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Panama Metro Bus System and Metro Line 1: An externalities analysis of CO_2 emissions spectre

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***Abstract* — In recent years there is has been a need to reduce traffic congestion with the objective of contributing to the reduction of CO_2 emissions or air pollution. This argument could be seen as a new tariff or tax to make society more aware and contribute to the care of the environment. Externalities are those effects of the production or consumption of some agents in order to producing or consuming others, for which no payment is made. In this sense, this paper presents some estimation of the socio-environmental externalities of the Metro Bus system and Panama Metro Line 1 for the years 2007, 2010 and 2015. These externalities correspond to variables such as: reducing of CO_2 emissions and decreasing in the occupation of urban roads, among others. In others words, this paper presents an American Public Transportation Association (APTA) standards practical development about the $C0_2$ emissions estimation in Panama City.**

Keywords—externalities, Panama Metro, $C0_2$ emissions, sustainability, public transport.

I. Introduction

The urban transport systems generate both positive and negative effects on pollution, in other words, externalities.

In this sense, an external cost arises when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group [1]. In the transportation sector, externalities arise when transportation users and providers impose additional costs to society without having to bear these costs themselves or pay compensations. Transportation externalities are primarily related to the impact of emissions (climate change and air pollution), accidents, noise, soil, contamination, disruption of the ecological systems, infrastructure damages, visual intrusion and congestion [2]. The topic of network externalities has been studied for almost two decades [3]. Varian [4] defines network externality with these words:

"Network externalities area a special kind of externalities in which person´s utility for a good depends on the number of other people who consume this good." Economists define positive network externalities, when the utility of a good increases with the consumption of others. Negative consumption externalities will occur if there are capacity constraints in the network. In this situation, users will suffer from crowded networks [5], and they will avoid the use a leader product because it is not useful for consumers anymore. According to Seyfi Top *et al.*, [6] externalities can be defined as a situation in which one agent is affected directly by the production of another product, or by consumption decision.

According to a the Latin American and Caribbean Economic Commission (CEPAL) 2009 study [7] on externalities of urban infrastructure projects, they should be studied in three lines of work: (a) in addition to identifying and valuing the interactions, the interactions among different externalities must be taken into consideration; (b) transversal analysis of the relations between these externalities and the forms of urban and regional occupation; and (c) realistic targeting of those "second best policies". Based on these lines of work, the focus of this study goes directly to the systematic observation and valorization of the positive externalities from the social, economic and mainly environmental point of view from the Panamanian society. In this sense, it is very interesting that organizations like the European Commission (based on the IMPACT published ratios), also attempts to internalize in a short period of time the external costs of transport in order to attain a more sustainable transportation systems [8].

II. Description of the Panama CITY Transportation System

It is possible to find in the literature information about the Panama City Transportation System. Among them are: ESTAMPA [9], ESTAMPA [10], ESTAMPA [11], Bermúdez

[12], Dames & Moore [13], INECO [14], Renardet[15], BCEOM [16], ESTUI [17], Bocarejo [18], Banco Mundial [19], Solis *et al*:,[20], Nikoei [21], SMP[22-25] Berbey *et al.*,[26-36].

A. Description of the Panama City Metrobus System

The bus transportation system in Panama City is operated by MiBus. This is a four thousand employee's organization, including bus drivers, staff and technical personnel among others. The company, which is state-owned company, operates a little more than 1,200 buses in the metropolitana area that includes the districts of Panama and San Miguelito. The buses are divided in over 250 routes, and operate vehicles with Volvo Technology assembled in Colombia and Brazil. The company operates with six operation centers distributed across the metropolitan area that provide dispatching and maintenance for the buses. [37]. Each bus hast 38 seats including several for handicapped and disabled people [38-39]. They can move up to 85 passengers. [40]. Originally the system was developed to replace the traditional *"Diablos rojos,"* old "school buses" imported from the United States. As of today, the system is highly inefficient and "alternative" or "pirate" transports have appeared through the metropolitan areas.

B. Description of the Panama Metro line 1.

The Panama Mass Transit Railway is a metropolitan subway with subterranean and elevated track sections[31] operated with a catenary-guided transport system. Currently there is only one line that connects the northern macrozone called "San Miguelito" with the mid-south macrozone in downtown Panama City. This macrozone is the one that attracts more trips[25], since it harbors the main banking and financial center, hospitals, universities and the National Bus Terminal Station(see the figure 1). The line 1 of the Panama Metro has a north-south direction and it connects the National Bus Terminal Station in "Albrook" with the Commercial Mall called "Los Andes" in the north of Panama City (Phase 1). This route is inserted into a high demand corridor of public transportation [22-25]. Panama Metro is the most efficient mode of the mass transportation system between the northern zone and the middle-southern zone.

Vuchic [41],Melis *et al.*, [42] presented a list of reasons to select a subway like an option urban transportation systems among other options: high capacity and low Space Use, efficiency of urban patterns, avoid surface congestion, mechanical efficiency and energy conservation, environmental quality [43]**,** safety and reliability, durability, proven experience, automation and civic image.

There is a facility for storage and maintenance at the end of the line 1 in the area of Albrook (near Albrook station in the south end), with a surface of 10 hectares. In this same area is located the Operations Control Center (OCC).

The Panama metro line 1 corresponded to a extension of 15,8 km. The length of the station's platform is 110 meters and its minimum width is 3 meters. Each train has 3 electric multiple units with a maximum capacity of 800 passengers/train. Since the first year of operation year, the headway is 3 minutes between 6:00 am – 8:00 am and it is 5 minutes (i.e. 12 trains/hour) in off-peak hours.

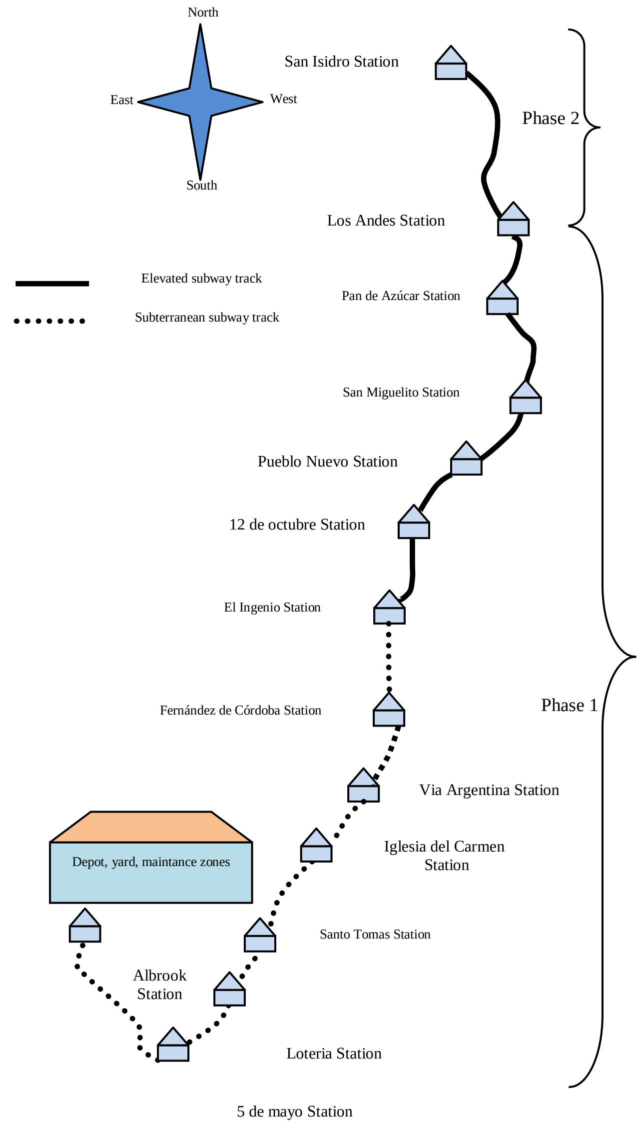

Figure 1. Scheme of Panama Metro line 1(Phase 1+Phase2). Source: A. Berbey-Alvarez.

The Panama Metro Line 1 seems to have transformed the previous traditional transportation systems with the use of a modern railway transportation system with the same characteristics of the big cities of the world. For this reason, it is important to assess the externalities that have derived from this urban rail transportation system like a benefit of the passenger mobility in Panama City. Panama Metro line 1 began its operations in April 6, 2014 [44][45]. According to the national oldest newspaper *La Estrella de Panama* [46], the Panama Metro line 1 overpassed the expected limit of travels with more of 273000 daily travels during the Black Friday in November, 2015. [47]

According the Panama Metro authorities [47][48], the current rail transport statistic of the Panama Metro line 1 are showed in the table 1.

Table.1 Rail Transport Statistics of Panama Metro line 1. *Research Date: December, 2016.Web page: Metro de Panama*

Total number of passenger since the initial day of operations.	92,539,462 passengers
Average number of monthly travelers, year 2014	4,802,929 monthly travelers
Total number of passengers in 2015 (9 months).	49,313,100 passengers
Average number of monthly travelers, year 2,015	5,479,233 monthly travelers

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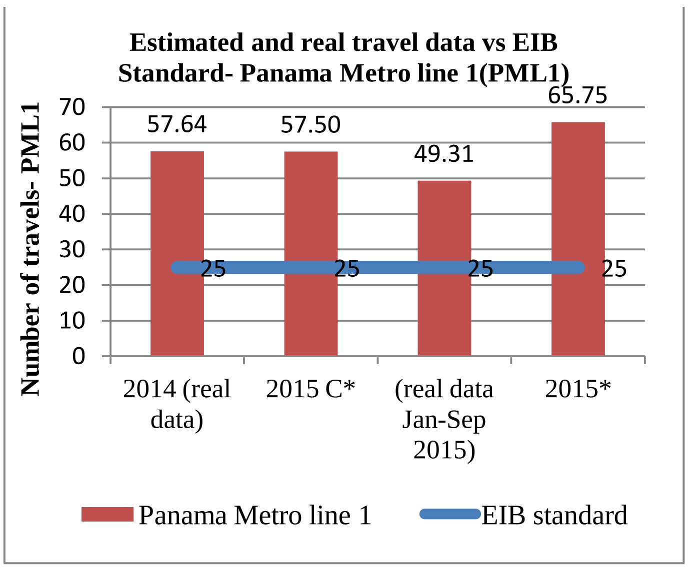
According to Zamorano et al., [49] the European Investment Bank (EIB) had stated that for a metro line project is necessary an annual travel demand of 25 million of trips. For February 2017, the Panama Metro line 1 authorities said that in 26 months, line 1 the Metro has averaged 270,000 passengers per day [50] and over 100 million trips.

Figure 2. Real travel demand vs EIB standard. Source: A. Berbey Alvarez.



According the figure 2 and table 1, it is possible to appreciate like the average real number of monthly travelers (2014) corresponds to 54.64 million annual of travelers (2014) estimated using the real average number of monthly travelers (2014).It was 4,802,929 monthly travelers This value is greater than 25 million of annual trips [49]. The scenario 2015*C corresponds to 57.50 million annual estimated of travelers (2015) using the estimated value of 230000 diary demand [22][25]. This estimated value is greater than 25 million of annual trips [49]. Also, the total real number of passengers between January to September of 2015 year was 49,313,100 passengers and the estimated number of travelers passenger for all the year 2015 could be 65.75 million. In both cases, these is greater the 25 million of annual traverls, which is the EIB standard [49].

III. METHODOLOGY.

There are some previous studies about methods to estimate railway externalities [51-54] in other countries. Tuchschmid [51] proposed a quantitative method for measuring the emission of multiple polluting gasses, like CO_2, deriving from the operation of the main European railway networks. Nocera *et al.,* [52] presented a case study concerning the endorsement of the construction of the Brenner railway tunnel, using a forecasted outcome of a suitable transportation policy. Carrese *et al.,* [53], on the other hand, analyzed the emission carried out from a bus line and a tramway line in an urban zone. As expected, they showed that the tramway services emissions were lower in comparison with the bus services emissions. In this study, the total emission for the tramway line was about 25% of those of the bus line. Finally, Shang *et al.,* [54] used the Skeleton Planning Method (SPM) to estimate HC, CO, NO_x emission reductions.

In this paper, the most relevant methodology of this research is the collection of statistical information of relevant data on Panama transportation systems (subway+metrobus). In addition to identifying pertinent data, an analysis of the main variables was conducted and compared with similar data from other countries. In the case of modern trams, light metros, heavy metros, or other catenary-guided transport systems, the choice of vehicle has no environmental effects, since it is a system of electric traction, smoke-free and quite silent. If the production of electrical energy is based on renewable sources (hydraulic, wind, solar ...), the emissions will be completely zero. [43][49].

In the Panama City, 90% of the emissions correspond to the transportation sector [55-57]. According, to Climate Change Standards Working Group [58] of the American Public Transportation Association (APTA), the estimate CO_2 emission corresponds to:

$$CO_2 \text{ emissions (g)} = TDD\_{mode} \times EF\_{mode} \quad (1)$$

Where:
CO_2 emissions (g) = gram of CO_2 emissions
TDD_{mode} = Travel Demand Data by transport mode
EF_{mode} = Emission Factor by transport mode in g/km of CO_2 emissions.

$$Emission\ of\ CO_2 = TAD * \sum_{i=1}^{n} \left(\frac{DTD_{mode} * EF_{mode_{esc}}}{OR_{esc}} \right)$$

TAD = Travel average distance (km)
DTD_mode = Diary travel demand by transportation mode
EF_mode_esc= Emission factor by mode (g/ km de CO_2) by scenario (minimun, mean and maximum)
OR_esc= occupation rate by transportation mode (passengers/vehicule) by scenario (min, max, pessimist, average, ideal)
The methodology used for this practical application, although based on the original APTA approach, used different scenarios considering the occupation rate of the vehicles, and minimum and maximum of emissions for different type, and brand of transportation equipment.

This approach is a more realistic approach since it uses a range of values depending on the different brands and models of vehicles driven in Panama. Thus, table 2 shows some of the reference values of CO_2 emissions depending on the type of vehicle and rate of occupation, for years 2007, 2010 and 2015.

Table 2. Resume of reference´s values.

Reference´s values	**2007**	**2010**	**2015**
Modal distribution of all public transport [19][59]	50.30%	50.30%	57%
Total diary travel demand [19][22-25] [59]	1714134	2000000	2300000
Private vehicle modal split [19][59]	21.7%	21.7%	43%
Minimun gC02/km Diablo Rojo bus [60]	978.04	N/As	N/As
Maximun gC02/km Diablo Rojo bus [60]	1061.31	N/As	N/As
Occupancy rate Diablo Rojo bus-passengers [19]	45	N/As	N/As
Metrobus average occupancy rate - passengers [38-40]	N/As	38	38
Metrobus maximum occupancy rate-passengers [38-40]	N/As	85	85
Minimun grams C02/km metrobus [61]	N/As	110	110
Maximun grams C02/km metrobus [61]	N/As	205	205
Average trip in kilometers [22-25]	16	16	16

A. *Estimation of the CO_2 emissions of the Diablos Rojos fleet, 2007*

During 2007 public transportation in the metropolitan area was operated by Diablos Rojos. Using the methodology depicted [58], CO_2 emissions were estimated within a range between 978.04 to 1061.31 g/km [60]. The amount of daily travels, information of a study conducted by the World Bank [19], and published in 2007 was used. The study stablished that the average demand of daily trips was 1,714,134; 50.3% of them correspond to public transportation. The average trip in bus used for the estimation of CO_2 was 16 km [22-25]. Since the school buses used by Diablos Rojos (and in other countries in Central America) have an average life of 10 years and over 240,000 km [62], the estimated range of CO_2 emissions was between 72,000 to 91,100 tons of CO_2 annually (See table 3).

Table 3. Estimation of the CO_2 emissions of the Diablos Rojos fleet, 2007.

Fleet School Bus Diablos Rojos			
Min	Max	Min	Max
g CO_2/passenger-km	g CO_2/passenger-km	2007	2007
21.73	23.58	18739451	23726175
	16 km[22-25]	299831212	379618795
Working days	Kg of CO_2 emissions	299831	379619
Working days	Ton of CO_2 emissions	300	380
Working year	Ton of CO_2 emissions	71959	91109

B. *Estimation of CO_2 emission for the new Metrobus fleet 2010.*

A new fleet of buses Metrobus type was introduced in the Panama City metropolitan area public transportation system in 2010. According to Volvo, the types of buses introduced have a range of CO_2 emissions between 110 to 205 g CO2/km [61]. The capacity of the buses is 85 passengers both seated and standing. According to the transportation authorities, the daily demand of bust trips average two million. With an average trip of 16 km, the estimated range of emissions for 38 seated passengers is 11,182 to 20,840 tons of CO_2 per year. For full occupancy of 85 passengers, the range will be 4,999 to 9,317 tons of CO_2 per year. As a consequence, the levels of CO_2 emissions decrease with the increment of the occupation rate by the vehicle (See table 4).

Table 4. Estimation of CO_2 emissions for Metrobus for Panama City-2010.

Occupancy rate: 38 passengers				Occupancy rate: 85 passengers			
Min	Max	Min	Max	Min	Max	Min	Max
g CO_2/passenger-km	g CO_2/passenger-km	2010	2010	g CO_2/passenger-km	g CO_2/passenger-km	2010	2010
2.89	5.39	2912105.263	5427105.263	1.29	2.41	1301882.353	2426235.29
	16 km	46593684.21	86833684.21		16 km	20830118	38819765
	Kg CO_2	46594	86834		Kg CO_2	20830	38820
Working days	Ton CO_2	47	87	Working days	Ton CO_2	21	39
Working year	Ton CO_2	11182	20840	Working year	Ton CO_2	4999	9317

C. *Estimation of CO_2 emissions for the Metrobus fleet in 2015.*

According to Metro de Panama, the demand of daily trips in the Metropolitan averages 2.3 million daily trips [59]. As seen in figure 3, 57% of people travel in the public system, among them 48% in Metrobus, while 43% travel in private cars. The average number of daily trips of the Metro was generated by the Metro statistics shown in figure 4. Thus, the estimated average demand of daily trips per months is 210,080 trips.

Figure 3. Percentage modal travel 2015.

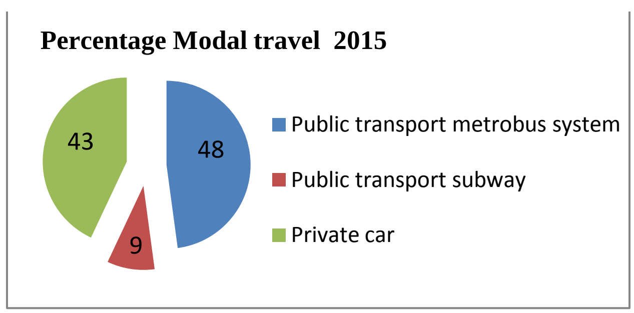
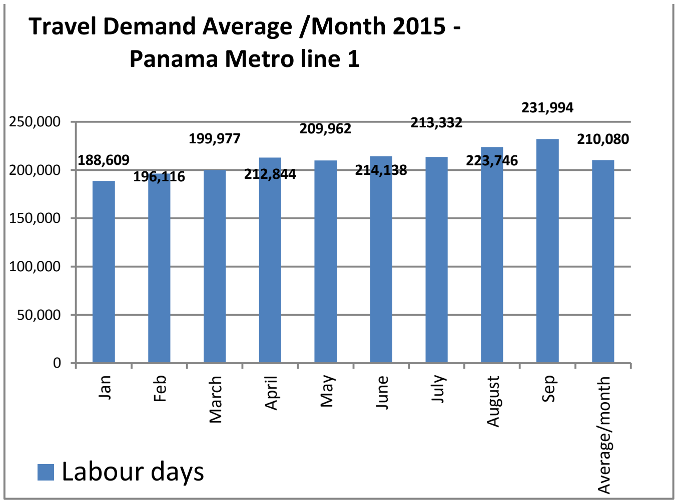


Figure 4. Travel Demand Average .PML1



Source: A. Berbey-Alvarez from real data of the Panama Metro line 1.

Table 5. Estimation of CO_2 emissions for Metrobus for Panama City-2015.

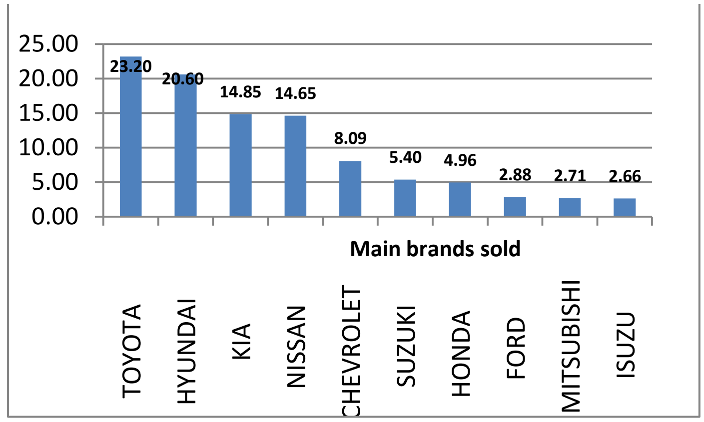
Occupancy of 38 passengers				Occupancy of 85 passengers			
g CO_2/passenger-km		2015		**g CO_2/passenger-km**		2015	
Min	**Max**	Min CO2 emission	Max CO2 emission	Min	Max	Min CO2 emission	Max CO2 emission
2.89	5.39	3186874	5939174	1.29	2.41	1424720	2655160
	16 km	50989979	95026779		**16 km**	22795520	42482560
	Kg CO_2	50990	95027		**Kg CO_2**	22796	42483
Working days	Ton CO_2	51	95	Working days	**Ton CO_2**	23	42
Working year	Ton CO_2	12238	22806	Working year	**Ton CO_2**	**5471**	**10196**

Finally, from the information above, the estimated range of CO_2 for metrobuses in 2015 for 38 seated passengers is between 12,238 to 22,806 yearly tons of CO_2. For full occupancy of 85 passengers, the range will be 5471 to 10196 tons of CO_2 per year. Table 5 shows the calculations.

D. Estimation of CO_2 emissions for private cars for years 2007, 2010 and 2015.

To have an estimation of cars circulating in the metropolitan area of Panama City, an average of car sales in the city between years 2009-2016 was determined. Figure 5 shows the main brands sold.

Figure 5. Percentage of automobiles sales 2009-2016 in Panama.



Source: Data from the Panamanian Association of Cars Dealers (ADAP).

As seen, the main brands sold are Toyota (23.20%), Hyundai (20.60%), and KIA (14.85%). While almost 80% of the cars sold in Panama are from asian brands, less than 15% are american brands (See figure 5). From the European Energy Portal [63-72], the guiding values of g/km emission of CO_2 for the different producers. For the estimation of g of CO_2/passenger-km three scenarios where selected. The pesimist scenario with one passenger, the best possible scenario with 5 passengers and an average scenario with 2.5 passenger. Values are shown in tables 6.

Table 6. Guiding values in g/km of CO_2 for different brands and estimation for of g of CO_2/passenger-km.

	g CO_2/km [63-72]			g CO2/passenger-km Occupancy rate (mean)		
MARCA	**Min**	**Max**	**Mean**	**1p**	**2.5p**	**5p**
CHEVROLET	132	350	241	241	96	48
FORD	98	232	165	165	66	33
HONDA	101	282	192	192	77	38
HYUNDAI	116	218	167	167	67	33
ISUZU	192	230	211	211	84	42
KIA	117	224	171	171	68	34
MITSUBISHI	130	328	229	229	92	46
NISSAN	120	261	191	191	76	38
SUZUKI	120	208	164	164	66	33
TOYOTA	104	208	156	156	62	31
Mean min/max	123	254		Pessimist	Mean	Best possible

Table 7. Scenario of CO2 emissions by private car 2007, 2010, 2015.

	2007			**2010**			**2015**		
MARCA	**1p**	**2.5p**	**5p**	**1p**	**2.5p**	**5p**	**1p**	**2.5p**	**5p**
CHEVROLET	21	8	4	24	10	5	55	22	11
FORD	13	5	3	15	6	3	34	13	7
HONDA	11	4	2	12	5	2	28	11	6
HYUNDAI	9	4	2	11	4	2	24	10	5
ISUZU	6	3	1	7	3	1	17	7	3
KIA	3	1	1	4	2	1	9	4	2
MITSUBISHI	4	2	1	5	2	1	11	4	2
NISSAN	2	1	0	2	1	0	5	2	1
SUZUKI	2	1	0	2	1	0	4	2	1
TOYOTA	2	1	0	2	1	0	4	2	1
gCO_2-pass (10^6)	**72**	**29**	**14**	**84**	**34**	**17**	**192**	**77**	**38**
gCO_2-pass/km (10^6)	1158	463	232	1351	540	270	3078	1231	616
Kg CO_2(10^6)	1.158	0.463	0.232	1.351	0.540	0.270	3.078	1.231	0.616
Ton annual CO_2 (K tons)	278	111	56	324	130	65	739	295	148
Average trip in kilometers [22-25]=16 km									

E. Emission estimations of CO_2 by the Metro of Panama.

According to the Energy Matrix of Panama for 2015, published by the Secretariat of Energy [73], the energy consumption corresponds to 26 Kbep, or thousands of equivalent barrels of petroleum. This is equivalent to 41.9 GWh/year. It is important to mention here, that the 26 Kbep is electric energy required to power the subway system and that no other public transport system in Panama is electrically-driven.

According to Vivapolis [74] for Panama, the relationship of emissions of CO_2/KWh is 0.298 Kg$C0_2$/KWh. Thus, the Metro of Panama generated 12,505 tons of CO_2/year in 2015. Compared to similar subways, Lisbon (2012) and Bilbao (2011) subways generated 14,500 and 16,638 tons of CO_2/year respectively [75-76]. On the other hand, the Metro of Rio de Janeiro [77] had emissions of about 9,300 tons of CO_2/year for 2013.

According to the figure 4, the average daily demand of trips for the Metro de Panama is close to 210 thousand trips in working days, for year 2015.

Since Line 1 was expanded in 2 km., the average grams of CO_2, per km - passenger is given by the following equation:

$$g\ CO_2 \frac{km}{pass} = \frac{grams\ of\ CO2\ Metro\ diary}{\overline{ATD_{diary}} * ATDist} \qquad (2)$$

Where

ATD_diary: corresponds to Average Diary Travel Demand (passengers)

ATDist: corresponds to average travel distance (km)

Table 9. Scenario of grams of CO2 km-pass by average travel distance (2015)

Ton of CO_2 annual by Panama Metro 2015)	12505	g CO_2 /km*pass
Ton of CO_2 monthly by Panama Metro (2015)	1042.08	
Ton of CO_2 diary by Panama Metro (2015)	34.73	
Grams of CO_2 diary by Panama Metro (2015)	34736111	
Average daily demand of trips by Panama Metro (2015)	210080	
Average Travel distance (km) by case		
Case 1	6 km	27.56
Case 2	8 km	20.67
Case 3	10 km	16.53
Case 4	13 km	12.72

Comparing this values with the resulting emissions of other subways around the world, Chile's metro has estimated emissions of 33 g of CO_2 pass-Km [79], Medellin's 28.27 [80], San Francisco's 24 g of CO_2 pass-Km [81], and Rio's 6.4 g of CO_2 pass-Km[77].

IV. Analyses and Discussion.

For the year 2007, the range of emissions for Diablos Rojos was between 72 to 91.1 thousands of tons of CO_2, being them 50.3% of the total share in transportation, while for private cars (including taxis) was 278 kton for the pessimistic scenario of 1 passenger (see table 7), while for the ideal scenario of 5 passengers was 55.6 thousand tons of CO_2. For this year, private cars were 22% of the share in urban transportation.

Table 10. Estimated CO2 emissions´s spectre of Panama City.

Scenary	**2007**		**2010**		**2015**	
T.M	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
1	72000	91100	0	0	0	0
2	55569	277845	64836	324181	147749	738744
3	0	0	4999	20840	5471	22806
4	0	0	0	0	12505	12505
5	72000	91100	4999	20840	17976	35311
6	55569	277845	64836	324181	147749	738744
7	127569	368945	69835	345021	165725	774055

T.M: Transportation Mode
(1) CO_2 Emissions by Diablo rojos (Public Transport)
(2) CO_2 Emissions by Private car
(3) CO_2 Emissions by Metro bus (public Transport)
(4) CO_2 Emissions by Subway (Public transport)
(5) Total CO_2 Emissions by Public Transport
(6) Total CO_2 Emissions by Private Transport
(7)Total CO_2 Emissions (Public+Private Transport)

By 2010, the Diablos Rojos leave the public transportation system and are replaced by a massive transportation system called Metrobus. The new system had emissions between 5 and 21 thousand tons of CO_2, while private cars were between 65 and 324 thousand tons of CO_2 per year. In April 2014 line 1 of the Metro of Panama had begun service. As seen in table 9, the Metro generated near 12.5 thousand tons of CO_2. For the

Metrobus the range was between 5 to 23 thousand tons, while private cars emissions were between 147 and 739 thousands of tons. Finally, for 2015 the Metro had emissions of near 12.5 millions of ton (See table 10). In 2014, the Panama metro line 1 started operating with success and an improvement of the bus transportation occurred between 2007 and 2015. However, the private emissions of private cars increased because the Panama City have others generated travel macro zones to the west and east of the Panama metro line 1, respectively. Now, the Panama Metro line 2 is being built and it has a 35 % of advance [82-83]. The Panama Metro line 2 will connect the generated travel zone of the east of the Panama City with the attract zone in the center-south of the Panama City. The estimation of diary travel demand for this Line 2 is about 500,000 [82]and the Panama metro line 1 is in process of obtain rolling stock with 5 train´s coach [83-84]. It will increase the capacity of the Panama Metro line 1 about 40% more.

V. Conclusions

The analysis of the externalities proposed here comes from the concept of sustainable urban development and the social costs that entail the implementation and operation of projects of great impact to society. Also, this research incorporates important concepts developed in works on urban projects, mainly those that contain urban externalities. The current work applies the APTA methodology for the calculation of emissions for different transportations modes in the metropolitan area of Panama City for year 2007, 2010 and 2015. Applying this methodology in different scenarios in order to have a spectrum of the behavior of different transportation modes in Panama City metropolitan area. It is interesting to notice that, independent from the scenario, the Metro de Panama stabilizes the CO_2 emissions, differently from the private transportation system. However, with the increase of the capacity of transport of the Panama metro line 1 of trains of 3 wagons to 5 wagons and the completion and putting into operation of the Panama metro line is expected a significant decrease of the private vehicles in the Panama City.

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