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Comparative Analysis of the Energy Consumption, Economic Cost and Environmental Impact between Fossil and Electric Buses in the Public Urban Transportation of the City of Ambato, Ecuador

Alberto Ríos*‡, Carlos Vargas**, Jesús Guamán**, Manuel Otorongo***

* Faculty of Systems, Electronic and Industrial Engineering Technical University of Ambato Ecuador, Research -PhD Electrical Engineer

**Department of Electrical and Electronic Engineering, National Polytechnic School, Smart Grids Masters Student

***Department of Electrical Engineering, Technical University of Cotopaxi, Research professor in Electrical Engineering

(a.rios@uta.edu.ec, carlos.vargas03@epn.edu.ec, jesus.guaman@epn.edu.ec, manuel.otorongo8995@utc.edu.ec)

‡ Corresponding Author; Alberto Ríos ‡

a.rios@uta.edu.ec

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Abstract- In Ecuador, the City of Ambato has a public transport system which dependents exclusively on oil derivatives. The Directorate of Traffic, Transport and Mobility of the Decentralized Autonomous Government Municipality of Ambato, is responsible for the planning, organization and regulation of traffic of interparochial, and urban land transport throughout the territory comprising the jurisdiction of Ambato's Canton. This organism prepares and signs the contracts of operation for the public transport in the city of Ambato. In this paper, a comparative analysis of the energy consumption, economic costs and environmental impact between fossil and electric buses for the urban public transport of the city of Ambato is evaluated. This study is based on information provided by GADMA operating contracts of the Directorate of Traffic, Transport and Mobility on simulation of urban transport routes in ArcGIS software and on technical characteristic of fossil and electric buses provided by manufacturers. Innovation in issues of urban mobility and public transport is a new field of research to minimize the environmental impact caused by traditional systems. In this way, the impact of two brands of electric buses in terms of flexibility, sustainability and emission of pollutants is analyzed. The results show a remarkable reduction compared to the traditional system based on the aforementioned terms.

Keywords: Electric Public Transport, e- buses, e-mobility, energy consumption, pollutant emissions.

1. Introduction

The reduction of primary energy consumption and greenhouse gas emissions is one of the most serious problems affecting society [1]. To obtain a sustainable transport system is necessary to introduce a new technology that permit reduce a greenhouse emission. The electrical vehicles are new technology that were development for this aspect. In Rome, a study is presented highlighting the importance of electric vehicles to achieve sustainable mobility, revealing a significant reduction in CO_2 emissions [2,3,4].

Likewise, the article presents a study of optimization of schedules in which it highlights the minimization of the cost of use of the vehicle and the cost of fuel when using electric buses to battery in the public transport system. Currently, electric buses have a great advantage over fossil fuels. In Curitiba, the implementation of electric buses has brought environmental benefits such as low noise and fewer greenhouse gases emissions [5,6]. However, the inclusion of these buses requires careful planning of the operation of the transportation system [7,8,9].

The evolution of primary energy production and final energy demand, between the years 1970 and 2030, is showed in figure 1, [10]. The daily production of petroleum barrels surpassed the 520 thousand barrels in December 2018 [11]. According to the information from the Central Bank of Ecuador, the exported daily average reached 356 thousand barrels of raw petroleum in the second quarter from April to June of 2018 [12]. Furthermore, the economic growth of the country has boosted petroleum consumption. Over 22 million barrels of petroleum derivatives were consumed in the second quarter of 2018 [12]. This amount is the equivalent to near 255 thousand barrels of oil derivatives daily. Ecuador will have serious problems to supply the oil local demand in 2030, figure 1. In this sense, is essential that the Republic of Ecuador develop and implement an accelerated program of electrification of the transport system, the largest consumer of oil derivatives in the national economy.

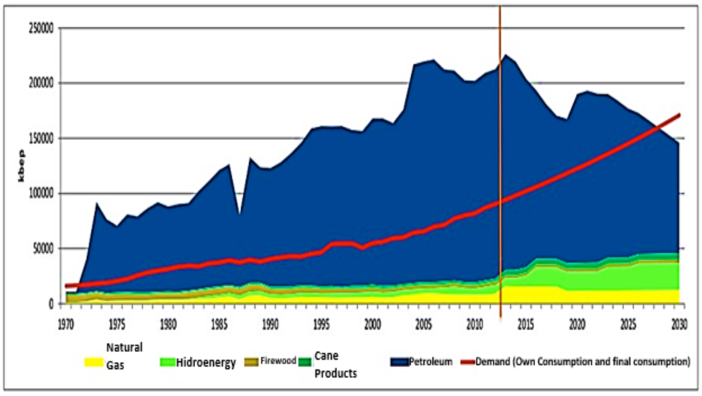


Fig.1: Expected evolution of primary energy production and final energy demand in Ecuador in the horizon from 1970 to 2030 [10].

If Ecuador becomes a net exporter of petroleum derivatives at the beginning of the third decade of the 21st century, the country could experience a serious social collapse. Therefore, the elaboration of a long-term strategy to uncouple Ecuador from oil derivatives and build a long-term sustainable energy system that is respectful of the environment is of vital importance.

Transportation is nationally the highest energy-consuming sector. This consumption level is equal to 44.284 kBEP. In 2016, 48,8% of the total final energy consumption corresponded to the transportation sector, figure 2 [13,14]. Within this sector, diesel and gasoline make up 45,3% and 44,5% of the consumed final energy total respectively, table 1 [13]. The use of electricity in the transportation sector is just 0,01% of the total consumption. The only electrified public transport system in Ecuador is the trolley in the city of Quito. The use of electric energy is basically non-existent in the country.

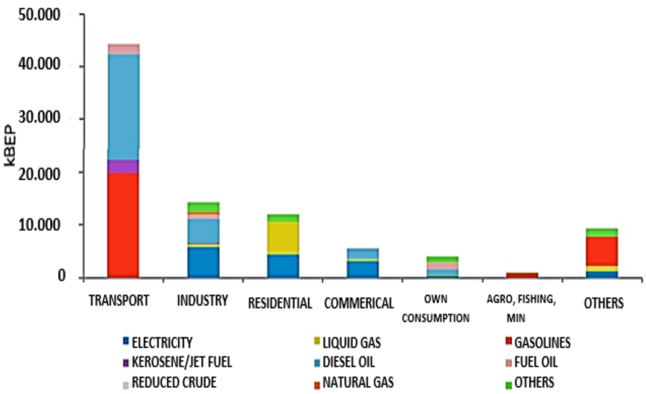


Fig.2: Structure of final energy consumption by sectors in Ecuador in 2016 [13].

Table 1: Percentage structure of final energy consumption in the transport sector in 2016 [13].

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ELECTRICITY	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01
LIQUID GAS	0	0	0,2	0,25	0,2	0,2	0,2	0,2	0,1	0,1
GASOLINES	32,5	31,5	32	39,8	40,3	41,7	41,5	40,6	43,5	44,5
KEROSENE / JET FUEL	8,6	8,7	8,2	7,1	6,8	6,5	6,9	6,4	5,9	5,5
DIESEL OIL	44,2	45,1	45,3	41,9	42,6	43,4	44,3	45,5	44,9	45,3
FUEL OIL	14,7	14,7	14,3	10,9	10,1	8,2	7,1	7,3	5,5	4,5
TOTAL	100	100	100	100	100	100	100	100	100	100

On the other hand, in 2016, 89% of final energy consumption in the transportation sector corresponded to road transport, figure 3 [13]. Marine and air transport consumed approximately 11% of the final consumption of the transportation sector. The consumption of petroleum derivatives in light and heavy cargo vehicles make up 53% of the total energy demand in the transport sector. The designing, sizing and implementation of an electric railroad throughout Ecuador should be planned in the near future since it will permit to substitute significantly the petroleum derivatives consumption of trucks, minivans, dump trucks, trailers and tankers. The substitution of the consumption of petroleum derivatives in cargo vehicles should be considered as the most important energy challenge in the country in the coming decades.

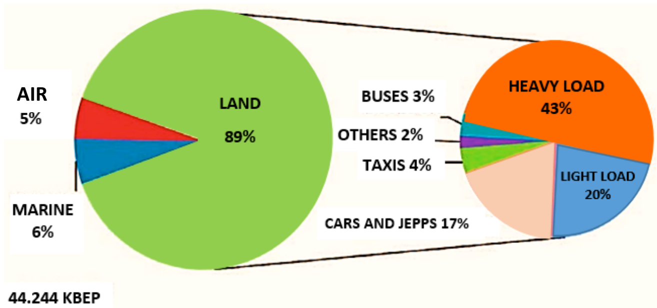


Fig. 3: Percentage structure of final energy consumption by type of transport of the transportation sector in 2016 [13].

Petroleum derivative consumption in taxis, buses, cars, jeeps and other vehicles constitutes 26% of the total energy demand in the transportation sector, figure 3 [10]. The implementation of electric public transportation systems and policies to promote the use of electric vehicle by private users will permit the substitution of consumption of petroleum derivatives and extricate the public and private transportation systems from a dangerous dependency on petroleum.

Thus, tackling the substitution of fossil fuel energy in the transportation sector as soon as possible is extremely necessary. This is due to an excessive dependency of the transportation sector on petroleum derivatives, as well as, a reduction in the petroleum production with the country and the general depletion of petroleum deposits world-wide. Therefore, the elaboration of a long-term strategy to terminate Ecuador's reliance on petroleum is urgent. The country's petroleum dependency must be combated by implementing electrified public transport systems. Promoting the use of private electric vehicles is another way to effectively fight the mentioned dependency and replace petroleum derivatives within the transportation sector.

In 2016, the greenhouse effect gas emissions emitted by energy processes in Ecuador reached 41,5 million tons of CO2 equivalents (broken down into 41,1 million of CO2, 0,152 of N2O and 0,21 of CH4), figure 4 [11].

The transportation system is the most contaminating sector in Ecuador, with 18,7 million tons of CO2 equivalents, constituting 45% of the total of gas emissions. An analysis of the information about greenhouse effect gas emissions by an energy source helped to determine that diesel is the most contaminating energy product. It makes up 33,5% of the total of gas emissions. Likewise, gasoline and fuel oil contribute to this country's contamination with 25,5% and 11,2% respectively, table 2.

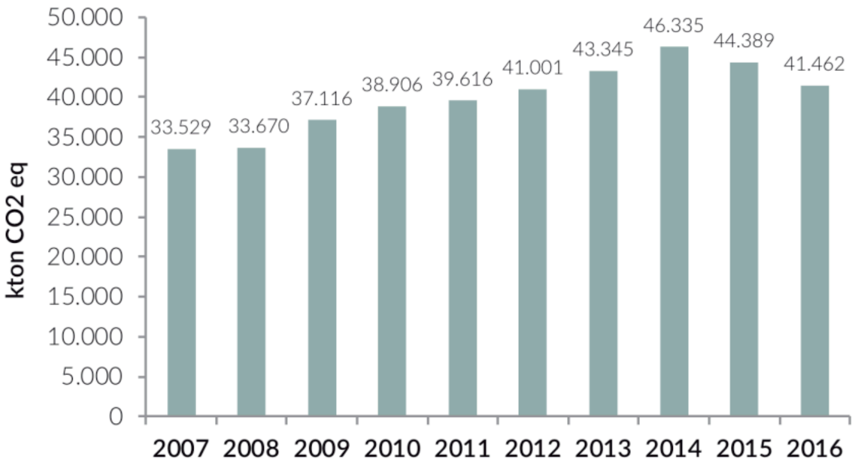


Fig. 4: Historical evolution of greenhouse effect and gas emissions in Ecuador from 2007 to 2016 [11].

Table 2: Percentage structure of final energy consumption in the transport sector in 2016 [11].

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
PRODUCTION	197	187	184	178	178	182	187	195	211	201	205
ELECTRICAL POWER STATIONS	4467	4046	3176	4501	5852	4597	4958	5784	6237	5981	4591
AUTOPRODUCER	1923	3235	2815	2574	2599	2729	2809	2942	3170	3316	3796
GAS CENTER	413	334	386	423	431	433	464	574	569	563	609
OWN CONSUMPTION	1807	1743	1856	1815	1758	1814	1837	1810	1814	1681	1615
TRANSPORT	12458	12492	12498	12896	14718	15700	15880	16841	17999	18349	18673
INDUSTRY	4168	3597	4216	5032	5066	5228	5704	5757	6066	5739	3938
RESIDENTIAL	3320	3364	3374	3370	3369	3415	3411	3425	3485	3377	3306
COMMERCIAL PUBLIC SERVICE	764	795	860	876	919	969	1099	1107	1149	1127	1113
AGRO FISHING MINING	168	184	220	247	275	305	340	350	374	374	332
OTHERS	2993	3552	4085	5205	3740	4245	4312	4561	5263	3681	3285
NOT ENERGETIC											
TOTAL EMISSIONS	32678	33529	33670	37117	38905	39617	41001	43346	46337	44389	41463

The environmental contamination in Ecuador is directly related to the energy consumption levels associated to the fossil fuels used in public and private transport. In 2016, the electric sector, which includes mainly thermal electric plants and private electric generator plants, takes second place with a total of 11,1% of contaminating gas emissions. The industrial sector comes in third with 9,5%, table 2 [15].

Electric transportation systems significantly reduce local contaminating emissions, optimize energy consumption from primary resources due to the high efficiency of electric motors and also minimize sound contamination in the streets. Electric transportation of people and goods within and among cities is one of the greatest challenges in the current process of transforming Ecuador's energy infrastructure. The integration of electric vehicles in the city of Ambato would allow the substitution of a contaminating, energy inefficient and economically unsustainable transportation system by a transport system that is environmentally-friendly, energy efficient and economically competitive. In such an environment of the depletion of worldwide petroleum resources and the inexorable reduction of crude oil production nationally, the excessive dependency of transportation on petroleum derivatives puts at risk the ability to guarantee transportation of people and goods within and among cities. Therefore, it is imperative to develop a long-term strategy which would permit Ecuador to eliminate its dependency on petroleum.

This article has the following scheme: section 2 describes the current public transport system of the city of Ambato based on the operation contracts. Section 3 presents the technical parameters of the electric buses analyzed in this investigation. Section 4 presents the results of the introduction of electric buses in the public transport system of Ambato. In section 5 the work is concluded and in section 6 the authors express their thanks.

2. Description of the Current Transport System of the City of Ambato

Ambato canton is administratively divided into a cantonal head, the city of Ambato and 18 adjacent rural parishes. According to the 2010 population census, 329 thousand 856 inhabitants reside in the city of Ambato. For 2030 the number of inhabitants is estimated to be over 446 thousand [16]. The city of Ambato is connected to three of the country's regions: the mountain, coast and Amazon forest. This is due to the city's strategic location within the country and it is a network of roads. The city of Ambato sits upon a complex geographic topography, which includes slopes that vary between 2500 and 2750 meters above sea level. Its topography greatly influences the distribution, charting and flow of urban and inter-parochial transportation routes. Likewise, it is important to indicate the existence of a railroad line which goes the city from north to south, though it is currently in restoration. Above mentioned, the railroad line provides an exploitable means of transport as part of a future electric transportation system for the city. The urban road network has a 95% impervious road surface (rigid, flexible or cobblestone), 88% of which is in good condition. Ambato possesses 525,5 km of urban roads for an approximate extension of 49,33 km2 in the urban area. Therefore, it has almost 10,65 km/km2 of road density [16]. Figure 5 highlights the main inter-parochial routes within Ambato canton. Explanations related to figures should be given before figure 5.

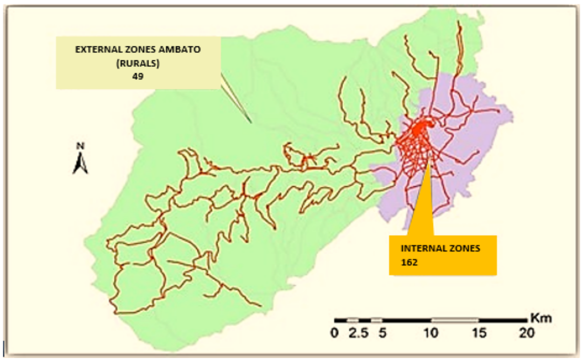


Fig. 5: Road Map Ambato's canton in the province of Tungurahua, Ecuador [17].

According to Ambato's canton Mobility and Transportation Master Plan, the urban public transport network is 132,42 km long. There are 68 public transportation routes: 40 are urban and 28 are inter-parochial [17]. The fleet of buses for public transport has 438 units for urban transport. These are divided into 5 cooperatives.

There are 65 buses that operate inter-parochial transportation, and these are divided into 8 cooperatives. Fossil buses, with capacity for 65 and 85 passenger's totals, operate in Ambato's canton transportation system.

The buses of public transport share the roads with private transportation. Even though measures have been taken to implement bus-exclusive lanes, they have yet to be separated from the lanes used by private vehicles. Furthermore, special treatment for bus stops and stoplights prioritized for public transport is non-existent. On the other hand, [11] it indicates that the number of deaths and injuries due to transit accidents in the province of Tungurahua is higher than the national average. 97 deaths were reported in 2011. This number represents a rate of 18,9 deaths per 100 thousand inhabitants, while the national rate was of 14,2 deaths per 100 thousand inhabitants. 5% of accidents reported in Tungurahua end in one or more deaths.

Table 3: Information of lines, routes and frequencies autorized for public Transport in the city of Ambato

Lines, Routes and Frequencies Autorized				
Transport Cooperatives	***Initial and Final Bus Station***	***Units***	***Bus Stops***	***Distance Route, km***
Tungurahua	*La Libertad – Ingahurco – Miraflores*	*21*	*83*	*40,2*
	Totoras – Terremoto – Ficoa	*19*	*44*	*33,4*
	Mercado Mayorista – Letamendi – Atocha – Constantino Fernández	*20*	*108*	*41,8*
	Montalvo - El Recreo	*18*	*110*	*31*
	Terminal Terrestre – Huachi Progreso - Izamba	*29*	*116*	*62*
	Terminal Terrestre – Barrio Solís – M. Mayorista – Atahualpa	*26*	*102*	*62*
	Pucurumi – Cunchibamba – Tiugua	*12*	*78*	*32*
Unión Ambateña	*Picaihua - Ciudadela España*	*16*	*60*	*28*
	Ficoa – Terremoto – Totoras	*15*	*44*	*33,4*
	Pinillo – Nuevo Ambato	*16*	*79*	*18,2*
	San Juan – Pisque – Barrio Amazonas	*15*	*67*	*35,4*
	La Joya – Ciudadela Militar – Parque Industrial	*25*	*77*	*38,2*
Los Libertadores	*Seminario Mayor - Ingahurco Bajo*	*11*	*77*	*38,2*
	La Florida – 4 Esquinas - Cashapamba	*22*	*62*	*25,9*
	Tangaiche – Shuyurco – Macasto - Pondoa	*10*	*77*	*38,2*
	La Península - Las Orquídeas	*11*	*77*	*38,2*
	Techo Propio – Mercado América - Andiglata	*11*	*56*	*38,2*
Jerpazsol	*Los Ángeles – Izamba*	*26*	*79*	*36,2*
	Manzana de Oro – Huachi Grande - Puerto Arturo	*34*	*93*	*43,5*
Vía Flores	Ambato – San Pablo – 4 Esquinas	20	66	40,5
	Juan B. Vela – La Concepción – Ex Redondel Izamba	25	67	31
Total		*402*	*1622*	*785,5*

Table 4: Operation schedule of line Los Angeles - Izamba of Jerpazsol Cooperative

U	LOS ANGELES			IZAMBA			JERPAZOL	
1	6:00:00	8:10:00	10:20:00	12:30:00	14:40:00	16:50:00	19:00:00	21:10:00
2	6:05:00	8:15:00	10:25:00	12:35:00	14:45:00	16:55:00	19:05:00	21:15:00
3	6:10:00	8:20:00	10:30:00	12:40:00	14:50:00	17:00:00	19:10:00	21:20:00
4	6:15:00	8:25:00	10:35:00	12:45:00	14:55:00	17:05:00	19:15:00	21:25:00
5	6:20:00	8:30:00	10:40:00	12:50:00	15:00:00	17:10:00	19:20:00	21:30:00
6	6:25:00	8:35:00	10:45:00	12:55:00	15:05:00	17:15:00	19:25:00	21:35:00
7	6:30:00	8:40:00	10:50:00	13:00:00	15:10:00	17:20:00	19:30:00	21:40:00
8	6:35:00	8:45:00	10:55:00	13:05:00	15:15:00	17:25:00	19:35:00	21:45:00
9	6:40:00	8:50:00	11:00:00	13:10:00	15:20:00	17:30:00	19:40:00	21:50:00
10	6:45:00	8:55:00	11:05:00	13:15:00	15:25:00	17:35:00	19:45:00	21:55:00
11	6:50:00	9:00:00	11:10:00	13:20:00	15:30:00	17:40:00	19:50:00	22:00:00
12	6:55:00	9:05:00	11:15:00	13:25:00	15:35:00	17:45:00	19:55:00	22:05:00
13	7:00:00	9:10:00	11:20:00	13:30:00	15:40:00	17:50:00	20:00:00	22:10:00
14	7:05:00	9:15:00	11:25:00	13:35:00	15:45:00	17:55:00	20:05:00	22:15:00
15	7:10:00	9:20:00	11:30:00	13:40:00	15:50:00	18:00:00	20:10:00	22:20:00
16	7:15:00	9:25:00	11:35:00	13:45:00	15:55:00	18:05:00	20:15:00	22:25:00
17	7:20:00	9:30:00	11:40:00	13:50:00	16:00:00	18:10:00	20:20:00	22:30:00
18	7:25:00	9:35:00	11:45:00	13:55:00	16:05:00	18:15:00	20:25:00	
19	7:30:00	9:40:00	11:50:00	14:00:00	16:10:00	18:20:00	20:30:00	
20	7:35:00	9:45:00	11:55:00	14:05:00	16:15:00	18:25:00	20:35:00	
21	7:40:00	9:50:00	12:00:00	14:10:00	16:20:00	18:30:00	20:40:00	
22	7:45:00	9:55:00	12:05:00	14:15:00	16:25:00	18:35:00	20:45:00	
23	7:50:00	10:00:00	12:10:00	14:20:00	16:30:00	18:40:00	20:50:00	
24	7:55:00	10:05:00	12:15:00	14:25:00	16:35:00	18:45:00	20:55:00	
25	8:00:00	10:10:00	12:20:00	14:30:00	16:40:00	18:50:00	21:00:00	
26	8:05:00	10:15:00	12:25:00	14:35:00	16:45:00	18:55:00	21:05:00	

Table 5: Estimation of Traveled Distance by Transport Cooperatives in the City of Ambato

Distances traveled in the urban transport system of Ambato						
COOPERATIVE	**LINES, ROUND TRIP**	**UNITS OF TRANSPORT**	**DISTANCE PER ROUTE, KM**	**RETURNS PER ROUTE WEEK**	**DISTANCE TRAVELED WEEK, THOUSAND KM**	**DISTANCE TRAVELED YEAR, THOUSAND KM**
TUNGURAHUA	La Libertad – Ingahurco –	21	40,2	460	18,492	961,58
	Totoras – Terremoto – Ficoa	19	33,4	742	24,782	1.288,70
	Mercado Mayorista – Letamendi – Atocha –	20	41,8	846	35,362	1.838,86
	Montalvo - El Recreo	18	31	900	27,900	1.450,80
	Terminal Terrestre – Huachi Progreso – Izamba	29	62	1074	66,588	3.462,58
	T. Terrestre – Barrio Solís – M. Mayorista – Atahualpa	26	62	1040	64,480	3.352,96
	Pucurumi – Cunchibamba – Tiugua	12	32	455	14,560	757,120
UNIÓN AMBATEÑA	Picaihua - Ciudadela España	16	28	575	16,100	837,200
	Ficoa – Terremoto – Totoras	15	33,4	590	19,706	1.024,71
	Pinillo – Nuevo Ambato	16	18,2	634	11,538	600,01
	San Juan – Pisque – Barrio Amazonas	15	35,4	451	15,965	830,20
	La Joya – Ciudadela Militar – Parque Industrial	25	38,2	575	21,965	1.142,18
LOS LIBERTADORES	Seminario Mayor - Ingahurco Bajo La Florida – 4 Esquinas -	11	38,2	599	22,881	1.189,85
	La Florida – 4 Esquinas – Cashapamba	22	25,9	805	20,849	1.084,17
	Tangaiche – Shuyurco – Macasto – Pondoa	10	38,2	310	11,842	615,78
	La Península - Las Orquídeas	11	38,2	649	24,791	1.289,17
	Techo Propio – Mercado América – Andiglata	11	38,2	581	22,194	1.154,10
JERPAZSOL	Los Ángeles – Izamba	26	36,2	1393	50,426	2.622,18
	Manzana de Oro – Huachi Grande - Puerto Arturo	34	43,5	1393	60,595	3.150,97
VÍA FLORES	Ambato – San Pablo – 4	20	40,5	700	28,350	1.474,20
	Juan B. Vela – La Concepción – Ex Redondel Izamba	25	31	700	21,700	1.128,40
TOTAL		402	785,5	15.472	601,072	31.255,754

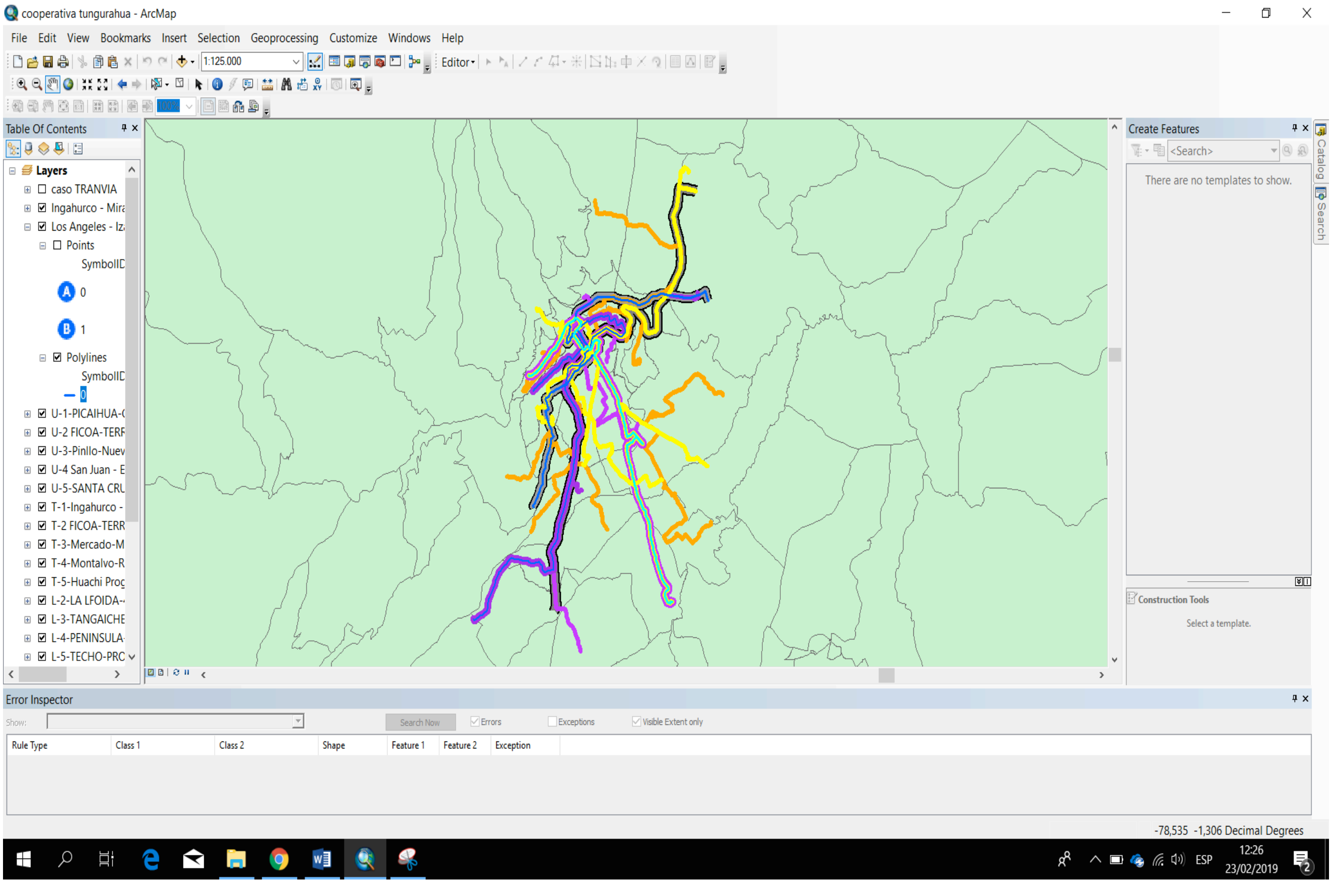


Fig.6: Lines of the transport service of the city of Ambato.

Between December 2015 and February 2016, the Transit, Transportation and Mobility Directorate of the Municipality of Ambato signed 5 operation contracts for the city's public transportation operation [16,17,18,19,20]. Information about the lines, routes and frequency of Ambato's public transportation system was extracted from the operation authorization contracts, table 3. Additionally, the operation time and schedules of the lines of each cooperative are established within the public transport services concession contracts. This information will help estimate the annually travelled distances and the corresponding energy consumption, economic costs and environmental impact as well. For example, the established time for Los Angeles – Izamba line is of 1 hour and 40 minutes with 79 stops. This line is operated by the Jerpazsol Cooperative and consists of 36,2 km. This line's schedule is: Mondays through Sundays from 6 am to 10:30 am, with a vehicle arriving every 5 minutes [19], table 4.

The total distances in kilometers run by each of the 5 transportation cooperatives in Ambato are determined from the information provided by the public transportation operation contracts. These distances can be calculated on an annual, monthly, weekly and daily basis, table 5. The annual total kilometers covered by all the cooperatives in the city surpasses 30 million. The approximated calculations of energy consumption, economic cost and contaminating gases can be determined based on the traveled distances in a given length of time. This article is based on the electric consumption of an hypothetical electric transport system in Ambato. For this scenario, all the buses in the transportation system are assumed to be electric and provide the same service as the real buses currently employed

The urban transport system is formed by 5 bus cooperatives, as it can be seen in the figure 6. The urban transport system has been simulated with the help of the ArcGIS computer package. The obtained data from ArcGis has been plotted in the ArcMap software. From figure 6, the Cooperatives Jerpazsol, Unión Ambateña, Libertadores, Tungurahua, and Via Flores are represented by blue, yellow, orange, violet and gray color lines respectively.

3. Methodology of Transport Energy Consumption Evaluation

In order to calculate the energy consumption of a transportation system in a city, province or specific territory it is necessary to determine:

- Number of routes per vehicle.
- Number of vehicles per route.
- The length of the routes.
- The frequency of vehicles per route and means of transportation.
- The service schedules per route and vehicle.
- Yearly number of trips per route and vehicle.

- Average velocity per route and vehicle.
- Average number of trips per vehicle.
- Average distance per trip and vehicle.
- Average time per trip and vehicle.

The parameters above mentioned help to calculate:

- The total monthly/annual distance covered per vehicle.
- The total monthly/annual energy consumption per vehicle.
- The transportation's annual economic cost system.
- Annual emissions per vehicle.

The energy consumption of any given time period, a week or month being the most commonly evaluated time periods, can be calculated using the total distance traveled by any vehicle. The energy consumption per kilometer of several transportation vehicles is needed to calculate as well as the energy consumption of conventional transportation systems.

Likewise, it is important to differentiate the final energy consumption from the primary energy consumption [21]. The final energy consumption of fossil fuel and electric vehicles is associated with the intake from the fuel tank or the pantograph that feeds electric transport systems, respectively.

The purpose of this study is only a comparative analysis of the energy consumption, economic costs and environmental impact between fossil and electric buses for the urban public transport of the city of Ambato.

To estimate the total of fossil energy consumed by the public transportation in the city of Ambato, the following aspects must be considered:

- The annual and weekly total distance, in kilometers, traveled by each of the lines in Ambato. The energy consumption estimations have been determined based on existing data of the lines, routes and operation frequency and the operation schedules established by the Municipality for each of the lines functioning in the city. Mentioned schedules are presented in the corresponding tables 3 and 4. The total annual distance traveled in Ambato is equal to the sum of kilometers traveled by each cooperative, table 5.
- The average velocity of buses in the city's urban transportation system. The maximum average speed of 38 km/h for urban routes was established in the Mobility and Transport Master Plan of Ambato's canton [11]. The city's maximum urban velocity average still surpasses those of big cities, such as, Madrid and Buenos Aires, which are 15 km/h and 10 km/h, respectively.
- The consumption average of urban buses with a capacity for 65 and 85 passengers, maintaining an average velocity of 38 km/h. A 70-passenger bus in an urban setting consumes 46 liters of diesel per 100 km. This is the equivalent consumption of 17,01 MJ per kilometer traveled [22,23].

The economic cost estimated for the Ambato's public transportation's fossil energy consumption was calculated based on two cases:

- For the national subsidized cost of a liter of diesel. The price of a liter of diesel in Ecuador up to December 31st, 2018 was $ 0,66 dollar per liter.
- And for the current highest price of a liter of diesel. Norway is the current country with the highest standing cost of diesel at $ 1,8 dollar per liter.

In relation to environmental impact of fossil energy consumption in Ambato's transport system, according to the greenhouse gas emissions an estimation was calculated based on [24]:

- The parameter that establishes the grade or level of the emission-generating activity is determined by the amount of liters of Ambato's urban transportation system consumed annually.
- The emission factor represents the number of emissions per unit of the activity data parameter previously mentioned. The emission factor would be 2,471 kg CO_2/liter of diesel in relation to urban public transportation [25].

For the calculation of the energy consumption of an hypothetical electrified transport system in the city of Ambato, all of the conventional diesel buses in Ambato's transportation system have been considered as electric buses. Two electric buses have been selected: the Chinese BYD and the Spanish Irizar i2e. Both electric vehicles possess similar size and capacity as the conventional buses currently in use in the urban transportation system of the city of Ambato [26]. It is important to indicate that this article doesn't take into account the investment cost of acquiring electric vehicles as this article is only focused on comparing electric consumption, economic cost and environmental impact of electric and internal combustion vehicles [27].

The two electric buses initially chosen to estimate the energy consumption of an hypothetical electric public transportation system in the city of Ambato in which all of the conventional buses have been replaced are:

- BYD K9 Chinese bus has the capacity for 65 passengers and a tested autonomy of 250 km for a 324 kWh consumption. The recharge time of the Chinese bus is 4-5 hours. The Chinese electric bus consumes around 1,3 kWh per traveled kilometer.
- Irizar i2e Spanish bus has a rated power of 180 kW and a storage capacity equal to 376 kWh. This bus provides an autonomy between 200-250 km depending climate conditions and driving cycle. Electrical recharge takes only 5 hours. This guarantees 14 to 16 driving hours in dense urban and interurban traffic while driving at a velocity of 17 km/h. The Irizar i2e consumes between 1,5 kWh and 1,88 kWh per kilometer traveled in relation to the distance traveled.

Table 6 presents the technical and economical characteristics of the electric buses selected for the energy consumption estimation of an electric transportation system in the city of Ambato:

Table 6: Technical characteristics of electric vehicles.

Technical Characteristics of Electric Buses	*Nominal Power kW*	*Batteries Capacity kWh*	*Autonomy km*	*Energy Consumption kWh/km*
BYD K9	200	324	250	1,3
Irizar i2e	180	376	220	1,7

In relation to the economic cost of electricity consumption of an hypothetical electrified transport system, currently, a general tax for low voltage public transportation electric vehicles with power over 10 kW doesn't exist in Ecuador. Regardless, in this article, the general tax by time register will be applied to consumers who are subjected to the low-tension general category and have an electric vehicle of up to 10 kW. This general tax was established by the Electricity Control and Regulation Agency, ARCONEL in [28]. The above-mentioned tax will be used to calculate the estimation cost of the energy consumed by an hypothetical electric transportation system in the city of Ambato. It is necessary to use a measuring system with a time register. This register will help identify the energy and power consumption in peak, medium and slow periods.

An additional ratio is the regeneration coefficient that must be changed from 0 to 60% of what is a certain efficiency of electric buses. The weight of the bus due to the battery must also be kept in mind, the weight of the BYD k9 bus is 14465kg. The use of electric buses in Singapore minimizes the daily cost of electric energy by 40% compared to internal combustion vehicles [23]. The reduction of the bus fleet is reduced to a 30%, for NOx 37%, for CO 30%, BEB 36%, HC 37% [29]. In the case of electric vehicles for urban transport, it's been considered that the recharging should be done during slow periods and the system should demonstrate certain level of flexibility by the converter control for renewable resources [30,31]. Slow periods are considered to be from 10 pm to 8 am Monday through Sunday and from 8 am to 6 pm on weekends. Additionally, the consumer will have to pay:

- A tax for commercialization in American dollars apart from the power and energy consumption.
- A monthly demand tax in American dollars per kW for every billable demanded kW. This will correspond to the maximum monthly demand registered on the respective meter, multiplied by a correction factor.

Table 7 shows the unique tax charges to electric vehicles in the city of Ambato [24].

Table 7: Tariff Charges for electric vehicles in the city of Ambato, Ecuador.

Range Consumption	*Power Tariff USD/kW*	*Energy Tariff USD/kWh*	*Commercialization USD / Seller*
	4,050	---	1,414
Monday - Friday: from 8h00 to 18h00	---	0,080	---
Monday – Sunday: from 18h00 to 22h00	---	0,10	---
Monday-Sunday: from 22h00 to 8h00 Saturday and Sunday: from 8h00 to 18h00	---	0,050	---

Like for the evaluation of fossil buses, the calculation of the greenhouse gas emission of electric buses will depend on:

- The evaluated activity's data, which is defined as the parameter that establishes the grade or level of the emission-generating activity. In the case of the urban electric transportation system of the city of Ambato, the electric energy in kWh consumed annually by each line of the cooperatives which operate in the city of Ambato.
- The emission factor represents the number of emissions per unit of the activity data parameter previously mentioned. The emission factor would be 167,58 gr of CO2 eq/kWh obtained from the data of electrical generation and emissions in the electric sector of the National Energy Balance 2017 [13].

4. Results and Discussion

Table 8 shows the fossil energy consumption of each of the lines of the different cooperatives that operates in the public transport system in the city of Ambato. The annual fossil energy consumption of the city's public transportation system is equal to 12 million 502 thousand diesel liters, which is the equivalent of 531,66 Tera Jules, TJ. Likewise, table 9 shows the economic cost and the greenhouse effect gas emission for the fossil transportation system of Ambato. The economic cost of the annual fossil energy consumption with subsidized diesel is $ 3 million 439 thousand dollars. In a scenario without subsidized fuel, like in Norway, the annual cost would be over $ 22 million 504 thousand dollars. The yearly contaminating emissions of this system surpassed 35 thousand tons of CO2.

Table 10 shows the electric energy consumption for each line of the different cooperatives which operate the public transportation system of the city of Ambato, considering that all the internal combustion vehicles have been replaced by electric buses. The evaluation has been done using the data of the technical characteristics of the electrical buses presented in table 6. The annual electric energy consumption of the city's electrified public transportation system is equal to around 40 MWh, by BYD buses, which is the equivalent of 146,27 Tera Jules, TJ, and around 53 Mwh, for Irizar i2e buses, where 191,28 Tera Jules, TJ is the equivalent. Likewise, table 11 shows the economic cost and the greenhouse effect gas emission for the electrified transportation system of Ambato. The estimation of the economic cost of the annual electric energy consumption, by BYD buses, is around $ 2 million 031thousand dollars, and by Irizar i2e buses, the annual cost would be over $ 2 million 656 thousand dollars. Finally, the yearly contaminating emissions of electrified transport system in Ambato is almost 10 thousand tons of CO2, by BYD buses, and by Irizar i2e buses surpassed 13 thousand tons of CO2.

Table 8: Estimation of Fossil Energy Consumption of the Transport Cooperatives in of city of Ambato [16,17,18,19,20].

Fossil Energy Consumption of Urban Transport System in Ambato						
Transport Cooperatives	***Initial and Final Bus Station***	***Transport Units***	***Traveled Distance per Year kilometers***	***Diesel Consumption per Month, Thousands liters***	***Diesel Consumption per Year, Thousands liters***	***Fossil Energy Consumption per Year , TJ***
Tungurahua	La Libertad – Ingahurco - Miraflores	21	961584	34025,28	384633,6	16,35654384
	Totoras – Terremoto – Ficoa	19	1288705,6	45600,352	515482,24	21,92088226
	Mercado Mayorista – Letamendi – Atocha – Constantino Fernández	20	1838865,6	65067,552	735546,24	31,27910386
	Montalvo - El Recreo	18	1450800	51336	580320	24,678108
	Terminal Terrestre – Huachi Progreso - Izamba	29	3462576	122521,92	1385030,4	58,89841776
	Terminal Terrestre – Barrio Solís – M. Mayorista – Atahualpa	26	3352960	118643,2	1341184	57,0338496
	Pucurumi – Cunchibamba - Tiugua	12	757120	26790,4	302848	12,8786112
Unión Ambateña	Picaihua - Ciudadela España	16	837200	29624	334880	14,240772
	Ficoa – Terremoto - Totoras	15	1024712	36259,04	409884,8	17,43035112
	Pinillo – Nuevo Ambato	16	600017,6	21231,392	240007,04	10,20629938
	San Juan – Pisque – Barrio Amazonas	15	830200,8	29376,336	332080,32	14,12171561
	La Joya – Ciudadela Militar – Parque Industrial	25	1142180	40415,6	456872	19,4284818
Los Libertadores	Seminario Mayor - Ingahurco Bajo	11	1189853,6	42102,512	475941,44	20,23940974
	La Florida – 4 Esquinas - Cashapamba	22	1084174	38363,08	433669,6	18,44179974
	Tangaiche – Shuyurco – Macasto – Pondoa	10	615784	21789,28	246313,6	10,47448584
	La Península - Las Orquídeas	11	1289173,6	45616,912	515669,44	21,92884294
	Techo Propio – Mercado América - Andiglata	11	1154098,4	40837,328	461639,36	19,63121378
Jerpazsol	Los Ángeles - Izamba	26	2622183,2	92784,944	1048873,28	44,60333623
	Manzana de Oro – Huachi Grande - Puerto Arturo	34	3150966	111495,72	1260386,4	53,59793166
Vía Flores	Ambato – San Pablo – 4 Esquinas	20	1474200	52164	589680	25,076142
	Juan B. Vela – La Concepción – Ex Redondel Izamba	25	1128400	39928	451360	19,194084
Total	** For the Vía Flores cooperative, the number of stops and kilometers traveled was calculated as the average of the previous 19 lines*	402	31255754,4	1105972,848	12502301,76	531,6603823

Table 9: Estimation of the economic cost and environmental impact of fossil urban transport in Ambato[16,17,18,19,20]

Evaluation of energy consumption, economic cost, and environmental impact of the fossil transport system of the city of Ambato							
Cooperative	**Lines, round trip**	***Units of Transport***	***Diesel consumption per year In thousands of liters***	***Fossil energy consumption per year In TJ***	***Annual economic cost In thousands of dollars***		***Environmental impact In Tn of CO2***
					0,27$/Lt	***1,8 $/Lt***	
Tungurahua	La Libertad – Ingahurco - Miraflores	21	442,33	16,356	105,825	692,340	1.092,994
	Totoras – Terremoto – Ficoa	19	592,80	21,920	141,825	927,868	1.464,820
	Mercado Mayorista – Letamendi – Atocha – Constantino Fernández	20	845,88	31,279	202,372	1323,983	2.090,164
	Montalvo - El Recreo	18	667,37	24,678	159,664	1044,576	1.649,066
	Terminal Terrestre – Huachi Progreso - Izamba	29	1.592,79	58,898	381,066	2493,054	3.935,771
	Terminal Terrestre – Barrio Solís – M. Mayorista – Atahualpa	26	1.542,36	57,033	369,003	2414,131	3.811,175
	Pucurumi – Cunchibamba - Tiugua	12	348,28	12,878	83,323	545,126	860,588
Unión Ambateña	Picaihua - Ciudadela España	16	385,11	14,240	92,136	602,784	951,611
	Ficoa – Terremoto - Totoras	15	471,37	17,430	112,772	737,792	1.164,749
	Pinillo – Nuevo Ambato	16	276,01	10,206	66,033	432,012	682,016
	San Juan – Pisque – Barrio Amazonas	15	381,89	14,121	91,366	597,744	943,656
	La Joya – Ciudadela Militar – Parque Industrial	25	525,40	19,428	125,700	822,369	1.298,270
Los Libertadores	Seminario Mayor - Ingahurco Bajo	11	547,33	20,239	130,946	856,694	1.352,458
	La Florida – 4 Esquinas - Cashapamba	22	498,72	18,441	119,316	780,605	1.232,337
	Tangaiche – Shuyurco – Macasto – Pondoa	10	283,26	10,474	67,768	443,364	699,937
	La Península - Las Orquídeas	11	593,02	21,928	141,877	928,204	1.465,352
	Techo Propio – Mercado América – Andiglata	11	530,89	19,631	127,011	830,950	1.311,817
Jerpazsol	Los Ángeles - Izamba	26	1.206,20	44,603	288,578	1887,971	2.980,530
	Manzana de Oro – Huachi Grande - Puerto Arturo	34	1.449,44	53,597	346,772	2268,695	3.581,577
Vía Flores	Ambato – San Pablo – 4 Esquinas	20	678,132	25,076	162,24	1061,424	1.675,664
	Juan B. Vela – La Concepción – Ex Redondel Izamba	25	519,064	19,194	124,183	812,448	1.282,607
Total		402	14.377,64	531,660	3439,786	22504,143	35.527,165

Table 10: Estimation of Electric Energy Consumption of the Electrified Transport of the city of Ambato [16,17,18,19,20]

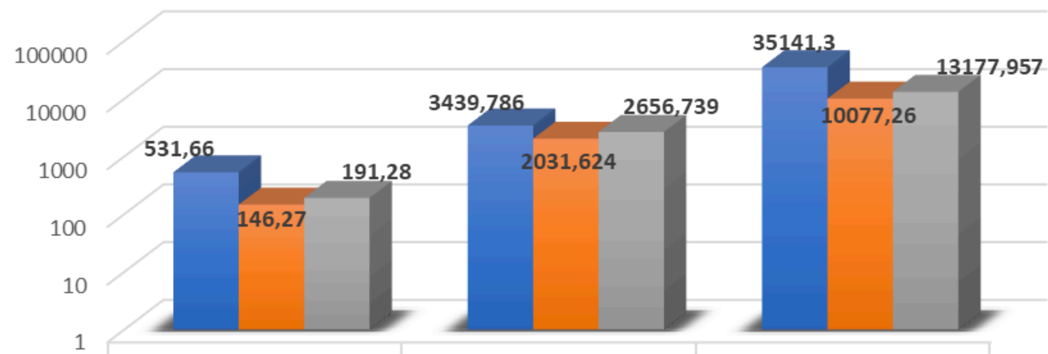
Electric Energy Consumption of Urban Electrified Transport System in the City of Ambato					
Cooperative	**Lines, round trip**	**Annual power consumption kWh**		**Annual energy consumption TJ**	
		Chinese Bus BYD 1,3 kWh/km	***Spanish Bus Irizar i2e, 1,7 kWh/km***	***Chinese Bus BYD 1,3 kWh/km***	***Spanish Bus Irizar i2e, 1,7 kWh/km***
Tungurahua	La Libertad – Ingahurco - Miraflores	1.250,05	1.634,69	4,50	5,88
	Totoras – Terremoto – Ficoa	1.675,31	2.190,79	6,03	7,88
	Mercado Mayorista – Letamendi – Atocha – Constantino Fernández	2.390,52	3.126,07	8,60	11,25
	Montalvo - El Recreo	1.886,04	2.466,36	6,78	8,87
	Terminal Terrestre – Huachi Progreso – Izamba	4.501,34	5.886,37	16,20	21,19
	Terminal Terrestre – Barrio Solís – M. Mayorista – Atahualpa	4.358,84	5.700,03	15,69	20,52
	Pucurumi – Cunchibamba - Tiugua	984,25	1.287,10	3,54	4,63
Unión ambateña	Picaihua - Ciudadela España	1.116,75	1.460,36	4,02	5,25
	Ficoa – Terremoto - Totoras	1.332,12	1.742,01	4,79	6,27
	Pinillo – Nuevo Ambato	780,02	1.020,02	2,80	3,67
	San Juan – Pisque – Barrio Amazonas	1.079,26	1.411,34	3,88	5,08
	La Joya – Ciudadela Militar – Parque Industrial	1.484,83	1.941,70	5,34	6,99
Los Libertadores	Seminario Mayor - Ingahurco Bajo	1.546,80	2.022,75	5,56	7,28
	La Florida – 4 Esquinas - Cashapamba	1.409,42	1.843,09	5,07	6,63
	Tangaiche – Shuyurco – Macasto - Pondoa	800,51	1.046,83	2,88	3,76
	La Península - Las Orquídeas	1.675,92	2.191,59	6,03	7,88
	Techo Propio – Mercado América – Andiglata	3.597,17	4.703,99	12,94	16,93
Jerpazsol	Los Ángeles - Izamba	3.408,83	4.457,71	12,27	16,04
	Manzana de Oro – Huachi Grande - Puerto Arturo	4.096,25	5.356,64	14,74	19,28
Vía Flores	Ambato – San Pablo – 4 Esquinas	1.916,460	2.506,14	6,89	9,02
	Juan B. Vela – La Concepción – Ex Redondel Izamba	1.466,920	1.918,28	5,28	6,90
Total		40.632,480	53.134,78	146,27	191,28

Table 11: Estimation of the economic cost and environmental impact of electrified urban transport in Ambato. [16,17,18,19,20]

Economic Cost and Environmental Impact of Electrified Transport System of the City of Ambato					
Cooperatives	**Lines, round trip**	**Annual Economic Cost, thousands Dollars**		**Environmental Impact, Tn Eq CO_2**	
		Chinese Bus BYD 1,3 kWh/km	*Spanish Bus Irizar i2e, 1,7 kWh/km*	*Chinese Bus BYD 1,3 kWh/km*	*Spanish Bus Irizar i2e, 1,7 kWh/km*
Tungurahua	La Libertad – Ingahurco - Miraflores	62,502	81,734	310,02	405,42
	Totoras – Terremoto – Ficoa	83,765	109,539	415,49	543,34
	Mercado Mayorista – Letamendi – Atocha – Constantino Fernández	119,526	156,303	592,87	775,29
	Montalvo - El Recreo	94,302	123,318	467,75	611,68
	Terminal Terrestre – Huachi Progreso – Izamba	225,067	294,318	1116,37	1459,88
	Terminal Terrestre – Barrio Solís – M. Mayorista – Atahualpa	217,942	285,001	1081,03	1413,66
	Pucurumi – Cunchibamba - Tiugua	49,212	64,355	244,10	319,21
Unión Ambateña	Picaihua - Ciudadela España	55,837	73,018	276,96	362,18
	Ficoa – Terremoto - Totoras	66,606	87,100	330,38	432,03
	Pinillo – Nuevo Ambato	39,001	51,001	193,45	252,97
	San Juan – Pisque – Barrio Amazonas	53,963	70,567	267,66	350,02
	La Joya – Ciudadela Militar – Parque Industrial	74,241	97,085	368,25	481,56
Los Libertadores	Seminario Mayor - Ingahurco Bajo	77,340	101,137	383,62	501,66
	La Florida – 4 Esquinas - Cashapamba	70,471	92,154	349,55	457,10
	Tangaiche – Shuyurco – Macasto - Pondoa	40,025	52,341	198,53	259,62
	La Península - Las Orquídeas	83,796	109,579	415,64	543,53
	Techo Propio – Mercado América – Andiglata	179,858	235,199	892,13	1166,63
Jerpazsol	Los Ángeles - Izamba	170,441	222,885	845,42	1105,55
	Manzana de Oro – Huachi Grande - Puerto Arturo	204,812	267,832	1015,91	1328,50
Vía Flores	Ambato – San Pablo – 4 Esquinas	95,823	125,307	475,30	621,54
	Juan B. Vela – La Concepción – Ex Redondel Izamba	73,346	95,914	363,81	475,752
Total		2.031,624	2.656,739	10.077,26	13.177,957

Table 12: Comparative Analysis of Fossil and Electrical Transport System in the city of Ambato

	Energy consumption TJ	*Economic Cost, USD*	*Environmental Impact, Tn CO_2*
Fossil Buses	531,660	3.439,786	35.141,30
BYD Buses	146,27	2.031,624	10.077,26
Irizar ie2 Buses	191,28	2.656,739	13.177,957



	ENERGY CONSUMPTION TJ	ECONOMIC COST, USD	ENVIRONMENTAL IMPACT, TN CO2
FOSSIL BUSES	531,66	3439,786	35141,3
BYD BUSES	146,27	2031,624	10077,26
IRIZAR IE2 BUSES	191,28	2656,739	13177,957

Fig.7: Comparative Analysis of Energy Consumption, Economic Cost and Environmental Impact for Fossil and Electrical Transport System in the City of Ambato.

5. Conclusions

This article describes Ambato's urban transportation system based on information obtained from operation contracts of the transport cooperatives in Ambato's city. Likewise, the annual traveled distance of all the vehicles have been estimated, as well as, the annual energy consumption and the economic cost of the fuel which is used. The attained results will allow the calculation of the cost of the primary energy which will be substituted for an electric urban transportation system. It will also permit the estimation of the energy consumption pertaining to a sustainable electric transportation proposal.

This study evaluates the changes in energy consumption, pollutant emissions and economic cost due to the replacement of electric buses in the urban public transport system of the city of Ambato. For sustainable mobility, two brands of electric buses have been analyzed, where the BYD brand stands out as an efficient solution. Demonstrating that for the transportation system of the city of Ambato, BYD buses would minimize energy consumption by 72%, 71% in polluting emissions and 40% in economic costs.

The estimation cost of the energy consumed by an hypothetical electric transportation system in the city of Ambato. It is necessary to will use a measuring system with a time register. This register will help identify the energy and power consumption in peak, medium and slow periods.

Future research will be directed to:

(i) Analysis of the performance of electric buses based on current routes of the urban transport system.

(ii) Impact of a multimodal transportation system for the city of Ambato

(iii) Mobility scenarios for electric buses based on Energy demand.

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