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ENVIRONMENTAL IMPACT ASSESSMENT OF DECENTRALIZED POWER GENERATION BASED ON HEAVY FUEL OIL IN SANTA CLARA CITY, CUBA

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ABSTRACT

Power generation is one of the most polluting activities in many countries due to large emissions of pollutants from combustion cycles. In Cuba, fossil fuels represent some 96% of the fuel mixture for power generation, fuel used in Decentralized Power Stations (DPSs) represents about 26% of this fraction (1 166 thousand toe) [1]. By DPSs Cuba has attempted to increase energy efficiency and to reduce the vulnerability on climate events. But potential external effects, e.g. health impact, due to polluting gases emissions were shyly considered in decision making. Some DPSs are sited nearby densely populated areas, and 70% of the fuel they use is heavy fuel oil (HFO).

This paper presents an analysis of the external effects of two HFO fueled stations sited in Santa Clara City. These stations have a similar technology, with an installed capacity of 20MW each one. An Integrated Assessment of Energy Supply (IAES), based on the state of the art in engineering, dispersion models, air quality and epidemiology was implemented. This included a perturbation analysis to reach better scenarios at low investment. Especial attention is paid to impacts on human health.

The baseline and two other scenarios were studied. It was calculated that station northwest causes the highest local impact in terms of years of life potentially lost due to incremental concentration of air pollutants. Largest CO_2 emitter is station southeast, covering an effective energy demand 1.8 times higher than northwest station. But its local impact is lower because is sited where the population density downwind is considerably lower. It was calculated an impacts reduction potential of about 20% and 9% for stations northwest and southwest respectively.

Keywords: Decentralized power generation, air pollution

NONMENCLATURE

Abbreviation

CI	Confidence interval
DPS	Decentralized power station
EED	Effective energy demand
EPA	Environmental protection agency
HFO	Heavy fuel oil
IAES	Integrated assessment of energy supply
ICE	Internal combustion engine
IPA	Impact pathway approach
LCA	Life cycle assessment
MAC	Maximum allowable concentration
REC	Raw energy consumption
SPA	System perturbation analysis
SPG	Station for power generation
Toe	Ton of oil equivalent = 41 900MJ
USG	Unhealthy for sensitive groups
UTM	Universal transverse Mercator
VU	Very unhealthy

Symbols

λ	Air excess coefficient
C	Carbon
CO	Carbon monoxide
CO_2	Carbon dioxide
g	gram
M	molar mass
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
PM_{10}	Particulate matter ≤ 10 µm
SO_2	Sulfur dioxide

Subscript

eq	Equivalent
f	fuel
g	gas

1. INTRODUCTION

In Cuba there is a growing concern of government on the environmental protection, with especial attention to atmospheric pollution. Air quality in some cities has become a visible problem, potentially related to uncontrolled emissions of polluting gases and particulates from energy conversion via combustion [2]. In central region of Cuba the city of Santa Clara is one of the affected by air pollution problem. This city, the fifth most important in the country, is the capital of the province of Villa Clara. Here, environmental authorities have called Scientifics and enterprises for the analysis and implementation of mitigation actions. The current situation calls for consider external impact of energy in decision making.

For atmospheric pollution control air quality management system is generally implemented. These systems are very similar around the world, their typical main components and interconnection can be consulted in EPA [3]. Air quality standards is a main component, it made the main difference in the system from one country to another. There are standards that set the maximum allowable emissions for each technology, so called technology-based standards [4, 5]. Other standards set the maximum allowable concentration of pollutants in air aiming to protect human health. But meet emission standards not necessarily means meet air quality standards, mainly in areas where several emission sources exist. In such cases, it is important elucidate the specific share of each source in air pollution, and sophisticated analyses including pollutants dispersion modeling are needed. In Cuba a regulatory frame based on air quality standards exist. Air quality management system is a good base for pollution control, but better results could be achieved by integrating management of energy and air quality, including the assessment of potential external effects of energy cycles. In this way the understanding of the link between energy consumption and technologies, air pollution and related environmental impacts at local scale is needed, but most of the time it is absent in current policy decision making.

External effects of energy are the outcome of complex interactions, technological, social, economic, and others. To establish cause-effects interactions with an acceptable accurate representation is a complex task, only achievable by huge modeling efforts. This makes it difficult to establish a universal tool for external impact assessment of energy systems or scenarios, but many tools already exist. The Impact Pathway Approach (IPA), developed in the frame of ExternE [6], the Life Cycle Assessment (LCA) [7] and the System Perturbation Analysis (SPA) [8] are important tools.

Convenience of LCA has been well demonstrated. But, it tends not to be specific on the calculation of impacts in regard to local scales. SPA, made improvement in regard to siting of impacts, by looking at geographical system balances of resources and effects, but is still at country scale. IPA, developed by ExternE was the first complete attempt to use a 'bottom-up' methodology to assess the external costs of different fuel cycles. This focuses on the assessment of the externalities due to increments in energy conversion in terms of marginal values, mainly in the electricity generation sector [9]. This may be perfect for the introduction of externalities into expansion-planning models, but not to include external effects in operational models, neither to assess impacts variation due to perturbations in operational variables. Since ExternE methodology estimates the externalities considering the average concentrations in the study domain, it is difficult to distinguish the spatial distributions of impacts due to the spatial distribution of pollutants concentration and population.

The most important methodologies have been created by and for developed countries, for that reason their application in developing countries is limited, due to the complementary studies and large data needed. But it is needed, because developing countries usually have access to less clean technologies and consume more polluting energy sources than developed nations [10] .

Important researches in local impacts assessment of energy have been presented by Wang [11], Turtos [10], and Mahapatra [7], with especial attention to health impacts estimation. These estimations were based on the average concentration increase in the study domain and the total population exposed. In this direction some contributions are made in the present work. First, the spatial variation of the concentration in the study domain is considered in the impacts analysis. Second, the spatial distribution of the population is also taken in to account. Finally, these developments allow for assessing in health impact estimation the effects of the emission sources location and the influence of small perturbations in operating conditions. The aforementioned contributions have been implemented in the Integrated Assessment of Energy Supply (IAES). This is builds on SPA [8] and the IPA [6], but includes modifications and additional developments. E.g. SPA is based on life cycle analysis, and its spatial resolution for impacts assessment does not make distinction about local siting of technologies. For IAES local siting of technologies is relevant, because gases emissions and their impacts on human health are tracked from release point to final receptors. As a common feature in both analyses the effective energy demanded is kept constant for scenarios assessment. The main difference with IPA is the choice of emphasis, for IPA, the external cost, and for the IAES, to determinate impacts and mitigation choices through perturbation analysis. The IAES allows, through the high spatial resolution of the analysis, identifying local areas where the major exposures and impacts are generated, the individual responsibility of polluters, as well as location and operation conditions effects on impacts variations.

The main goal of this work is to assess the local impact of HFO fueled power stations in Santa Clara City, emphasizing on health impact. CO_2 emissions are also assessed. Health impacts and Global warming are recognized as the larger impacts of energy conversion via combustion [6, 12]. The assessment was carried out for the year 2010.

2. METHODOLOGY

The methodology presented here aims of establishing the link between energy consumption and technologies, air pollution, and resulting impacts on public health. In this way an integrated assessment approach is used. The main steps are shows in figure 1. This takes into account the availability of data to produce valid results to be considered in decisions-making. The criterions established with this purpose are: exposure of the public to polluting gases, related human health risk and CO_2 emissions.

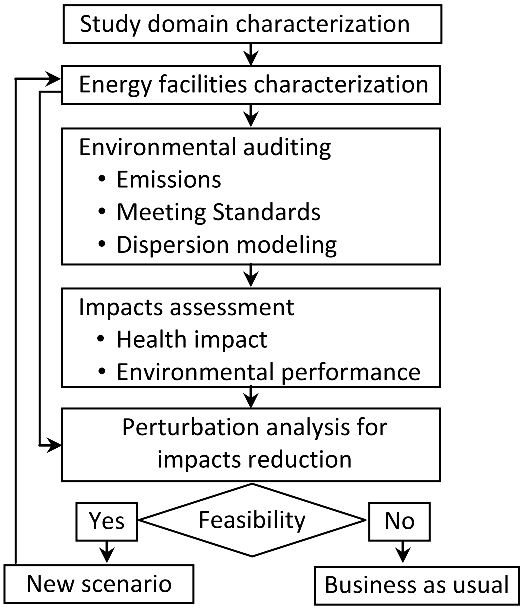


Figure 1 Main steps in integrated assessment approach

2.1 Case-study, characterization of the study area

Santa Clara city is the geographic area where the present survey is carried out. The area of the city is 40.6 km^2, with a population of about 210 000 inhabitants. The habitat and services area covers 69% of the urban zone, industry 26% and green areas 1%. Population density in the city is 5 180 inhabitants per km^2 [13]. In the city the general air quality has been diagnosed by environmental authorities as Unhealthy for Sensitive Groups (USG) [2] . Figure 2 shows the population size and its distribution in the study area, with an extension of 33.6 km^2, and locations of the facilities included in this survey, designated with the initials 1SPG and 4SPG and highlighted with a red circle.

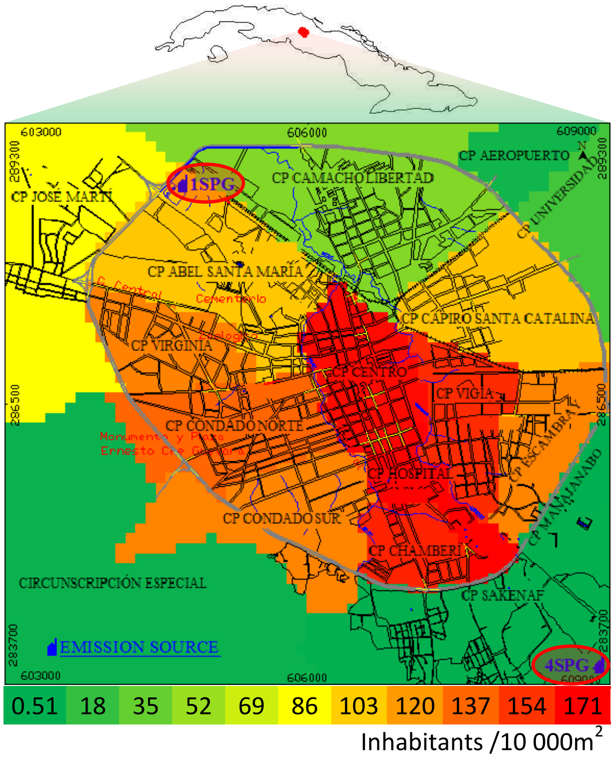


Figure 2 Study area: 6x5.6 km; location: 22º.24’.00”N, 79º.58’.00”W. Representation of population distribution, and emission sources location.

Meteorology and topography are determinants factors in the gaseous pollutants dispersion. In this way, detailed data for modeling are required. Hourly meteorological data including wind direction and speed, environment temperature, stability class and mixing height were provided by the Meteorological Center of Villa Clara [14] . Topographic data were gotten from the Office of Physical Planning [15], a topography grid with a resolution of 100x100 m has been used.

2.2 Energy facilities characterization

To establish the operating condition and characteristics of the facilities were performed energy audits. It was determined that these plants consume about 63% (23 380 ton of HFO/yr) of the fuel demanded by the 31 major polluters of the city [14]. These so called, package power stations are based on sets of internal combustion engines. Each plant is formed by three power generating cells which in time are formed by four power units. Figure 3 shows the set of one cell.

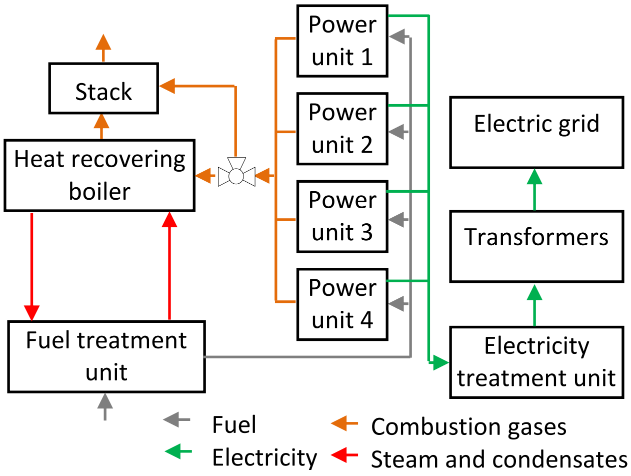


Figure 3 Representation of one power generation cell

These stations, according to the indications of the Cuban Electric Union, are operated in base load regimes, at a load factor of the power units about 0.85. The main typical parameters for power units are summarized in table 1.

Table 1 Typical operating parameters for power units

Technology	ICE-HFO
Installed power (MW)	1.7
Typical load factor	0.85
Specific fuel consumption (g/kWh)	210
Hourly fuel consumption (kg/h)	303.5
Efficiency (%)	41

At plants exists a data base where horary operating parameter of each unit is recorded. The operating parameters of the power stations, given in table 2, are based on these records.

Table 2 Main operating parameters of the power stations

Power station	1SPG	4SPG	total
Installed power (MW)	20.4	20.4	40.8
Operating hours (h_{motor}/yr)	27 918	49 120	77 038
REC (toe/yr)	8 330	14 656	22 986
(MWh/yr)	96 954	170 585	267 539
EED (MWh/yr)	40 342	70 978	111 320

As shows table 1, the efficiencies determined for the power units, with a value of 41% is on the upper limit for these technology.

The term raw energy consumption (REC) is referred to the amount of energy dedicated to be converted, in a given energy facility or group of them, from one form to another final useful form of energy, e.g. the HFO converted by the power units in electricity.

The term effective energy demand (EED) is referred to the amount of energy demanded by the user system in its final form, e.g. electricity demanded by the electric grid from the power stations.

2.3 Environmental auditing

A corner stone in this study is the emissions characterization. An emission inventory with high spatial and temporal resolution was made. The polluting gases assessed are those established by the Cuban standard NC 111: 2004 [16] as main polluting agents, including PM_{10}, SO_2, NOx and CO. Besides the CO_2 emissions were inventoried.

The emission inventory is based on emission factors for the specific species and the fuel rate consumption. For the pollutants SO_2, NO_2, and CO the emission factors were determined based on gas combustion analysis. The emission factor for CO_2 is based on the fuel carbon content, the conversion efficiency of carbon (C) into CO_2, and the molar mass ratio CO_2/C. Carbon conversion efficiency has been established based on combustion reaction modeling. The emission factor for PM_{10} was taken from FIRE (Factor Information Retrieval Data System) [17], which is a database containing EPA's emission factors for criteria and hazardous air pollutants.

The gas combustion analysis was performed according to the methods established by EPA [18], and adopted by the Cuban standard NC TS 803: 2010 [19]. These methods are, for SO_2 the 6C, and for NO_2 and CO the 7E and 10 respectively. Combustion analysis results are presented in table 3.

Table 3 Results of gas combustion analysis

Measure parameter	value
T_{mean} (°C)	$32_{[0.82]}$
T_g (°C)	$250_{[1.25]}$
O_2 (%)	$13.3_{[0.07]}$
CO (ppm)	$750_{[20.02]}$
NO (ppm)	$901_{[8.03]}$
NO_2 (ppm)	$10_{[0.92]}$
SO_2 (ppm)	$369_{[2.72]}$
CO_2 (%)	$6_{[0.05]}$
λ	$2.6_{[0.03]}$

[ ] Standard deviation, the given values are the average for 10 replicates.

Based on gas combustion analysis results and fuel composition the combustion reaction was modeled and all corresponding parameters were calculated. The emission factors established are given in table 4. Nitrogen oxides (NOx = NO+NO_2) is expressed as $NO_{2eq25\%}$, in this way it has been assumed that 25% of NO is transformed into NO_2 by direct chemical oxidation when it is released in to the atmosphere, $NO_{2eq25\%} = NO_2 + 0.25NO \cdot M_{NO_2}/M_{NO}$. This assumption is based on the observation that once emitted, NO can be transformed into NO_2 by direct chemical oxidation. However, at low concentrations this reaction is slow, and only quantities less than 25% of all NO are converted [20].

Table 4 Emission factor for the specified species

Specie	Emission factor
CO (g/kg_f)	24
SO_2 (g/kg_f)	27
$NO_{2eq25\%}$ (g/kg_f)	12.8
$^*PM_{10}$ (g/kg_f)	5.28
CO_2 (kg/kg_f)	3.1

* Source: EPA [17]

2.3.1 Meeting Cuban emission standard

In Cuba, the gaseous emissions to the atmosphere are regulated by the Standard TS 803:2010, which is applied on a trial phase throughout the national territory till 2013, when it should be updated. This standard establishes the maximum allowable emissions from electricity and steam generating facilities in order to protect the human health and the environment [19].

According to the standard, the maximum allowable emissions should not be exceeded in the operational stage, and it must be taken in to account for planning new energy facilities.

Table 5 shows the maximum allowable emissions and the values determined.

Table 5 Accomplishment of the NC-TS 803: 2010

Technology	Emissions (mg/Nm^3)*		
	SO_2	NO_x	PM_{10}
ICE-HFO	813	946	155
Maximum allowable emission	*2500*	*2000*	*160*

*Reference conditions 273.15 K, 101.325 kPa, dry gases, O2 ref. 15%

These values were measured and expressed at reference condition according to the methods established in the referred standard. The PM_{10} was adopted from EPA [17], as shows table 4, and later it concentration in gas combustion at reference condition was calculated.

The emissions standards are met (table 5). However, to assess the impact on air quality and its consequences on human health pollutants dispersion modeling is needed.

2.3.2 Dispersion modeling

For most air pollutants, other than the globally dispersing greenhouse gases, atmospheric dispersion is significant over hundreds to thousands of km, due to important effects not negligible at local scale neither regional [6]. However the dispersion of pollutants chemically stable in the region of the emission can be predicted using a Gaussian plume model. These models assume that pollutant emissions are carried in a straight line by the wind, mixing with the surrounding air in both directions, horizontally and vertically, to produce pollutant concentrations with a normal (or Gaussian) spatial distribution [21]. The use of these models is typically constrained to a distance of 50 km from the source. In this survey, as the scope is local, it has been adopted a Gaussian plume model. This allows assessing the increment in pollutants concentration related to point sources of emissions, such as power stations. The software adopted is the ISC-AERMOD View [22].

The local dispersion was modeled with ISCST3 Dispersion Models, using complex terrain, concentration and regulatory options. The modeling was carried out in a domain of 6x5.6 km, the domain extent settled in the model cover the survey area shown in figure 2. A uniform Cartesian grid of receptors with a resolution of 100x100 m has been used.

The main emission parameters for one power unit are given in table 6. These correspond with a condition in which only one power unit in a cell is operating. In the set for one cell, four units are connected to one stack (figure 3). This mean that emission rates, gases flow, and velocity through the stacks varies by a factor from 1 to 4, depending of the units running in parallel at the same cell.

Table 6 Emission parameters for one operating power unit

Parameters		value
Stack height(m)		12
Stack diameter (m)		1.02
Velocity (m/s)		5.6
Temperature (K)		523
Emission rate (g/s)	SO_2	2.3
	CO	2.1
	NO_{2eq}	1.1
	PM_{10}	0.4

Besides emission parameters, the emission patterns for each stack included in the analysis are needed. These patterns consist in the hourly variations of the emission parameters during the survey period. In this way it was necessary to build hourly emissions files. These files include the hourly variation per stack of the emission rate, temperature, and gas exit velocity. The emission files were completed based on the typical emissions parameters established for one power unit and the facilities data bases. These data bases allow establishing the power units in operation per cell at every hour; which has been defined as operating arrangement. Operating arrangement has high influence in the emission parameters, and could it be modified without cost to improve the environmental performance of these stations.

2.4 Impacts assessment

Several impacts are assessed, including impact on air quality, impact on human health, public exposure to polluting gases, and CO_2 emissions. Main contributions are made in impact on health and exposure estimations. Exposure maps to identify more affected areas by air pollution are built. Chronic mortality due to PM_{10} exposure is used as health impact indicator. A marginal exposure indicator is used to assess the location effect of emission sources in their impacts potential. The foundations to calculate most important indicators are given below.

2.4.1 Impact on human health estimation.

A consensus has been emerging among public health experts that air pollution, even at current ambient levels, aggravates morbidity (especially respiratory and cardiovascular diseases) and leads to premature mortality [6, 23-25]. Generally, impacts assessment of air pollution on human health is performed through concentration-response functions (CRFs). Those functions correlate the increment of ambient pollutant concentration, during a given time period of exposure, with the corresponding health risk increment. CRFs are determined by epidemiological studies using statistical analysis. Recent epidemiological studies have found approximately linear correlations between the increment of pollutants concentration and health risk, in a range applicable for ambient concentrations, without a threshold below which no adverse effects could be expected [26-31]. These findings support the statement of the equation 1 to estimate the impacts on human health variations related to a determined outdoor air pollution changes.

$$\Delta I_{n(A;q)} = S_{CR(q)} \int\int Pop_{(\partial x,\partial y)} \cdot \Delta C_{n(\partial x,\partial y;q)} dxdy \qquad (1)$$

Where $Pop_{(\partial x,\partial y)}$ is the Population in the area fraction $\partial A=\partial x\cdot\partial y$ in Inhabitants. The area fraction size depends on the spatial resolution defined for the receptors grid in the study domain. $\Delta C_{n(\partial x,\partial y;q)}$ incremental concentration in $\mu g/m^3$ of the pollutant q in the fraction of area ∂A due to emissions from n sources. $S_{CR(q)}$ is the slope of the concentration-response function for general chronic mortality. In this study it is adopted from ExternE [6] S_{CR} = 4.0E-4 YOLL/inhabitants·yr·$\mu g/m^3$) for PM_{10}. This value was determined from a recalculation of loss of life expectancy implied in a relative risk increase of 1.06 % per $10 \mu g/m^3$ of $PM_{2.5}$ given by Pope et al [28].

The use of chronic mortality to assess impact on health is based on results from several surveys regarding the effects of air pollution on health. Important finding are mentioned here after. Chronic mortality due to PM_{10} exposure tends to dominate the overall burden of diseases [32], accounting at least for 80% of health effects [6]. Compared with chronic mortality, acute mortality means only a small fraction, in any case included in chronic mortality. Under certain assumptions have been demonstrated that acute mortality represents only about 1% of the total impact on mortality caused by the exposure to particulate matter [33].

For application of equation 1, the establishment of matrices of population distribution and incremental concentrations is required. Then the distribution of the population and incremental concentrations in the survey area is considered.

2.4.2 Exposure estimation

From equation 1 the elements within the integral can be used as indicator of the total incremental exposure, when the incremental concentrations of the pollutants q are expressed as PM_{10eq}. As shows equation 2,

$$\Delta E_{n(A;PM_{10}eq)} = \int\int Pop_{(\partial x,\partial y)} \cdot \Delta C_{n(\partial x,\partial y;PM_{10}eq)} dxdy \qquad (2)$$

The total pollutant concentration as PM_{10eq}, $\Delta C_{n(\partial x,\partial y;PM_{10eq})}$ is the sum of the concentrations of all pollutants included in the assessment expressed as PM_{10eq}. To express the pollutants as PM_{10eq} is considered their relative potential to impact human health with respect to PM_{10}. In this way weights factors are established based on the relative risk for total acute mortality. In table 7, values of the relative risk used in this study and the weights factors for the specified species are given.

Table 7 Relative risk for total acute mortality as %/10 $\mu g/m^3$, and weights factors

Pollutant	Value (95% CI)			Source	Weight* factor
	Low	Central	High		
NO_2	0.47	0.62	0.78	Stieb [34]	0.62
SO_2	0.28	0.36	0.48	Stieb [34]	0.36
PM_{10}	0.6	1	1.5	Ostro [32]	1

*based on the central value

Based on weight factors given in table 7, e.g $1 \mu g/m^3$ of SO_2 is equivalent to $0.36 \mu g/m^3$ of PM_{10eq}. This means, e.g. that in a receptor site where the incremental concentrations are $NO_2=10 \mu g/m^3$, $SO_2=15 \mu g/m^3$ and $PM_{10}=7 \mu g/m^3$, the total incremental concentration is $PM_{10eq}= 7+15\cdot0.36+10\cdot0.62= 18.6 \mu g/m^3$.

By the Hadamard product of the population distribution matrix and the incremental concentration matrix for PM_{10eq} a total incremental exposure matrix is determined. Based on this matrix a total exposure map can be built. This is valuable information to lead priorities in mitigation actions, by identifying more affected areas.

2.4.3 Marginal exposure estimation

The marginal incremental exposure allows determining the level of exposure generated by a specific source or a group of them per MWh of effective energy demand. This indicator is calculated by equation 3,

$$\Delta Em_{n_i(A;q)} = \Delta E_{n_i(A;q)}/EED \qquad (3)$$

Where, $\Delta Em_{ni(A;q)}$ is the marginal exposure to the pollutant q caused by the emission source n_i expressed in $\mu g/m^3{}_q\cdot$Inhabitant/MWh, $\Delta E_{n_i(A;q)}$ is the exposure to the pollutant q expressed in $\mu g/m^3{}_q\cdot$Inhabitant, and EED is the effective energy demand.

This is a useful indicator to assess the location effect of the facilities. It enables to establish operating strategies in order to generate the lowest exposure of the population to polluting gases. It also allows identifying the best possible location for new facilities.

2.5 Perturbations analysis for impacts reduction

Modifications in several variables can be assessed for impacts reduction, e.g. source location, conversion efficiency, end of pipe emission control, technology, and operating arrangement. But in the facilities included in this work only some perturbations are feasible. E.g. source location is basically modifiable in design stage, because in operating stage it will require important investments. In this study the efficiencies calculated for the power units are close to the upper limit for the installed technology, so, improving conversion efficiency will require big efforts for a small impacts reduction. End of pipe emissions control has not been included in the analysis because lead to investments not affordable by the stations in the short term.

Finally in this work is assessed to modify operating arrangements and stacks high. Increase in stack height is included in the investments plan of the stations. A high stacks tend to cause less local concentration increase, due to the widespread dispersion of the effluents.

Modification in operating arrangements is based on the configuration of these stations (see description in section 2.2.). A given EED can be met by different operating arrangements. This means that the emission parameters may differ, despite equal EED and net emissions. For each EED it is possible to establish the emission parameters causing the lowest local exposure. This can be done based on the marginal exposure indicator. In this way the operating arrangement can be optimized for minimum local impact. In this study all operating arrangements to meet all possible EED were assessed.

An example is summarized in table 8; it shows all operating arrangement to meet 10MW of EED. The marginal exposure to SO_2 is adopted as indicator, instead the total exposure. This is because making analysis for a single technology in similar operating condition the pollutants emission is correlated. So, no different result will be reached including all pollutant, but a higher modeling effort will be required.

Table 8 Possible operating arrangements for 10 MW of EED, emissions parameters, and SO_2 marginal exposure

Operating arrangements		***1***	2	3	4
Power units in operation		7			
Operating units per cell	Cell 1	***4***	4	3	3
	Cell 2	***3***	2	3	2
	Cell 3	***0***	1	1	2
Gas exit velocity, (m/s)	Cell 1	***22.4***	22.4	16.8	16.8
	Cell 2	***16.8***	11.2	16.8	11.2
	Cell 3	***0***	5.6	5.6	11.2
SO_2 emission rate, (g/s)	Cell 1	***9.24***	9.24	6.93	6.93
	Cell 2	***6.93***	4.62	6.93	4.62
	Cell 3	***0***	2.31	2.31	4.62
SO_2 marginal exposure ($mg/m^3\cdot$Inhabitant/MWh)		***2.71***	3.15	3.23	3.36

The set in italic and bold causes the lowest local impacts in terms of exposure to polluting gases, which lead also to the lowest impacts on health. In conclusion three scenarios were assessed; the variations from one scenario to another are given in table 9.

Table 9 Parameters variation in different scenarios

Scenarios	Baseline	A	B
Stack height(m)	12	12	24
Operating arrangements	Business as usual	Optimized	Optimized

3. RESULTS AND DISCUSSION

Efficiency determined for the power units was close to the highest for this technology, about 41%, indicating a good maintenance routine and operating regimes.

The station 4SPG is exploited at higher regimes (see table 2). This is a good operating strategy aiming to reduce the population exposure to polluting gases, if considered that the station 4SPG is located where the population density is lower (see figure 2).

Apart from CO_2 emissions, the highest emissions correspond to SO_2. This is related to high sulfur contents in the HFO. The characterization of the emissions is an important data to make decisions about gas cleaning.

From combustion gas analysis it was concluded that all stations meet the Cuban emissions standard. This can be related to a good maintenance routine and operating regimen. These facilities, built in 2007, have a short exploitation period. The life time for this technology is 20 years.

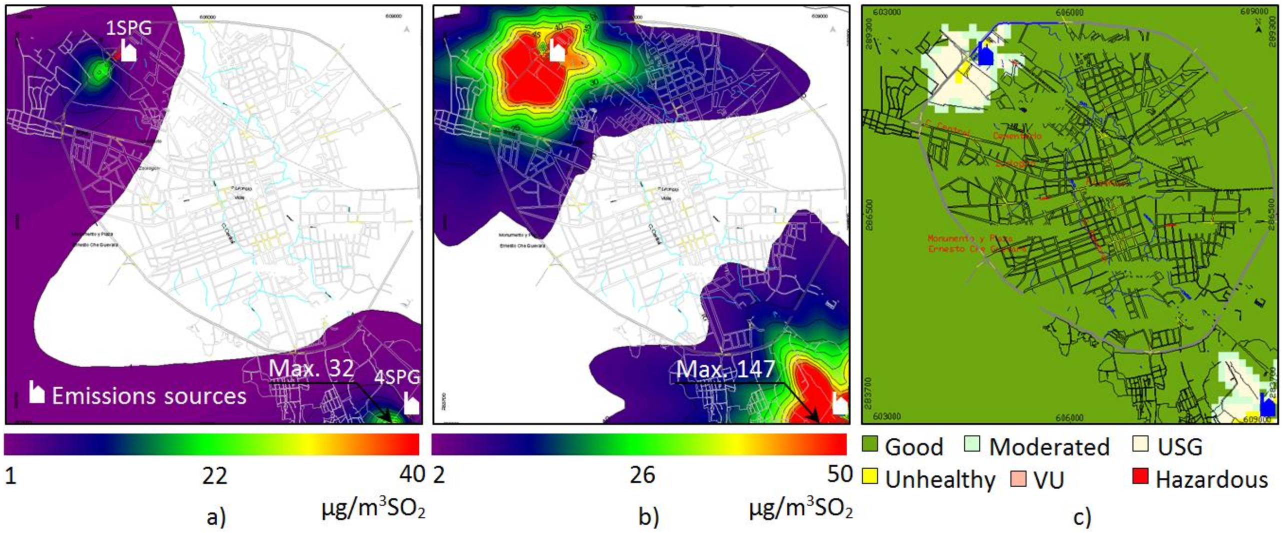


Figure 4 Impact on air pollution related to SO_2 emissions for the baseline scenario: a) Incremental annual average concentration, b) Incremental highest concentration for 24 h averaging time, c) Impact on air quality condition according to NC 111: 2004

Figure 4 shows modeling results for SO_2 emissions in the baseline scenario, and the related impact on air quality conditions. SO_2 has been adopted as reference for air quality impact analysis because it appears to be the main causal agent of air quality deterioration.

In the figure 4a the maximum value in the color scale corresponds to the Maximum Allowable annual average Concentration (MAC) set by EPA in the national ambient air quality standards for USA [35]. This is done with the purpose of recognizing the areas where the MAC is exceeded. This value has been adopted from EPA standards in view that the NC 39: 1999 [36] do not regulate the annual average MAC. In all the area the calculated incremental concentrations are lower than the MAC. However in some sites, even a relatively low value of the background concentration, could lead to exceed the MAC.

In the figure 4b, the maximum value in the color scale, corresponds to the MAC for 24h averaging time established in NC 39: 1999 [36]. This map represents the worst scenario for periods of 24h. In the areas in red the incremental concentration calculated exceeds the MAC. A percentile analysis, for the two receptors with the highest calculated incremental concentration, in the northwest and the southeast area, revealed that in the southeast receptor the incremental concentration exceeds the MAC 60 days in the year, and in the northwest 55 days. The figure 4c, shows the impact on air quality deterioration of the scenario presented in figure 4b. Note that even, without considering the background concentration, in some sites the air quality condition is unhealthy.

Figure 5 shows annual exposure maps for the different scenarios assessed. To generate these maps the annual incremental concentrations and the exposed population were considered.

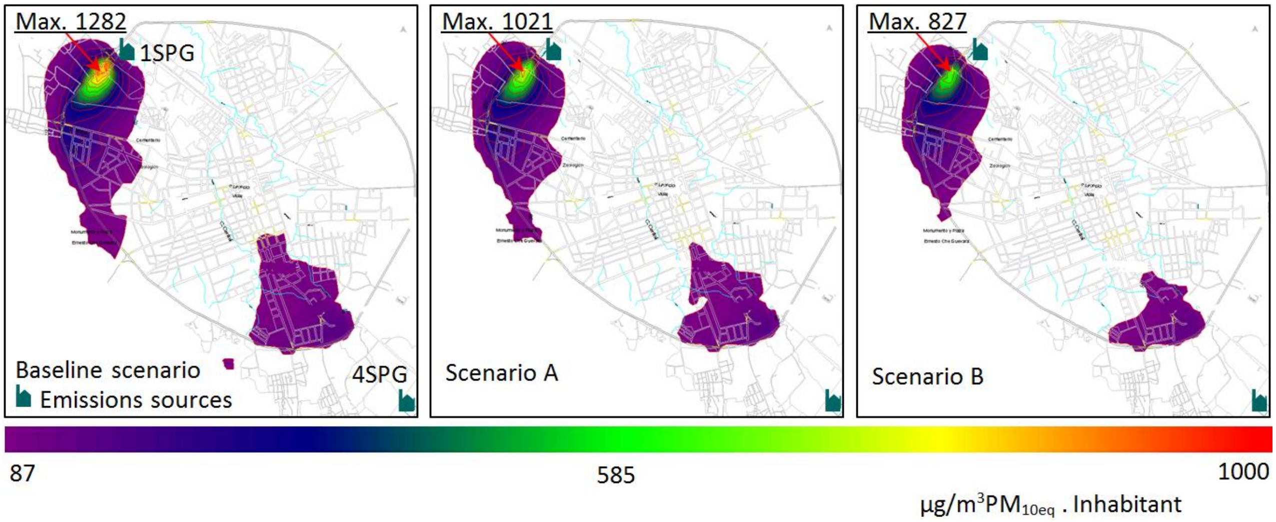
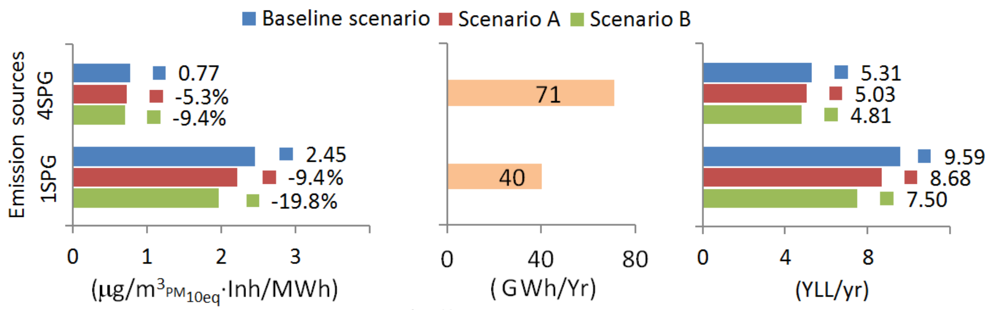


Figure 5 Annual exposure maps generated for different scenarios



a) Generated exposure b) Effective energy demand c) General mortality

Figure 6 a) Annual exposure, b) Annual EED, c) Impact on health expressed as years of life potentially lost per year

The incremental exposure level decrease from the baseline scenario to scenario B bout 35% (figure 5). In spite of the maximum concentrations occur in the southeast, the northwest area is identified as the most affected, mainly due to the station 1SPG is located in a high populated area.

The station 1SPG generates a higher local impact despite that station 4SPG meets a higher effective energy demand than 1 SPG by a factor of 1.8. According to the marginal exposure indicator (figure 6 a) can be established which station should be operated at highest regimes in order to reduce the population exposure to polluting gases. Note how the exposure generated by the station 1SPG could be reduced by 20% approximately from the base line scenario to the scenario B.

Figure 6c shows for each specific facility the impact on health expressed in years of life potential lost per year. The highest impact is generated by the station 1SPG. The general mortality from baseline scenario to scenario B can be reduced about 17% approximately. The major achieved reduction is 20% in the station 1SPG.

The CO_2 emissions are entwined to the raw energy consumption. In this way, as the operating efficiencies are in the upper limit for the installed technologies, and the effective energy demand is considered constant, no mitigation opportunities were identified.

In developing countries economic limitations hamper environmental and energy managements. This work shows some low investment actions that can reduce local environmental impacts. The modifications in the operating arrangement derived from this survey have been implemented at the stations without cost. In addition investments have been prioritized to raise the stacks height at 1SPG station.

4. CONCLUSIONS

At present the environmental impacts of energy conversion calls for the assessment of external effects in decision-making.

Chronic mortality due to PM_{10} exposure has been adopted as health impact indicator. It is expressed in years of life potentially lost per year. To distinguish the exposure level to mixtures constituted by different proportions of pollutants a total exposure indicator has been established. A map of total incremental exposure has been developed and adopted to elucidate the exposure pattern in the study domain.

The marginal exposure generated by each specific facility is settled as indicator to assess the location effect on the impact generated.

Based on this survey it is possible to have an appropriate representation of the impacts related to energy use at local scale.

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