function*

Variable	Coefficient	Std. error	Z-statistic	Prob.
A	-6.07823	0.146609	41.45883	0.0000
B	-0.755685	0.019782	-38.20062	0.0000
Robust statistics				
R-squared	0.814706	Adjusted R-squared		0.810678
Scale	0.030649	Deviance		0.000939
Rn-squared statistic	1459.288	Prob. (Rn-squared stat.)		0.000000
Non-robust statistics				
Mean Dependent var.	0.543411	S.D. dependent var.		0.174744
S.E. of regression	0.123028	Sum squared resid.		0.696254

Source: Estimation results based on Gretl.

The β coefficient determines the level of income where the elasticity reaches its maximum and α determines the maximum value of elasticity given the income. In absolute values, α is 6.078 and β is 0.75. Note the smaller the value of β the greater the per capita income at which the maximum elasticity is reached. At the same time, this parameter also determines the income level at which vehicle saturation is reached (see **Table 6**).

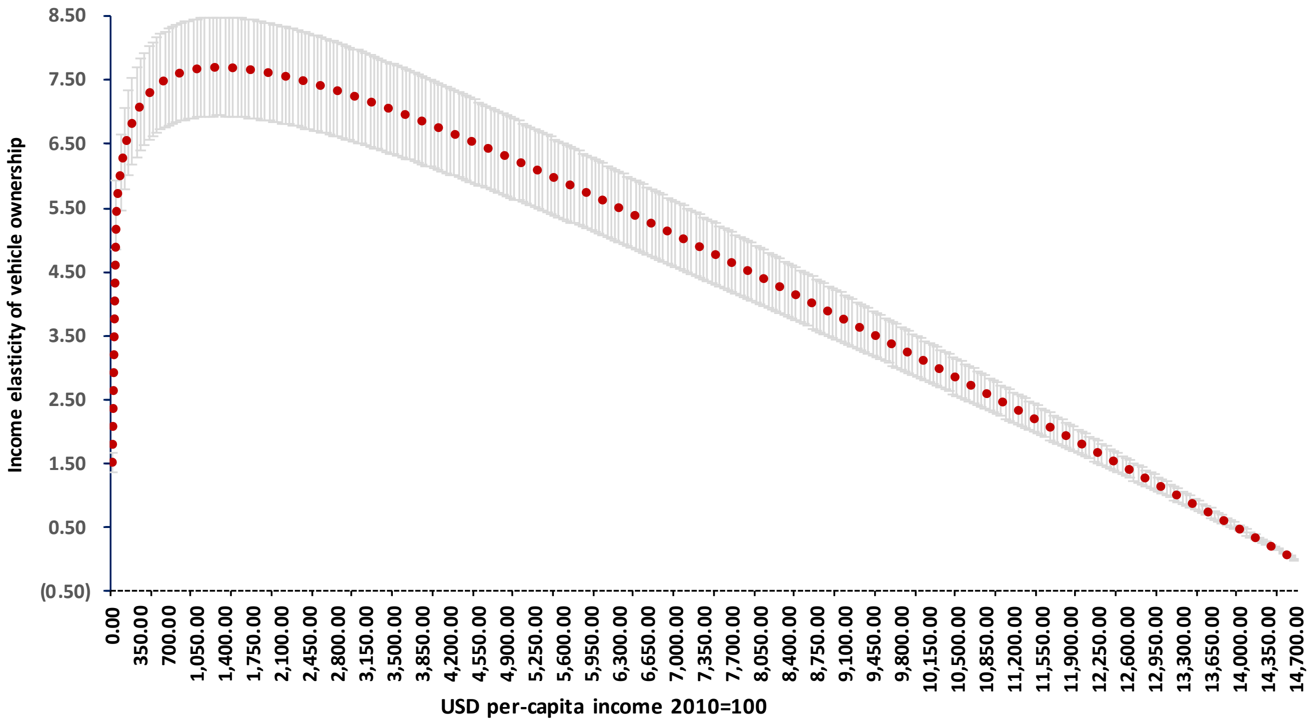
Table 6. *The vehicle ownership function*

Beta coef.	P-value	vehicle ownership saturation (per 1000 people)	Per-capita income (thousands 2010 $ PPP) at which vehicle ownership aprox. 100
-0.75	0.00	741.89	5,919.84

Source: Own preparation based on robust regression.

On the one hand, the saturation level is 741.89 vehicles per 1,000 people, which is reached with 5,919 real dollars per capita income of 2010 and a vehicle ownership-GDP per capita elasticity of 5.74. On the other hand, the maximum defined elasticity for Bolivia is 7.71, corresponding to 2,500 real dollars per capita of 2010. In Figure 4, the elasticity increases to the lowest levels of per capita income (up to 1,200 real dollars) and then there is a gradual decrease of this as the incomes increase until reaching saturation.

Figure 4. *Long-term elasticity of vehicle holding*



Source: Own preparation based on Gretl with Monte Carlo simulation.

Elasticity is not constant over time; it depends on the level of vehicle ownership that exists. Since the level of vehicle ownership depends on income, elasticity will depend on income level. An increase in revenues increases the demand for vehicles; however, the effect diminishes over time as saturation levels are reached. When this point is reached, elasticity decreases.

Table 7. *Consumption of derivatives, 2000-2035, in KBOE*

Year	GNC	Diesel Oil	Gasoline	Others	Total
2000	36.09	2,534.91	3,291.00	1,055.00	6,917.00
2005	761.10	3,489.90	2,960.00	1,098.00	8,309.00
2010	2,714.00	4,543.00	5,668.00	1,021.00	13,946.00
2015	4,591.80	6,587.50	8,280.50	1,170.45	20,630.25
2020	6,478.29	8,698.50	10,970.50	1,292.27	27,439.56
2025	8,350.10	10,811.58	13,662.92	1,426.77	34,251.37
2030	10,207.99	12,923.10	16,353.53	1,575.27	41,059.89
2035	12,050.51	15,034.16	19,043.60	1,739.23	47,867.51

Source: Own preparation based on EMA model.

Our Business as Usual (BAU) scenario (see **Appendix 2**) describes how the Bolivian energy-mix will evolve in the future, in the absence of energy or mitigation policies. The energy supply follows the production and consumption trends of the last 10 years. The production forecast for natural gas and petroleum are adjusted based on factual changes related to those estimated in the "Bolivian Hydrocarbons Strategy 2007". For the transport sector, a moderate improvement in its energy intensity, of 5%, is expected. Since our model does not consider energy efficiency measures in the transport sector (not our goal), the total consumption of derivatives for transport will grow 6.9 times from 2000 to 2035 (see **Table 7**). Throughout the 2000-2017period, total consumption grew at a rate of 7.42%, and for the 2018-2035 period, total consumption will grow at an average rate of 3.94%.

In the 2000-2017 period, total consumption changed from 6,917 to 23,342.38 KBOE. Notice that DO[10] consumption changed from 2,534.91 to 7,425.25 KBOE, with an average growth rate of 6.53%. Note that the expansion of the automobile fleet grew at 6.33%, which is a rate higher than the average of the previous two decades (4.01%). For the 2018-2035 period, total consumption would change from 24,729.25 to 47,867.51 KBOE. In the case of DO consumption would grow at a rate of 3.89% for the entire period (from 7,860.75 to 15,034.16 KBOE). Gasoline consumption will increase with the vehicle fleet growth, at an average rate of 3.92% (from 9,902.25 to 19,043.60 KBOE). Finally, natural gas consumption would grow to 4.48% from 5,724.16 to 12,050.51 KBOE.

Table 8. *Production and imports of derivatives, 2000-2035, in KBOE*

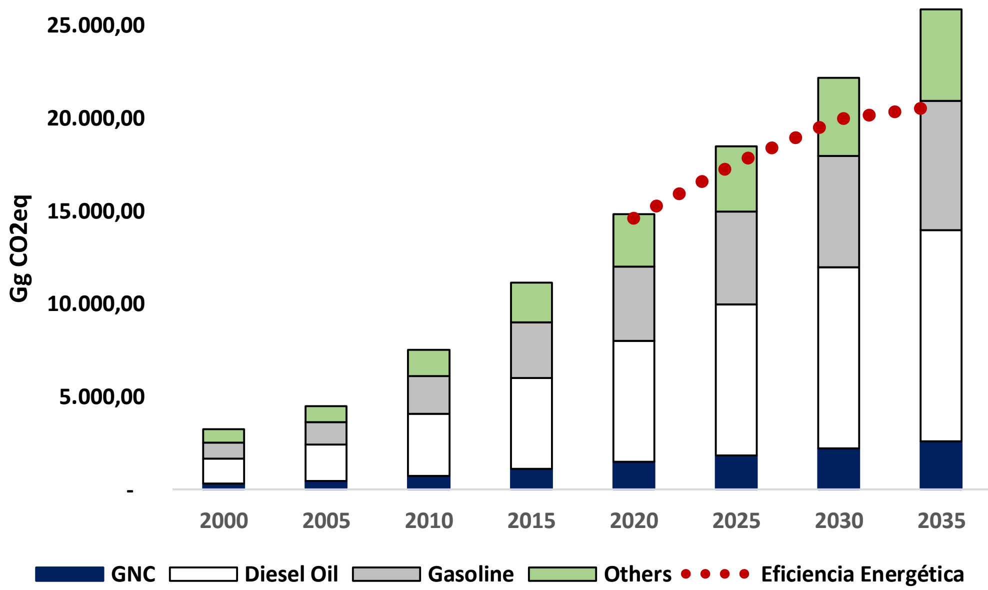
	Production					Imports				
	GNC	Diesel Oil	Gasoline	Others	Total	GNC	Diesel Oil	Gasoline	Others	Total
2000	36.09	2,767.41	4,050.62	1,006.76	7,860.89	-	-	-	48.24	48.24
2005	761.10	4,204.34	3,630.83	1,098.00	9,694.27	-	-	-	-	-
2010	2,714.00	4,211.66	4,937.48	895.61	12,758.75	-	331.34	730.52	125.39	1,187.25
2015	4,591.80	6,073.20	6,635.94	1,006.44	18,307.38	-	514.30	1,644.56	164.01	2,322.87
2020	6,478.29	5,174.78	10,279.07	1,077.76	23,009.89	-	3,523.72	691.43	214.51	4,429.67
2025	8,350.10	5,048.66	12,728.60	1,146.20	27,273.54	-	5,762.92	934.33	280.58	6,977.82
2030	10,207.99	4,922.54	15,293.71	1,208.29	31,632.53	-	8,000.56	1,059.81	366.98	9,427.36
2035	12,050.51	4,796.42	17,843.61	1,259.23	35,949.77	-	10,237.75	1,199.99	480.00	11,917.74

Source: Own preparation based on EMA model.

On the one hand, derivatives production grew at a rate of 5.60%, going from 7,861 to 19,858.95 KBOE in the 2000-2017 period, and will reach 35,949 KBOE in 2035 (**Table 8**). The country started to import DO in 2009 (305.20 KBOE), it reached 2,305.28 KBOE in 2017 (average growth rate of 28.76%) and we expect that imports will continuously increase (average growth rate of 8.31%), from 2,635.53 to 10,237.75 KBOE up to 2035. On the other hand, gasoline imports also started in 2009, with 356.72 KBOE, and reached 995.55 KBOE in 2017. For the 2018-2035 period we expect that gasoline imports will increase from 531.03 to 1,199.99 KBOE.

[10] Diesel oil

Figure 5. *Gg CO2eq emissions, 2000-2035*



Source: Own preparation based on EMA model.

On the other hand, greenhouse gas (GHG) emissions related to fuels would be 7.93 times in 2035 compared to 2000. From 2000-2017 the emissions grew at an average rate of 8.28%, from 3,260 to 12,612.56 Gg CO2eq. The emissions related to DO will rise significantly, from 5,879.25 to 11,380.24 Gg CO2eq in 2000-2017 (average growth rate 8.31%) and will increase from 13,361.92 to 25,864.19 Gg CO2eq in 2018-2035 (average growth rate 3.96%). It is important to note that the total emissions related to gasoline and VNG will remain stable (see Figure 5).

6. THE CONCLUSION

Firstly, the core aim of this paper was to analyze the relationship between income and vehicle ownership in Bolivia during the 1970-2035 period. Secondly, following the former pattern, we used an energy-mix accounting model to analyze how the vehicle fleet evolved over time, and observed demand for gasoline, natural gas and diesel oil in the coming years. Third, we observed the evolution of CO2eq in the transport sector by different types of categories. Here we limit ourselves to presenting results, hoping that the document will open up several key public policy criteria that we do not discuss in the document.

We have proven that the relationship between vehicle ownership and per capita income is highly non-linear. Income elasticity of vehicle ownership began at a very low level, but increased rapidly (higher than its average) over the last decade, during the last economic boom: 2006-2015. If this pattern continues, in the next decade, vehicle stock will be 12.8 times greater in 2035 than it was in 2000, with important implications on derivatives consumption.

Since income-vehicle ownership elasticity is not constant over time – it depends on the changing level of vehicle ownership – the vehicle fleet saturation level (741.89 vehicles per 1,000 people) is reached with

5,919 real dollars of per capita income of 2010 and a vehicle ownership-GDP per capita elasticity of 5.74 (the maximum elasticity is 7.71, that correspond to 2,500 real dollars of per capita income of 2010).

The evolution of the vehicle fleet shows that private vehicles are the largest part of the distribution and will continue to be in the future. Economic growth explains why households can now afford to buy their own cars. The excessive increase in the size of the vehicle fleet during the last decade will exert pressure on the consumption of derivatives in the next five years (*i.e.* gasoline, natural gas and diesel oil) and we expect some supply imbalances, mainly due to diesel oil consumption. Finally, CO2eq emissions will be higher in the long-run due to the high expansion of the fleet (related to the income increase) and will probably cause some congestions issues.

It is evident that there is uncertainty in our results due to several unobservable variables omitted in the model specification (*i.e.* user costs, effects of prices, changes in transport policies, demographic changes, changes in transport networks, infrastructure constraints, policy alterations in the transport sector, and new technology penetration in the market). However, we clearly prove that there is a significant relationship between per capita income and the growth of vehicle ownership (as income increases, the automobile fleet grows also).

We have also proven that without energy efficiency measures, derivatives consumption would grow 6.9 times from 2000 to 2035 due to the increase in diesel oil consumption - mainly related to –the agriculture sector – and due to the greater expansion of the car fleet. Within this scenario, the total emissions of CO2eq would grow 7.93-fold by 2035. To supply the internal consumption of derivatives, the country began to import diesel and gasoline in 2009 and will continue to do so, increasingly, in the future. On the one hand, the importing of gasoline could be reduced in the short-term with, for example, ethanol production. On the other hand, diesel imports are expected to remain very significant until 2035.

To close the argument, we proved that the positive relationship between income and vehicle ownership will speed up the saturation of the overall fleet, especially in the private sector. The rest of the results (*i.e.* consumption, emission, congestion) are contingent on public policies in the next years, such as transport efficiency measures, derivatives production and transport congestions policies. This means that the excessive increase of vehicle fleets is an inefficient allocation of resources, the reduction of which is however feasible with, for example, tax instruments; and mitigation of its negative impacts is possible with sectoral policies.

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APPENDIX 1. MODEL EXTENSION

It is important to consider that there may be lags in the impact of an increase in income on vehicle demand, for which an adjustment mechanism is used, as shown in the equation:

$$V_t = V_{t-1} + \theta(V_t - V_{t-1}) \text{ (A1)}$$

Where V is current vehicle ownership, and θ represents the speed of adjustment of the variable ($0 < \theta < 1$). The lags shown in the equation represent the slow and gradual adjustment of an increase in income. Individuals do not respond instantaneously to changes in income (or to prices) and the adjustment takes place gradually over time. These reasons go hand in hand with attachment to habits, search costs and imperfect information (Dargay *et al*., 2001; 1999). An example of this is housing patterns associated with increased ownership. If we join equations (2) and (4) we obtain:

$$V^* = \gamma\theta e^{\alpha e^{\beta PCGDPt}} + (1-\theta)\, V_{t-1} \text{ (A2)}$$

As previously mentioned, the literature[11] discusses the validity of this characteristic, since assuming symmetry could generate biases in the calculation of elasticities.

Goodwin (1995) and Pendyala *et al*. (1995) examine this characteristic empirically, using successive panels to analyze changes in vehicle demand and periods of increase and reduction of per capita income. They found evidence of asymmetry, meaning that the elasticity related to periods when income decreased is less than the elasticity when income increases.

The concept of asymmetry is valid when a dynamic analysis is made over time; however, most models have the implicit assumption of symmetry.

Bolivia has experienced a decrease in its income levels through time and this phenomenon must be considered for calculations. To take this asymmetry into account, the distinction of θ_f and θ_r is made, where the first parameter refers to the adjustment when income decreases, and the second term is the adjustment when income increases. Two dichotomous variables are created to represent this:

$$R_{it} = 1 \; si \; PIBPC_{it} - PIBPC_{it-1} > 0 \; y = 0 \; otherwise \quad \text{(A3)}$$

$$F_{it} = 1 \; si \; PIBPC_{it} - PIBPC_{it-1} < 0 \; y = 0 \; otherwise \quad \text{(A4)}$$

[11] Goodwin (1995) is one of the pioneers in analyzing this subject.

Replacing θ in equation (5) with:

$$\theta = \theta_r R_{it} + \theta_f F_{it} \tag{A5}$$

This last equation does not change the equilibrium relationship between vehicle stock and per capita income shown in equation (1), or the long-run elasticities. The adjustment parameters are different in such a way that the short-term elasticities and the time adjustment are different; this does not happen in the long-term elasticity. This logic assumes that the demand for vehicles will not decline as fast in the face of a decrease in income as it increases when income increases, so we would expect that $\theta_r > \theta_f$. The hypothesis of symmetry between both variables can be statistically tested. If both coefficients are not statistically different then the hypothesis of symmetry can not be rejected.

Substituting equations (6) and (8) in equation (5), the model to be estimated econometrically becomes:

$$V^* = (\gamma_{max} + \lambda\overline{D_{it}} + \varphi\overline{U_{it}})(\theta_r R_{it} + \theta_f F_{it})e^{\alpha e^{\beta PCGDPt}} + (1 - \theta_r R_{it} + \theta_f F_{it})V_{t-1} + \varepsilon_{it} \tag{A6}$$

Long-term elasticity can be calculated as:

$$\eta_{it}^{LP} = \alpha\beta_i PCGDP_{it} e^{\beta iPCGDPit} \tag{A7}$$

The latter represents the same as the symmetric model of equation (2) does. Short-term elasticity is adjusted by the parameter θ:

$$\eta_{it}^{CP} = \theta\, \alpha\beta_i PCGDP_{it} e^{\beta iPCGDPit} \tag{A8}$$

Where θ = θ_r for when income increases and θ = θ_r when income decreases. A robust estimate of the saturation level requires observations of vehicle ownership that is approaching saturation. Similarly, the estimation of the parameter α, which determines the value of the Gompertz function at the lowest income levels, requires low-income observations in order to have a good estimate in this part of the function, which is the lower part.

APPENDIX 2. BUSINESS AS USUAL SCENARIO (BAU)

Our Business as Usual (BAU) scenario analyzes the evolution of the automobile fleet in Bolivia in two time periods: 2000-2017 and 2018-2035. The scenario induces technological and energy use patterns, future energy consumption and corresponding GHG emissions. In the base year the population was 9,552,870 persons within 2,303,158 households; 65.1% lived in urban areas and 34.9% in rural areas. For the year 2025 we expect 12,368,347 persons with an annual average growth of 1.45%; 71.4% will live in urban areas and 28.6% in rural areas.

Population, 2007-2025

	2001 (*)		2007 (**)		2025 (**)	
Population	8,274,325	100.0%	9,552,870	100.0%	12,368,497	100.0%
Urban	5,180,433	62.6%	6,218,918	65.1%	8,831,107	71.4%
Rural	3,093,892	37.4%	3,333,952	34.9%	3,537,390	28.6%
Households	1,978,144	Inhab./household	2,303,158	Inhab./household	3,092,124	Inhab./household
Urban	1,214,902	4.26	1,480,695	4.20	2,207,777	4.00
Rural	763,242	4.05	822,463	4.05	884,348	4.00

Source*:* Own preparation based on Censo de población (Census) 2001; CEPAL.

On the other hand, GDP will grow in average of 4% per year in the 2007-2025 period and at 3.5% in the rest of the period. The transport, and commerce and services sectors will be among the most dynamic in the economy. For further detail, see the following table:

Sectoral GDP, 2007-2025

(Basic prices, thousands of bolivianos, 1990)

Sectors	2007		Rate, 2007-2025	2025	
Agriculture, fishery,	7,091,144	27.6%	3.50%	13,171,723	25.3%
mining	4,929,111	19.2%	4.30%	10,516,861	20.2%
Industry (manufacture)	3,066,342	11.9%	4.20%	6,430,423	12.3%
Transpot	10,158,460	39.5%	4.15%	21,120,044	40.5%
Commerce and services	468,833	1.8%	3.38%	852,572	1.6%
Other sectors	25,713,890	100.0%	4.00% (*)	52,091,623	100.0%
Total					

Source*:* Own preparation: "Plan de Desarrollo Energético — Análisis de escenarios 2008-2027", Ministry of Hydrocarbons and Energy.

APPENDIX 3. PASSENGER CAR EQUIVALENT METHOD

Transport and traffic literature frequently utilize a common unit, known as the Passenger Car Equivalent (PCE). Equivalence factors calculated are vital to provide a mechanism though which vehicles are converted into a reference vehicle. Common vehicle types are assigned a conversion factor so that an equivalent PCE value can be generated from classified vehicle data collected. Since the publication of HCM (1965), several different studies have come up with different methods to determine PCE values adapted to the unique characteristics of every country or study. Key methods for this include Walker´s method, the headway method, the multiple linear regression method, the simulation method, and the density method.

Multivariate linear model

This type of regressions analysis is used to predict the value of one or more responses from a set of predictors. It can also be used to estimate lineal associations between the predictors and responses. The multivariate model is a statistical method that uses multiple variables to forecast possible outcomes.
The model has the form:

$$y_{ik} = \beta_{0k} + \sum_{j=1}^{p} \beta_{jk} X_{ij} + \varepsilon_{ik}$$

Where y_{ik} is the *k-th* real valued response for the *i-th* observation, β_{0k} the regression intercept for *k-th* response and X_{ij} *j-th* predictors. The model is multivariate because we have m > 1 response variables and it is multiple because we have p > 1 predictors.
The main characteristic of multivariate statistics is the multiple correlated dependent variables that are predicted, rather than a single scalar variable. The method used in this paper is a reduced one, since it uses few independent variables. Multivariate regressions estimate a single regression model with more than one outcome variable, meaning that there are multiple correlated dependent variables predicted, rather than a single one. When there is more than one predictor, the model is a multivariate multiple regression.

Multiple linear regression

The regression analysis method is normally used to a great extent in studies that calculate PCE factors (Adnan, 2013). The multiple linear regression is the most common form of linear regression analysis that is used to explain the relationship between one continuous dependent variable and two or more independent variables. This type of model is an extension of the simple regression model that assumes that the regression relates the dependent variable with the other, independent variables:

$$y_i = \beta_0 + \sum_{j=1}^{p} \beta_j X_{ij} + \varepsilon_i$$

The model is multiple because we have $p > 1$ predictors and it is linear because y_i is a linear function of the parameters. This type of models predicts the equivalence factors to transform every type of car to the value of one passenger car. The coefficients obtained in the regression indicate the equivalence factors obtained in relation to the reference vehicle, which is the passenger car, that takes the value of 1.