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Panama metro line 1: Analysis of CO_2 emissions from 2015 to 2017. Principles for an eco-transportation city

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Abstract

This article presents an analysis of CO_2 emissions in the Panama Metro Line 1 (PML1) performed using the APTA methodology. The first section of this document presents a brief description of the Panama Metro line 1 and its current operational parameters. Moreover, the document presents a practical application of APTA methodology to determine the estimated CO_2 of PML1. Finally, a comparison with previous works of the Panama Railway Engineering Research Group about estimated CO_2 of PML1 for 2015, 2016 and 2017. The paper presents a set of a conclusion and future development lines in the topic covered.

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Keywords: Panama metro; Panama subway; Eco-transportation; CO_2 emissions

1. Introduction

The Panamá City Transportation System presents different challenges and opportunities of analysis since this system is going through a series of changes that attempt to improve and modernize it. The Panamá Metro line 1 (PML1) began its operations on April 6, 2014 [1, 2]. Although initially with a length of 13.2 km, now it has a length of 16 km, connecting the north area at the *San Isidro* station, to the south, to the *Albrook* station, as seen in Fig. 1.

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This final station connects with the National Bus Terminal of Transport of *Albroo*k that serves the overall country and the city. This station is, in addition, is quite to close the local airport, Marcos A. Gelabert. Currently, the headway is 3:20 minutes between 6:00 am – 8:00 am (i. e.18 train/ hour) and it is 4:30 minutes (i.e. 14 trains/hour) in off-peak hours [3, 4, 5]. Moreover, PML 1 is a metropolitan subway with subterranean and elevated track sections [6] operated with a catenary-guided transport system. At the southern bound, in the Albrook zone, the Panama Metro line 1 has a facility for storage and maintenance of the rolling stock with a surface of 10 hectares. Also, the Operations Control Center (OCC) is located at this facility. The rolling stock float have trains with 3 and 5 electric multiple units coach with a maximum capacity of 800 and 1000 passengers/train respectively [4]. Currently, the PLM 1 dwelling time corresponds to a range of 25 to 30 seconds.

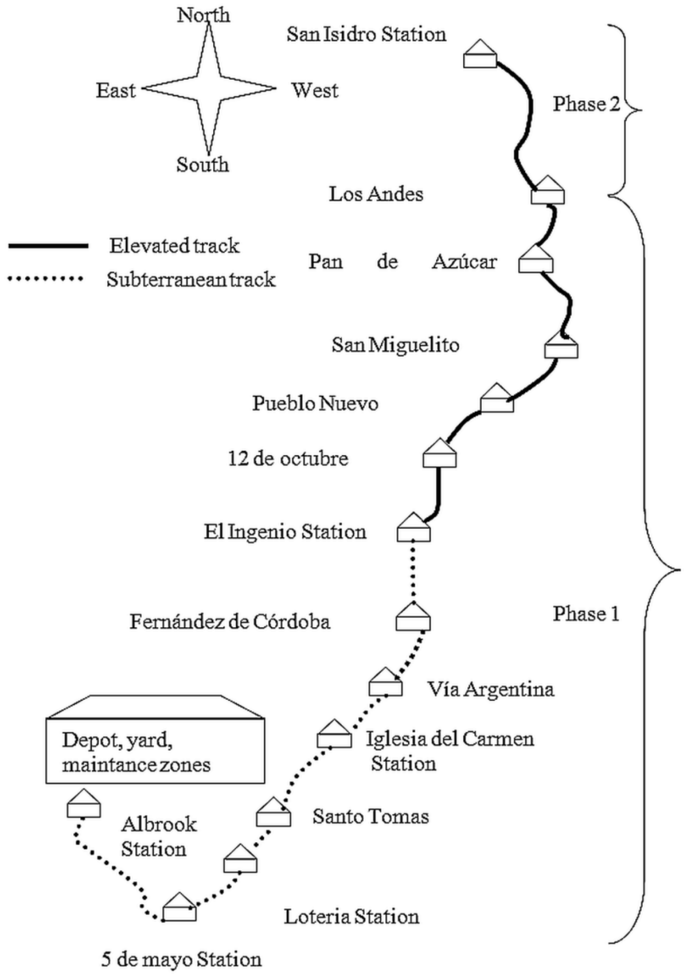

Fig. 1. Scheme of Panama metro line 1 (Phase 1+Phase2). Source: A. Berbey-Alvarez [7, 8, 9] .

According to Morrison [10], who elaborated an interesting bibliographic and photographic review on the beginnings and origins of the electric tramway system of Panama City during the dawn of the birth of the Republic of Panama, Panama City had the first street railway system. Other authors such as Alons [11], Scoullar [12], and Upegui [13] commented that this first street railway system was inaugurated on October 1, 1893 by the British company United Electric Tramways Co. [14]. It was one of the first tramway electric systems in the American continent together with Mexico, Brazil and Argentina [13]. The British company opened the system with six streetcars; two closed and four open with the capacity to seat comfortably 25 passengers each.

The second street railway system was built by the American company, Panama Tramway Co. headquartered in

New Jersey. Upegui [13] mentions that, on August 1, 1913 it opened its doors at Plaza Santa Ana with twenty-two brand new 4-wheel closed cars, with controls and door arranged for Panama's left hand traffic inherited by the initial British streetcar transportation system. These units were conventional electric streetcars with General Electric motors and trolley poles. Scoullar [12] and Celerier [15] mentions that the Capital of the Republic of Panama had two light and power plants, a gas plant and an excellent tramway services which communicated the towns of Ancon and Balboa on the Canal zone, as well as, with suburban district called Las Sabanas. One of the street car branches did run to the Balboa docks at the Pacific end of the Canal where the larger steamers arrive.

Upegui [13] mentions that the vehicles on both of the city's streetcar systems drew electric power from overhead wires. As far as the information was reviewed, Panama City never had passenger trams powered by animals, steam, batteries, or fossil fuels (gasoline or light diesel).

2. Methodology

The methodology to determine CO2 emissions used for this practical sensibility analysis application is based on the original APTA approach [16] of the Climate Change Standards Working Group of the American Public Transportation Association (APTA).

Although based on the original APTA approach, the authors [7, 17] applied an adapted methodology, seen in Fig. 2, in different scenarios to determine CO_2 emissions, considering the occupation rate of the vehicles, and minimum and maximum of emissions for different types. This approach was more realistic since it used a range of values depending on the different brands and models of vehicles driven in Panama [7].

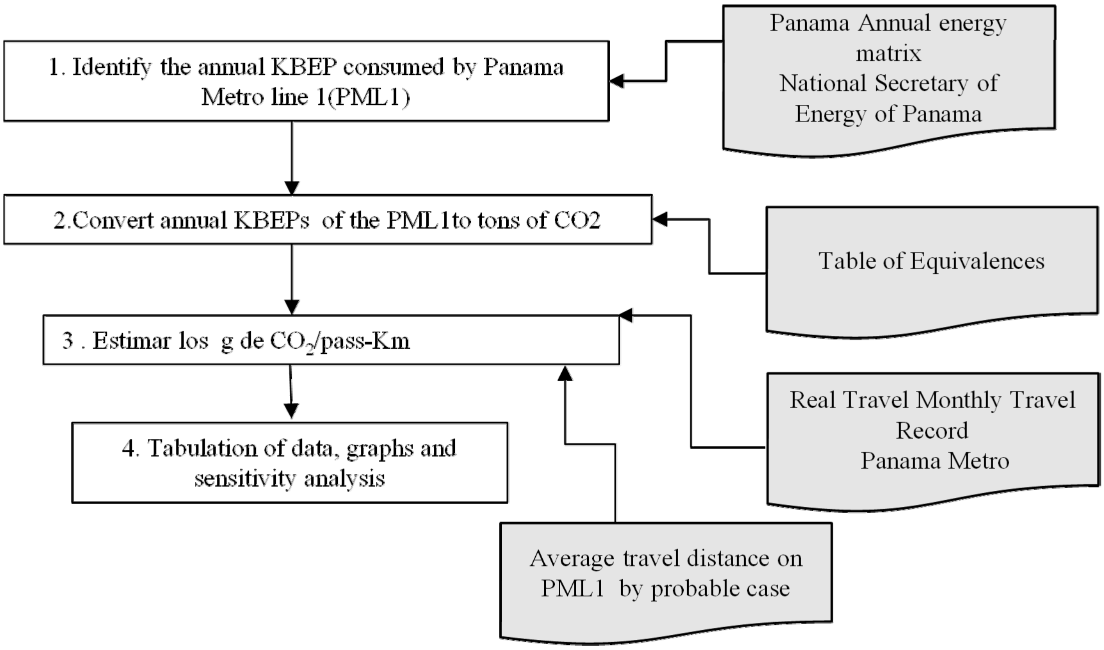

Fig. 2. Methodological scheme for practical application and sensitivity analysis.

3. Results and discussion

As indicated by the Panama Energy Matrix [18-21] for the years 2015, 2016, 2017 the annual energy consumptions of the PML1 are 26 Kbep (2015), 23 Kbep (2016) and 26Kbep (2017) or thousands of equivalent barrels of petroleum, respectively. It is important to mention here, that all these values about the annual electrical consumption in Kbeps correspond to the electric energy required to power the subway system and, since no other public transport system in Panamá is electrically driven, it is necessary to standardize the indices to make the metro equivalent to other transportation systems.

According to [7, 16], the average grams of CO_2, per km - passenger is given by the following equation:

$$g\,CO_2\,\frac{Km}{pass} = \frac{grams\ of\ CO_2 Metro\ diary}{[ATD\_diary][ATD\ distance\ by\ case]} \tag{1}$$

where:

- ATD_diary: corresponds to Average Diary Travel Demand (passengers)
- ATDist: corresponds to Average (potential) travel distance (km) by case

Table 1 shows the estimated values for grams $C0_2$ km-pass for years 2015, 2016 and 2017. The estimated results incorporate a new travel distance case(case 5), as consequence, of the extension of the Panama Metro line .The PLM1 original length was 13.7 km(phase 1) and with the conclusion of the phase 2, the new length is 15.8 km.(16km) [5, 22, 23]. In the Table 2, it is possible appreciate five potential of ATDC (6, 8, 10, 13 and 16 km) by the PML1.

For example, the Table 2 shows that the annual electrical energy consumption of the PML1 was been 26 Kbep in the 2017 year [21], it represents 34736111 grams of CO2 emissions for the PML1 by the 2017 year. Now, the Average daily demand of trips (ADDT) by PML1 was 261669 passengers during the same 2017 year. The ADDT was estimated as the average of the Monthly Daily Demand during all 2017 year using real data travel of PML1 [3, 4]. In Table 1, it is possible to appreciate 5 potential case of average travel distance (6, 8, 10, 13 and 16 km) by the PML1.

Table 1. Results of g C02 km-pass by year and travel distance case.

Period	2015	2016	2017	Var 2016-15	Var 2017-16	Var 2017-15
Energy consumption Panamá Metro Line 1(KBEP) [18, 19, 21]	26	23	26	-3	3	0
Ton of CO2 annual by Panama Metro	12505	11062	12505	-1443	1443	0
Ton of CO2 monthly by Panama Metro	1042	922	1042	-120.25	120.25	0
Ton of CO2 daily by Panama Metro	35	31	35	-4.01	4.01	0
Grams of CO2 daily by Panama Metro	34736111	30727778	34736111	-4008333	4008333	0
Average daily demand of trips by Panama Metro	210080	234527	261669	24447	27142	51589
Average Travel distance (km) by scenario (ATDC)	2015	2016	2017	Var 2016-15	Var 2017-16	Var 2017-15
Case 1:6	27.56	21.84	22.12	-5.72	0.29	-5.43
Case 2: 8	20.67	16.38	16.59	-4.29	0.22	-4.07
Case 3: 10	16.53	13.10	13.27	-3.43	0.17	-3.26
Case 4: 13	12.72	10.08	10.21	-2.64	0.13	-2.51
Case 5: 16 (PML1 – Phase 2)	xxxxx	8.19	8.30	8.19	0.11	8.30
0.6196; 0.298 $KgCO_2$/KWh[24]						

According to the results shown in Table 1, it is possible to see that the average grams of CO_2, per km - passenger decreases with both the increase in Average Diary Travel Demand (passengers) and average (potential) travel distance (km) by case. For example, for the 2017 year, the average grams of CO2 were 22.12 by case 1(6 km), 16.59 by case 2(8 km), 13.27 by case 3 (10 km), 10.21 by case 4(13 km) and 8.30 respectively.

In addition, the annual results of average grams of CO_2, per km - passenger are influenced by the increment of Average daily demand of trips by Panama Metro in the cases of 210080 (2015), 234527 (2016) and 261669 (2017) too.

Moreover, Table 1 shows that the change in tons of daily CO_2 emissions by PML1 between 2017 and 2016 was 4 tons, while it was zero between the 2017 to 2015 years because the Energy consumption Panamá Metro Line 1 (in KBEP) had the same value (26 KBEP). For the period, 2016- 2015 the change of tons of CO_2 emissions daily by PML1 was -4 tons. In addition, Table 2 presents the results of the estimated of CO_2 grams per km – passenger by month with real daily demands by month for years 2015 to 2017 for PML1.

Fig. 3 and Fig. 4 graphically present estimated results of of CO2 emission in grams/pass –km scenarios and 3 respectively. These scenarios were selected was because their respective Average Travel distances (6 and 8 km) are close to the distance track section with more congestion for the PML1. This track section is between the San Miguelito Station and Iglesia del Carmen Station in direction North-South [8, 25, 26]. According the geometric conceptual design of the PML1, its length is 6.075km [27, 28].

In the opposite direction, the track section with more congestion is between 5 de Mayo station and Via Argentina Station, which length is 3.695 km [29, 30]. The second phase of the PML1incorporated a new length of 2 km to the original first phase. It is very reasonably that average (potential) travel distance (km) increase, a possible scenario, case 3 (8km) is presented in the Fig. 4.

Table 2. Estimation of the grams of CO_2 (per km – passenger by month).

Month 2015	Jan15	feb-15	mar-15	April15	may-15	jun-15	jul-15	Aug15	sep-15			
Real Demand Daily by month (2015)	188609	196116	199977	212844	209962	214138	213332	223746	231994			
6 km	30.69	29.52	28.95	27.20	27.57	27.04	27.14	25.87	24.95			
8 km	23.02	22.14	21.71	20.40	20.68	20.28	20.35	19.41	18.72			
10 km	18.42	17.71	17.37	16.32	16.54	16.22	16.28	15.52	14.97			
13 km	14.17	13.62	13.36	12.55	12.73	12.48	12.53	11.94	11.52			
16km	x	x	x	x	x	x	x	9.70	9.36			
Month 2016	Jan16	feb-16	mar-16	Apr16	may-16	jun-16	jul-16	Aug16	sep-16			
Real Demand Daily by month (2016)	217239	223952	226903	236025	237425	237210	234693	242239	248702			
6 km	23.57	22.87	22.57	21.70	21.57	21.59	21.82	21.14	20.59			
8 km	17.68	17.15	16.93	16.27	16.18	16.19	16.37	15.86	15.44			
10 km	14.14	13.72	13.54	13.02	12.94	12.95	13.09	12.68	12.36			
13 km	10.88	10.55	10.42	10.01	9.96	9.96	10.07	9.76	9.50			
16 km	8.84	8.58	8.46	8.14	8.09	8.10	8.18	7.93	7.72			
Month 2017	Jan17	feb-17	mar-17	Ap-17	may-17	jun-17	jul-17	aug17	sep-17	oct-17	nov-17	dec17
Real Demand Daily by month (2017)	245869	251789	253829	259206	264889	260283	256054	260732	265410	271072	268708	282192
6 km	23.55	22.99	22.81	22.33	21.86	22.24	22.61	22.20	21.81	21.36	21.55	20.52
8 km	17.66	17.24	17.11	16.75	16.39	16.68	16.96	16.65	16.36	16.02	16.16	15.39
10 km	14.13	13.80	13.68	13.40	13.11	13.35	13.57	13.32	13.09	12.81	12.93	12.31
13 km	10.87	12.69	10.78	12.43	10.55	12.65	10.72	12.42	10.53	12.16	10.63	11.58
16 km	8.83	8.62	8.55	8.38	8.20	8.34	8.48	8.33	8.18	8.01	8.08	7.69

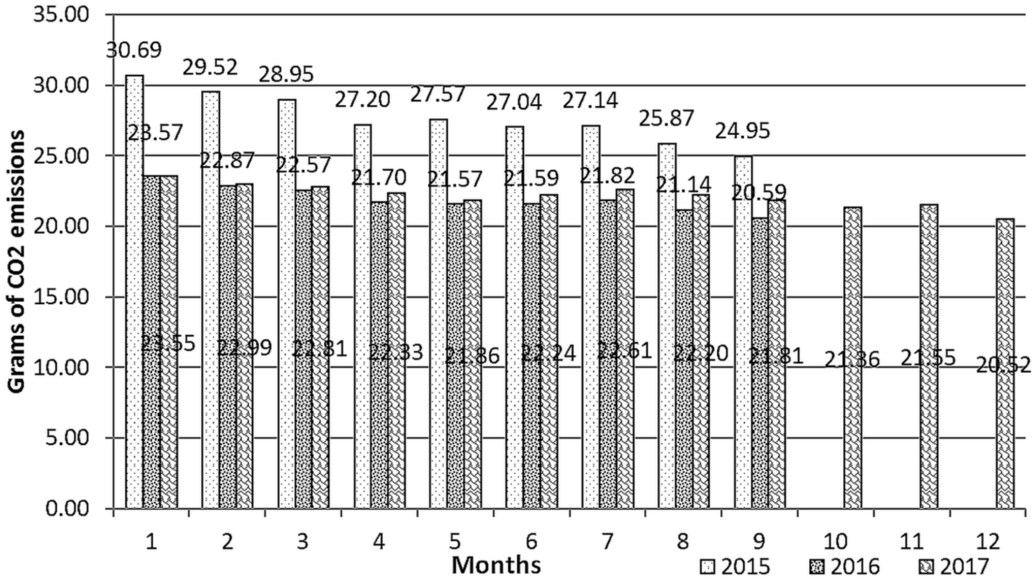

Fig. 3. Grams of CO2 emission /pass –km by the 6 km scenario.

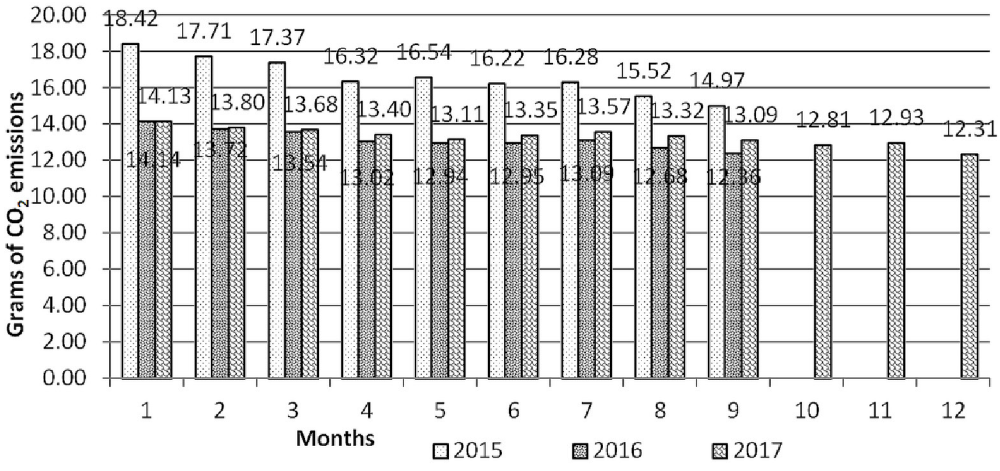

Fig. 4. Potential operative scenario by case 10 km of the PML1.

4. Conclusion

As a result of the study, the Panama Railway Engineering Research Group presents the evolution of the estimation CO2 emission for the PML1 during the period of 2015-2017 years.

According the results presented here, it is possible to see that the average grams of CO_2, per km - passenger decreases with both the increase in Average Diary Travel Demand (passengers) and average (potential) travel distance (km) by case.

The paper proposes to consider the option of extended this practical application of the next Panama Metro line 2 (PML2). Currently, the PML2 presents a 87% of advanced in the construction project. This information be useful to the Panama Metro authorities, national environmental authorities, and interested social groups.

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