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Feasibility of photovoltaic system in midi-lisy and panoramo equipment for pipeline rehabilitation

Pablo Ricardo Aguirre-Espinoza [a], Mario Guadalupe González-Pérez [b] & Yefer Asprilla-Lara [c]

[a] *Sistema Intermunicipal de Agua Potable y Alcantarillado, Jalisco, México. mtro.pabloguirre@gmail.com*
[b] *Universidad de Guadalajara, Jalisco, México. inge_united@hotmail.com*
[c] *Universidad Distrital Francisco José de Caldas, Bogotá, Colombia. yaspirillal@udistrital.edu.co*

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Abstract
Changes in the availability and accessibility of alternative energy sources have been observed in recent years. This study analyzes the economic viability of the use of photovoltaic solar energy systems in equipment for the control and inspection of drinking water pipes. For this, the consumption, costs and operating times were reviewed using conventional sources and photovoltaic energy. The air conditioning system was found to be outdated and needs to be replaced with a leaner, more efficient one. However, portable electric generators should not be disabled, since they will serve as a backup on days when sunshine is the minimum necessary to recharge the batteries, with a contribution of close to 13.5% of the energy. These findings are useful for systems that are part of the jacket dipping process (rehabilitation of trenchless drainage pipes) used by municipal companies that provide home services.

Keywords: savings; feasibility; photovoltaic systems; sustainability.

Viabilidad de sistemas fotovoltaicos en equipos midi-lisy y panoramo para rehabilitación de tuberías

Resumen
En años recientes se observan cambios en la disponibilidad y accesibilidad a fuentes alternas de energía. Este trabajo analiza la factibilidad económica de utilizar sistemas de energía solar-fotovoltaica en equipos de monitoreo e inspección de tuberías de agua potable. Para ello, se revisó el consumo, costos y tiempos de operación utilizando fuentes convencionales y energía fotovoltaica. Se encontró que el sistema de aires acondicionados de los equipos es obsoleto y deben ser sustituidos por uno más esbelto y de mayor eficiencia. Sin embargo, los generadores eléctricos portátiles no se deben inhabilitarse, porque servirán de respaldo en días en que la insolación sea la mínima necesaria para recargar las baterías, con un aporte cercano al 13,5% de la energía. Estos hallazgos son útiles para equipos que forman parte del proceso de inmersión de mangas (rehabilitación de tuberías de drenaje sin zanja) utilizados por empresas municipales prestadoras de servicios públicos domiciliarios.

Palabras clave: ahorro; factibilidad; sistemas fotovoltaicos; sustentabilidad.

1 Introduction

Currently there are technologies (robotic cameras) that allow a diagnosis of the physical conditions of underground pipes prior to rehabilitation. This means that a renovation of drainage pipes is possible without the need for excavation (trenching). This process known as Cured-in-Place Pipe (CIPP) involves the introduction of flexible pipe usually mixed with epoxy resins into a damaged pipe [1,2].

These methods are widely used for study, monitoring and rehabilitation without trenching [3]. Normally, it hardens in situ and does not consume long times of execution of works or affectations to the users of the service. The application of this method results in a new pipe, with a useful life of more than 60 years and 50 years of guarantee according to the results of tests carried out on pipes in the United States of

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America [1], and as it is a one-piece pipe, the probable failures due to the joints between each pipe are completely eliminated, guaranteeing hermiticity. In addition, the roughness of the sleeve (pipe) is equal to or less than that of polyvinyl chloride (PVC), and high density polyethylene (HDPE).

However, the operation of these systems requires a significant power supply, due to the use of portable electric generators that run on gasoline as shown in Fig. 1.

The IBAK Midi-Lisy system stands out in this context of robotic cameras. This system of German origin is structured by a robotic video camera with the possibility of being assembled to different tractors to inspect pipes with diameters from 200 mm to 600 mm. It has a mechanical arm that allows entering a home download from the main network. These robots are hermetically protected, withstand a pressure of 0.6 kg/cm^2 and can work partially submerged in water) as shown in Fig. 2.
Source: The authors

The obtained videos are recorded in the WinCam software; which allows to print a detailed report of the precise position of each download. Every image or video is stored in a removable hard disk, which when saturated with information is lowered to a central station (with 4 terabyte disks); due to the great universe of pipes that generally have to be diagnosed generates a great amount of images and videos, Duanshun Li and collaborators propose a method of

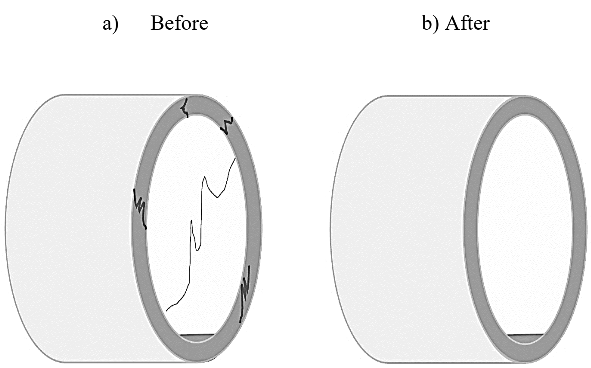

Figure 1. Drainage pipe rehabilitation section
Source: The authors

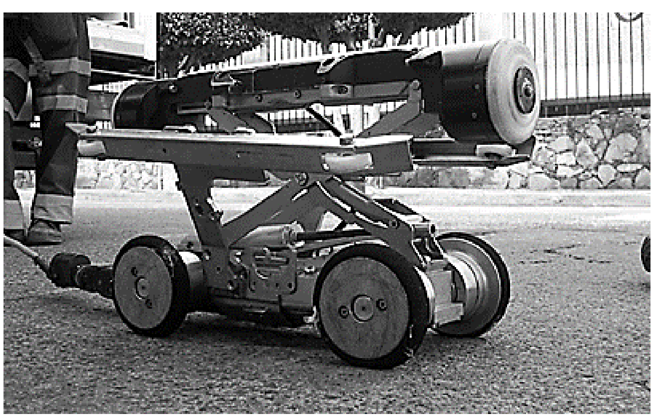

Figure 2. Midi lisy Robot
Source: The authors

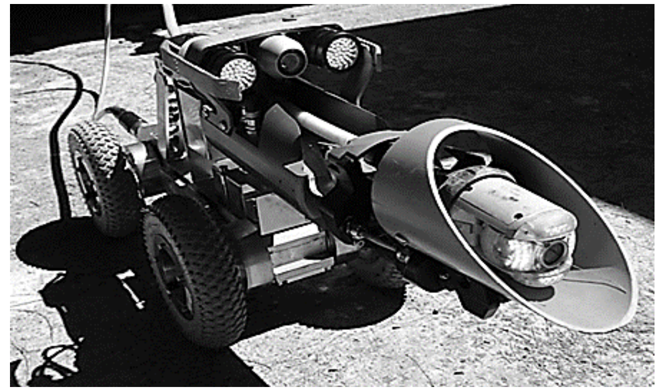

Figure 3. Panoramo Robot
Source: The authors

detection of CCTV data, automated where they classify defects in the sewerage system; a similar case occurs with morphological segmentation of CCTV images of damage in pipes according to Tung-Ching Su and others [5,6].

On the other hand, the IBAK Panoramo system is a robotic video scanner, whose main feature is a scanner that can measure diameters, lengths, thicknesses, etc. This is possible because it has two cameras, one at the front and one at the back, as shown in Fig. 3.

Every 5 centimeter that the robot advances, it takes radial photographs of 181 celsius degree; its software forms a digital three-dimensional image and it is possible to make a virtual journey inside the pipe at any point or direction; this allows to size the separation between joints, internal diameter and width of cracks or damage; this quality of images has served as a basis for the realization of robust algorithms for automatic detection of the flow behavior inside the pipes [7].

The electricity for the operation of all the elements that make up the system is supplied by a 6000 Watts portable generator.

2 Materials and methods

This research describes the current situation of the Panoramo and Midy-Lisy systems, emphasizing the necessary actions and costs for the daily exercise of the video-scanner and video-camera work inside pipes, with the intention of making a diagnosis of the conditions in situ and its subsequent intervention without excavation. The daily process consists of the following stages:

a) At first, an official study report is delivered to the specialized operator, with the location of the area or quadrant for video-scanning of drainage pipes. The operator fills out a checklist with materials and tools necessary for the correct execution of his work, which includes having the necessary fuel for the generator in his unit.
b) The operator goes to the work site or area; once there, he accommodates the unit and supervises the safe transit conditions and personal protective equipment [8].
c) To lower the scanning robot and/or any component of the system it is necessary to turn on the gasoline electric generator.

Table 1.
Theoretical electrical load of Panoramo and Midy-lisy systems.

Description	Power (Watts)	Current (Amps)
Computer Equipment	127	1.00
TV monitor	152	1.20
Control unit	127	3.00
Reel	398	3.13
Robots (Midi-Lisy or Panoramo)	28	2.00
Crane	151	6.20
Lighting	127	1.00
Air Conditioning	500	3.94
Utility contacts	160	2.00

Source: The authors.

d) At the end of the working day, the operator returns his work report to the headquarters with the lengths of scanned pipe sections and their respective addresses. In addition, the information in the Panoramo System.

Operation Manual provided by the manufacturer was revised to produce, as shown in Table 1. It contains power and current data that are the basis for the calculation and design [9] of the proposal for the feasibility of replacing conventional energy consumption for photovoltaic panel systems.

A representative sample of fueling dates, number of liters, hours worked per generator, and other parameters recorded in official reports from one of the two Panoramo-type units corresponding to May 2019 [4] (with update prices of 2022) was taken from an inter-municipal operating agency in the metropolis of Guadalajara, Mexico. In this example, the month was chosen because it presented an average workload; this brings the purpose of evaluating not only the cost for fuel consumed but also the hourly cost for each piece of equipment used to perform this load, as shown in Table 2. There were eight visits per month to refuel, five of which involved refueling the unit's engine and electric generator, and the other three involved moving the entire unit just to refuel the electric generator. Between 1990 and 2011, gasoline consumption in Mexico alone grew by 66% [10].

According to schedules recorded in the daily report checked with the operators responsible for these units [4], the trip to refuel requires two hours of travel time to resume the work schedule. If it is known that the work center is located in the water treatment plant No. 3: Luis Basich Leija, located in Camino a Colimilla km 0+800, Colonia San Gaspar, Municipality of Tonala and the station that provides the fuel supply service is located on the road to Matatlan 1383, Colonia Urbi Tonala; then, the Euclidean distance is 6.2 km, or a complete route of more than 12 km.

In addition, an estimated time of 1.8 hours for each visit generated to refuel the electric generator. Thus, according to the data in Table 2, three monthly load trips are made, with a value of 5.4 hours destined for supply. According to data from SIAPA, the unit cost per hour of each system is US $45.62 for the Midi-Lisy and US $50.35 for the Panoramo. Specifically, the calculation of losses per year. It is described using eq. (1)-(2):

$$X_1 = A * B * C \tag{1}$$

Table 2.
Gasoline consumption by electric generator in the SIAPA example.

No. of unit	Date	Liters	Fee (dollar) *	Hours of operation	Comments
790	05/07/2019	17.00	16.65	1276	The unit and the generator were refueled
790	05/14/2019	11.48	11.24	1284	The unit and the generator were refueled
790	05/15/2019	10.00	9.79	1290	This day only the generator was refueled
790	05/19/2019	11.01	10.77	1298	The unit and the generator were refueled
790	05/21/2019	12.00	11.76	1307	This day only the generator was refueled
790	05/26/2019	10.04	10.18	1314	The unit and the generator were refueled
790	05/29/2019	15.00	14.69	1323	The unit and the generator were refueled
790	05/30/2019	8.03	7.83	1330	This day only the generator was refueled.
		94.56	92.91		TOTAL

Source: The authors.
*Exchange value of 20 mexican pesos for one US dollar, julio 2022

where:
A = Midi-Lisy hourly cost
B = hours/month
C= months of the year
X_1= Annual money loss
Calculation of losses per year:

45.62 * 5.4 * 12 = US $2956.18

$$X_2 = D * B * C \tag{2}$$

where :
D = Panoramo hourly cost
B = hours/month
C= months of the year
X_2 = Annual money loss
Calculation of losses per year:

50.35 * 5.4 * 12 = US $3262.658

Knowing that the gasoline generators used are of 6 kW power, a factor is applied to convert them to HP (horsepower). It is described using eq. (3):

$$X_3 = \frac{P}{f} \tag{3}$$

where :
X_3 = power value in HP
P = Power in kW
f = factor

Calculation of power value in HP: 6 / 0.746 = 8.04 HP Considering the 5 hours of daily operation and using the eq. (4):

$$X_4 = G * T \tag{4}$$

where :
X_4 = power value in HP-hr/day
G = Generator power in HP
T = working hours per day
Calculation of power value in HP-hr/day:

8.04 * 5 * = 40.21 HP-hr / day

The process of designing an isolated photovoltaic system follows the following steps:

a) Determination of the installed electrical load.
b) Determination of the tilt angle of the PV array and the system design current.
c) Determination of the battery bank.
d) Determination of the arrangement of photovoltaic modules.
e) Selection of other components.

In this context, taking into account both the technical information of the electrical equipment and some measurements to corroborate the demands and consumption of electrical energy by each component of the Midi-Lisy and/or Panoramo systems as shown in Table 3, that was elaborated with the description of the electrical loads.

Once the electrical loads demanded by each element of the system are known, the quantity of each is quantified and the installed power (Pi) per element is determined. From this, the total power (Pt) is obtained and the total system current, it is described using eq. (5)-(6):

$$Pt = \sum Pi = 2057 \text{ W} \tag{5}$$

$$I_t = \frac{P_t}{V_s} \tag{6}$$

Table 3.
Description of the electrical load and determination of the total installed power.

Description of the equipment	Power per unit (W)	Quantity (piece)	Power of the load P_i (W)
Computer Equipment	127	1	127
TV monitor	152	1	152
Control unit	127	1	127
Reel	398	1	398
Robots (*Midi-Lisy or Panoramo*)	28	1	28
Crane	151	1	151
Lighting	127	2	254
Air Conditioning	500	1	500
Utility contacts	160	2	320
Total Power ($_{PT}$)			2057 W

Source: The authors.

where:
It = Total Current
Pt = Total power in W
Vs = System Voltage

In photovoltaic systems, it is recommended to handle electrical currents of no more than 100 A, to reduce risks and to install thinner conductors; therefore, a system voltage of 24 V was chosen. From there, the total current results in:

It = Pt / Vs = 85.7 A

The total current is then calculated and corrected**,** as shown in eq. (7):

$$Ihi = (Pi \times Ud \times (Us /7)) / (\eta cp \times Vs) \tag{7}$$

where:
Ud = Daily use of the load (h/day)
Us = Weekly use of the load (day/week)
ηcp = Power conversion efficiency.

However, because an inverter is required to convert the direct current of the PV system, the alternating current of the connected equipment is assumed to be 0.85 efficiency. Based on the above equations, the results, as shown in Table 4.

Once the total daily hourly current (IhT) is obtained, the corrected total hourly current is calculated, it is described using eq. (8):

$$IhTc = Ihi / (\eta w \times \eta b) \tag{8}$$

where:
IhTc = Total corrected hourly current (Ah/day)
Ihi = Daily hourly current of the load i (Ah/day)
IhT = Total daily hourly current (Ah/day)
ηw = Cable efficiency factor (0.98)
ηb = Battery efficiency factor (0.90)

Substituting the values in the eq. (8), IhTc equals 251.75 Ah/day. So, even though there are several methods to calculate the sunshine; one of the most used because of its easy application is the one that takes data provided by NASA on its website: https://eosweb.larc.nasa.gov/sse/.

Table 4.
Determination of the system's hourly current.

Description of the equipment	Power of the load (W)	Daily use (hr/day)	Weekly use (day/week)	Hourly load current (Ah/day)
Computer Equipment	127	5	5	22.23
TV monitor	152	5	5	26.61
Control unit	127	5	5	22.23
Reel	398	3	5	41.81
Robots (Midi-Lisy or Panoramo)	28	5	5	4.90
Crane	151	0.5	5	2.64
Lighting	254	3	5	26.68
Air Conditioning	500	3	5	52.52
Utility contacts	320	2	5	22.41
Total hourly current IhT				222.04

Source: The authors.

Table 5.
PV system design current calculation.

Month	Sunshine at rush hours (Kwhr/m²day)	Corrected total hourly current (Ah/day)	Design Stream (A)
January	4.81	251.75	52.34
February	5.77	251.75	43.63
March	6.86	251.75	36.70
April	7.24	251.75	34.77
May	7.15	251.75	35.21
June	6.20	251.75	40.60
July	5.66	251.75	44.48
August	5.63	251.75	44.72
September	5.21	251.75	48.32
October	5.36	251.75	46.97
November	5.17	251.75	4869
December	4.59	251.75	54.85
Average value	5.80	System Design Stream	43.37

Source: The authors

Here, by providing the geographical data of the latitude and longitude specific to the place to be studied, data of the maximum, minimum, average monthly insolation and other parameters are obtained, as shown in Table 5, for example, shows the data obtained from this portal. With the geographic location of the city of Guadalajara (20.5° N and -103.5° W), the data of sunshine (hr/day) was collected.

In this sense, the monthly design current is the ratio of the corrected total hourly current to the insolation.

The design current of the photovoltaic system will be the average current in the Table 5, i.e. 43.37 A. The insolation data correspond to a horizontal surface, since the possibility of tilting the photovoltaic array was ruled out, due to the operating conditions of the system [11] The number of batteries is a function, as shown in eq. (9):

$$C_b = I_{hTc} \, X_{da} / P_{dmax} \, x \, f_{rT} \quad (9)$$

where:
Cb = Required battery array capacity (Ah)
da = Days of storage (only one day is considered for this project)
Pdmax = Maximum depth of discharge of the selected battery (0.7 corresponding to a lead-acid battery as selected).
frT= Temperature correction factor (assumed to be 1.0 according to the manufacturer's information).

Also used to calculate the batteries in parallel, it is described using eq. (10):

$$Bp = Cb / Cbs \quad (10)$$

where:
Bp = Parallel batteries
Cbs = Selected battery capacity (the selected battery is a Trojan brand with a capacity of 357Ah).

The calculation of the batteries in series, it is calculated using eq. (11):

$$Bs = Vs / Vbs \quad (11)$$

where:
Bs = Serial batteries
Vbs = Voltage of the selected battery. In this case 12 V.

The number of modules in series, it is calculated using eq. (12):

$$Ms = Vs / Vms \quad (12)$$

where:
Ms = Serial modules
Vms = Voltage of the selected module for 24 V systems.

The number of modules in parallel, it is calculated using eq. (13):

$$Mp = Ida / Ims \quad (13)$$

where:
Mp = Parallel modules
Ida = Adjusted design current
Ims = Nominal current of the selected module, which corresponds to 8.3 A.

The adjusted design current, it is calculated using eq. (14):

$$Ida = Id / Frm \quad (14)$$

where:
Id = System design current (whose value is 54.85A)
Frm = Reduction factor of the selected module (for crystalline silicon modules a factor of 0.9 is assumed)

3 Results

When solving eq. 9, the result is:

$$Cb = \frac{\left(251.75\frac{\text{Ah}}{\text{day}}\right)(1\text{ day})}{(0.7)(1)} = 359.64\text{ Ah}$$

Substituting this value in eq. 10, the result is:

$$Bp = \frac{359.64\text{ Ah}}{357\text{ Ah}} = 1.01 \text{ that is a parallel battery}$$

Based on the above and because:

$$Bs = \frac{24\text{ V}}{12\text{ V}} = 2 \text{ Serial batteries}$$

The total amount of batteries results in:

Bt = (Bp)(Bs)

where:
Bt = (1 parallel battery) (2 serial batteries) = 2 Batteries.

Like this: $Ms = \frac{24\text{V}}{24\text{ V}} = 1$ Serial module, and because

$$\frac{43.37A}{0.9} = 48.18\ A$$

then: $Mp = \frac{48.18A}{8.3\ A} = 5.8$ Parallel modules

The total number of modules will be: MT = Mp* Ms = 5.8 modules.

Due to the dimensions of the selected module and the space available on the dry box, an arrangement of 5 modules was decided upon. Thus, according to the quantity of panels and batteries, a 2 k VA inverter-charger was selected, sufficient for the photovoltaic array.

Indeed, in energy efficiency or energy source substitution projects, the reduction of energy costs is what generally pays for the investment [12]; however, it must be evaluated whether the recovery is in line with the company's economic possibilities and policies.

The necessary adjustments to install the photovoltaic system in the Panoramo and MidyLisy systems vehicles, involve removing the current air conditioning equipment located on the roof to install a mini-split type on the side of the work cabin; this, with the intention of obtaining a larger surface where to place the photovoltaic panels.

Considering that the most significant costs of the project are the replacement of the air conditioning and the photovoltaic system, the economic evaluation is made accordingly. In this sense, the new mini-split type equipment would be located at the side of the cabin, which would allow leaving the entire upper surface for the installation of the solar panels.

The price quotation for such an exchange, that is to say dismantling the old air system and installing a new one, rises to US $312.49 plus US $12.49 of labor force per installation for a total of US $324.98, and according to the design the following quotation, as shown in Table 6.

With the cost data obtained, an economic evaluation is made for the purpose of determining profitability according to three parameters: net present value, internal rate of return and benefit/cost ratio. The input data to perform the analysis are: total investment of US $3175.16, annualized savings from the incorporation of the photovoltaic system of US $76,811.89 / year. This value was estimated by considering the monthly consumption of gasoline (US $92.93). Thus, when considering the installation of only 5 panels of the 5.8 calculated, it is estimated that 13% of gasoline will continue to be used; therefore, the monthly savings would be of US $80.85 and the monthly losses of US $246.36, for a total of US $327.13.

Table 6.
Photovoltaic System Quote

Description	Quantity	Unit Price (US$)	Total (US $*)
Photovoltaic panels of 250 Wp	5	90.55	452.75
Inverter Charger 2kVA/24V/60th	1	817.34	817.34
Batteries 12 V, 249 A, C 100	2	427.54	855.08
Labor force and adjustments (item)	1	724.99	725.99
Total			2851.16

Source: The authors

The real discount rate is considered to be 5.65% per year estimated from the average bank data (7.8%) of Mexico in December 2018 and the inflation rate for Mexico (3.5%), with a 20 years lifetime project. In this sense, considering the useful life of the photovoltaic systems, a 20 years economic evaluation was assumed, which includes the annual maintenance cost, the replacement of the batteries every 5 years, as well as the replacement of the inverter every 10 years.

The results of the financial run are as follows:

a) Net Present Value = US $87,149.81
b) Internal Rate of Return, = 194.11% annually
c) Profit/Cost Ratio = US $13.58
d) Return on investment = 28.55 months

4 Discussion

From an environmental perspective, the implementation of an energy generation system with photovoltaic cells will avoid the emission of 4730.4 kg of CO_2 per year [13,14], for each of the five units that SIAPA has. In this way, in a period of twenty years (the project's duration), these five units will have stopped emitting around 473.4 tons of CO_2 into the atmosphere. The initial investment is recovered in full in the month 07 of the startup of the project, representing a saving of at least US $327.13 per month and a net present value of the order of US $78,893.88 for each of the 5 units that SIAPA has; in short, a saving of US $1635.65 per month and an accumulated net present value of US $394,469.4 at the end of 20 years. Electric power switching (almost entirely) comes from solar energy rather than gasoline combustion. This could be considered a cost-effective hybrid system and be applicable in small village designs as proposed by Alibakhsh Kaseaien and Collaborators [15].

The elimination of the need to make long fuel trips translates into a direct 27% increase in equipment availability and can increase monthly targets for diagnosed pipeline lengths. In this sense, derived from the results of the feasibility of the implementation of photovoltaic energy generation it is necessary to mention that

a) The air conditioning system of the Midi-lisy and Panoramo equipment is obsolete due to its lack of programming and high consumption of electricity. This means that it must be replaced by a slimmer and more efficient one.
b) The portable electric generators that the equipment currently has should not be disabled, because they will serve as a backup, since in extreme cases they will have to provide about 13.5% of the energy on the days when the sunshine is not the minimum necessary for the total charge of the batteries. In addition, they can continue to operate in any contingency situation (failure of some system item) or solar deficiency, due to prolonged cloudy days.
c) The results presented here may be useful for vehicles and equipment that are part of the Cured-in-Place Pipe (rehabilitation of trenchless drainage pipes).

5 Conclusions

One of the main obstacles in Mexico for the use and application of new technologies; is the initial cost and the time of recovery of the investment; the technical-financial analysis shows an attractive proposal in terms of savings in the short, medium and long term, since for the present study it is obtained that the ecological proposal (US $3175.16) versus the acquisition of an electric generator with a gasoline engine (ONAN-CUMMINS 5.5 kW US $ 8521.87) is 62% more economical, considering that the current installed generator requires its replacement due to the expiration of its useful life of more than 13 years and more than 6500 hours worked, with an annual saving of the order of 1138.32 liters of gasoline for each unit. In addition, it would avoid an increase in operating costs since it would not be affected by the increase in oil prices. In Mexico, the price of gasoline from 2012 to 2018 increased by 57% (in January 2017 alone, there was an increase of between 14% and 20%) [16].

At present, the most prestigious brands in the world in this field are no longer delivered with fossil fuel burning generators and are offered with a lithiumion battery bank (a Nobel Prize winning topic in chemistry). However, they do not propose the use of photovoltaic panels on the top of vehicles as proposed in this research. The great window of opportunity in Mexico is that in the great majority of its geographic extension it receives irradiations with values superior to 4 kWhr / m^2 day, reason why successful designs of photovoltaic solar energy are presumed [17], as well as the environmental benefits from the substitution of fossil fuels. Burning this type of fuel for electricity generation is not the only cost-effective option, since the conventional use of fossil energy directly and indirectly involves the additional use of energy related to the transfer of vehicles.

The results obtained have an immediate application for the Inter-municipal System of Potable Water and Sewerage Services (SIAPA for its acronym in Spanish), not only in the area to which the systems subject to this research belong, but also in the large fleet of vehicles and equipment that this inter-municipal organization has. These actions are in line with the guidelines of the 2015 Energy Reform on the use of energy to achieve national energy sovereignty [18]. Based on the above, the implementation of this project would be a sample compatible with the global mega-trends in the use of renewable energy sources and the reduction of pollutant emissions; furthermore, it could be a reference point for future projects not only for SIAPA, but for the industry in general.

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P.R. Aguirre-Espinoza, is a BSc. Eng. in Civil Engineer and MSc. in Water and Energy Engineering from the University of Guadalajara, Mexico. Diploma in Evaluation of the Efficiency of Water Operating Organizations from the Mexican Center for Training in Water and Sanitation (CEMCAS), Diploma in Sustainable Water Management from El Colegio of Jalisco and

the State Water and Sanitation Commission, Diploma in Directive and Management Skills from the University of Guadalajara. Expert in CIPP Systems (cure in place pipe), Integral systems for the rehabilitation of trenchless pipes, Design of Hydrometric Districts and Flow Recovery, Robotic Milling and Sealing Systems, Video cameras and Scanners for diagnosis and repair of hydraulic pipes and implementation of photovoltaic systems in the robotic systems Midi Lisy and Panoramo.
ORCID 0000-0002-5446-8325

M.G. González-Pérez, is a Bsc. Eng. in Civil Engineering from the Faculty of Culiacan Engineering of the Autonomous University of Sinaloa, Mexico. MSc. in Civil Engineering with a specialization in Construction Administration from the Faculty of Engineering of the UNAM, Mexico and PhD. in City, Territory and Sustainability by the University Center of Art, Architecture and Design of the UdeG, Mexico. He has worked as a consultant, builder and teacher in various universities of the private sector and since the year 2014 he joined to the University Center of Tonalá of the University of Guadalajara, Mexico as a research professor in the Division of Engineering and Technological Innovation. His research interests include: entropic systems in the urban system associated with urban mobility, transportation systems, natural resource management, housing construction and systems dynamics. He is currently a distinguished member of the National System of Researchers.
ORCID: 0000-0002-5457-5948

Y. Asprilla-Lara, is a BSc. Eng. in Civil Engineer, from the Universidad la Gran Colombia, Sp. in Road Infrastructure and Transportation, MSc. in Civil Engineering, both from Universidad de los Andes, Colombia, and PhD in Mobility, Transportation and Territory, University of Guadalajara-Mexico. Is associate professor of the Francisco Jose de Caldas District University. Junior Researcher of the Servipublicos Group. Author and co-author of several book chapters and scientific articles in the area of interest, published in different magazines categorized by Minciencia. National and international speaker on issues of urban mobility, road safety, drinking water and sanitation.
ORCID: 0000-0001-6569-7441