# Exergetic Life Cycle Analysis in the selection of energetic sources for isolated communities in Latin American

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**Abstract**

The distributed generation (DG) is the electric power generation, to small and medium scale, located nearest to the load center, with the option of being interconnected with the network for the purchase effects or sale. Usually a technical and economic analysis defines which kind of energy source to use, having in consideration the characteristics of the region from the climatological point of view; normally for this evaluation some software like HIBRID2, HOMER or VIPOR are used to do alternative evaluation, these analysis don't consider the environmental aspect. The proposal of this work is carried out this analysis combined economic and environmental aspects , by using Environmental Exergetic Life Cycle Analysis (ELCA) methodology in order to assure this point of view in the final decision, considering the relation between non renewable and rewenewable categories in all stage of life cycle of each technology considered.

## 1. Introduction

Electricity generation in general, is to transform an energy that can be chemical, thermal, mechanical, hydraulic, and solar and wind into electrical energy. In the early years, the electricity industry was characterized by the presence of small generators of electricity generated that used direct current (DC), but as the population was increasing and therefore the big cities, especially in first world countries, it was difficult to transport this current from the center of generation to the place of consumption should be installed so many generating units within cities. The development of systems of alternating current (AC) allowed the development of building more generators capacity and the creation of large generation facilities, and away from load centers, which together with the development of different technologies allowe constructing the power system (EPS) that carry electricity to different points of consumption.

On the other hand today, one of the most difficult problems in the planet is global warming, caused largely by burning fossil fuels like oil and coal, causing emission of toxic gases that affect the environment, in particular altering the atmospheric compositions.

In the world there is a high percentage of people still living in areas where it is difficult to access electricity networks (such as mountain, jungle and others). . In those areas, being far from power grids, has been the need to evaluate alternatives for solving this problem, usually tests are aimed at evaluating different energy sources, including a much wider use of renewable energy sources; these analysis have considered fundamentally technical and economic viewpoint, but without taking into account the environmental issuees, or more simple: the possible replacement of fossil fuels as energy solution by renewable energy.[1]

The Exergetic Life Cycle Analysis (ExLCA) examines the flows of exergy within a system and its objective is focus to the reduction of destruction of exergy and improves the efficiency of processes and systems. In production systems of energy, the Exergetic Life Cycle Analysis evaluates the pressure to exergetic resources: the fossil power consumption tends to destroy them and the renewable power consumption tends to create them. For that reason that considers a very valuable tool for combining with the economic analysis in the decision making.[2]

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## 2 Research methodology

Renewable energy sources have the characteristic of being relatively clean and inexhaustible, but highly dependent on the weather situation in each area for your level of electricity production. Despite these above criteria there is fairly widespread, in fact, any source that is completely clean, because if assessed from the point of view of their life cycle (from birth until death or depletion) all have a certain level of damage to the environment, it is very important to include the impact of infrastructure when an energy source must be selected, specifically in isolated communities from development countries because in the majority of cases the technology is imported

To carry out a technological, economic and environmental impact assessment there is no general method, each method refers to specific environmental impacts and none of them are fully developed precisely because of the specificity and inability to generalize a particular methodology. The first step in establishing a methodology is to give an idea of the magnitude of impact, with many procedures for environmental impact studies on the environment or any of its factors, the following may be general and other specific or concrete, some qualitative and some operate with large databases and tools more or less sophisticated calculations.

Future development will enable a further reduction of environmental impacts of renewable energy systems.

Different factors are responsible for this development, such as progress with respect to technical parameters of energy converters, in particular, improved efficiency; emissions characteristics; increased lifetime, etc.; advances with regard to the production process of energy converters and fuels; and advances with regard to ‘external’ services originating from conventional energy and transport systems, for instance, improved electricity or process heat supply for system production and ecologically optimized transport systems for fuel transportation. [3]

A tool which allows evaluating this aspect in a way perhaps more complete can be found in the life cycle analysis (LCA).[4]

LCA studies the environmental aspects and potential impacts throughout the product life (ie cradle to grave) from raw material acquisition through production, use and disposal. The general categories of environmental issues that require consideration include resource use, human health and ecological consequences. However by using LCA the quality of energy is not considered.

On the other hand, the Demand of Exergy Accumulated DExA has proposed like an indicator of the resources energetics quality [5]. DExA represents the total elimination of exergy of the nature in the generation of a system product, adding exergy of all the necessary resources. In addition it evaluates the quality of energetic resources: chemistry, kinetic, hydroelectric, nuclear, to pave and of thermal radiation. The DExA is equivalent to the definition of accumulated exergy consumption (CExA) [6,7] both quantify exergía total required for a product.[8] The DExA calculates when adding the total of exergy required by a process during a period of time, has by units MJ eq • period-1.

$$DExA=\sum_i m_i.Ex_{(ch),i}+\sum_j [\![ n_j.rex_j ]\!] \qquad (1)$$

Where:

DExA is the accumulated exergetic demand by unitary product or process in MJ-eq,
mi it is the mass of resource i in kg,
Ex- (ch), i is exergy by kg of substance in MJ-eq•kg-1,
nj is the amount of the carrying energy in MJ
rex is the relation of exergy to energy of the carrier.

In Sima Pro Soft ware there is Cumulative Exergy Demand Method directly taken from Ecoinvent 2.0. Amount of substances present are compatible with the EI 2.0 database and extended for other databases. [9]

In this method exergy is used as a measure of the potential loss of "useful" energy resources. Nonrenewable and renewable categories have considered. The DexA can be obtained in point (Pt)

The methodology used is this research content the following step:

1. To determine the energy consumption for the community.
2. To Simulate different alternatives by using software HOLMER. These include the use of different energy sources, renewable and no–renewable and their combination.
3. To do economic analysis of each alternative.
4. To do LCA using Ecoindicador 99
5. To do ELCA by using Cumulative Exergy Demand Method.
6. To calculate the relation between non renewable and renewable categories.
7. To select the best alternative considering environemntal, exergetic and economic aspect.

## 3. Results and discussion

This study covers the electricity generation including the construction, infrastructure, transport and distribution phase for a given community consisting of 30 houses, the equipment present in the community and consumption of electricity demand, were inventoried and obtained the daily electricity demand. Different energy sources that include the use of renewable energy wind (W) and photovoltaic (FV) and non-renewable (diesel) were considered in generation schemes with a single source or hybrid schemes (two or more sources of energy).

The first step, before applying the LCA and ELCA, was to make the design of selected energy systems, as a support tool for this purpose (from the simulation systems) software HOMER is used, the HOMER was developed by the National Renewable Energy Laboratory of the U.S. (NREL) and is a tool that gives users a powerful environment with many variables to get a detailed system analysis as

well as allowing simultaneously perform different simulations to compare the result of the different configurations and sizing of components .
Demand and energy consumption represent usually needs to satisfy in cases where a solution is sought appropriate energy to the user, is therefore necessary to know the details and characteristics of energy demand in order to provide a solution satisfactory. Fig. 1 shows the time distribution of that demand in the community under study.

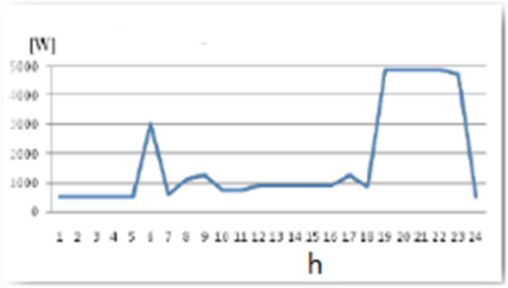


Fig1. Hourly distribution of electricity demand in the community.

Based on these conditions is made the scale of each energy sources. The economic and technical analysis of each variant was made and the result showed that from the viewpoint of the initial investment the alternatives wind and hybrid by using wind + diesel generators are more economical than others. But if the comparison is a 20-year horizon, the results vary widely, being the most economical hybrid systems wind + diesel generators and photovoltaic + wind. See table 1
Tab 1 Economic Analysis of electricity generation by using different sources

| Alternative | Investment cost ($) | Production cost ($) |
|---|---|---|
| Photovoltaic (FV) | 153 429.14 | 46 132.64 |
| Emergency generators (EG) | 129 048.27 | 55 275.03 |
| Wind (W) | 87 549.70 | 54 469.48 |
| FV+EG | 186 840.92 | 32 984.24 |
| FV +W | 179 300.88 | 39 730.00 |
| EG +W | 80 343.27 | 24 145.91 |
| FV+W+EG | 185 148.00 | 43 801.25 |

The functional unit was the production of 41.48 MW-h for all alternatives to generate electricity, can this be changed according to the purpose of study.

Since inventory is the most complex stage , it was obtained values with highest quality of inputs and outputs for all variants (from actual measurements), which were obtained from the databases of the Wind Energy Association, the Emergency Management Group, both of the UNE, and the company ECOSOL POWER COPEXTEL. Besides the data base Ecoinvent was used.

***3.1 Life Cycle Assessment***

The impact assessment is carried out with the aid of the software SimaPro 7.2, developed by Pré Consultants. The methodology used was the Eco indicator 99.

The Fig. 2 shows the impacts categories of electricity generation for all energetic sources considered in the study. The alternatives where the emergency generator is used have relevant impact in fossil fuel category being considerably major when the emergency generator is used alone.

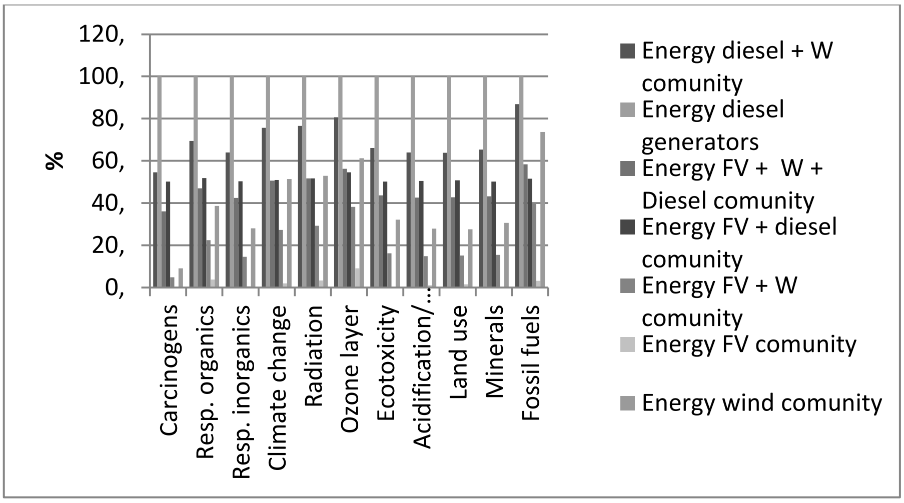


Fig. 2 Environmental profile of alternatives. Ecoindicator 99 methods.

In the assessment of these technologies has a key role the category carcinogenesis due to the emission of carcinogenic substances in the construction stage for renewable sources and for both phases for diesel generator sources , also affects other categories such as mineral, fossil fuel , climate change, ecotoxicity and inorganic respiration.

The use of photovoltaic system and its combination with others sources have influence in land use category, however the photovoltaic sources don’t have impact considerable in any impact categories.

In Fig. 3 the total score of different alternatives is showed for the function unit.

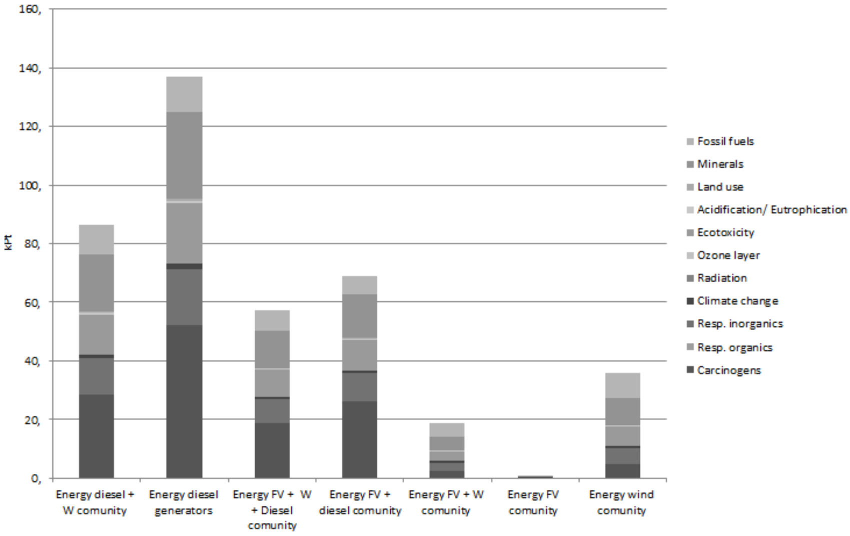


Fig 3 Total score of electricity generation alternatives.

The mayor impact is obtained when the electricity is generated with emergency generator and in all alternative where it is used the total impact is appreciable, being less when the tree sources are combined.

### *3.2 Exergetic Life Cycle Assessment*

The methodoly cumulative exergy demand from Sima Pro 7.2 software was used in order to estimate the potential loss of "useful" energy resources in each alternative. The results are showed in Fig. 4, The major score are related with the use of diesel generator ,other alternatives that combine diesel generator with other renewables sources have similar results and mayor than the alternatives that use photovoltaic energy.

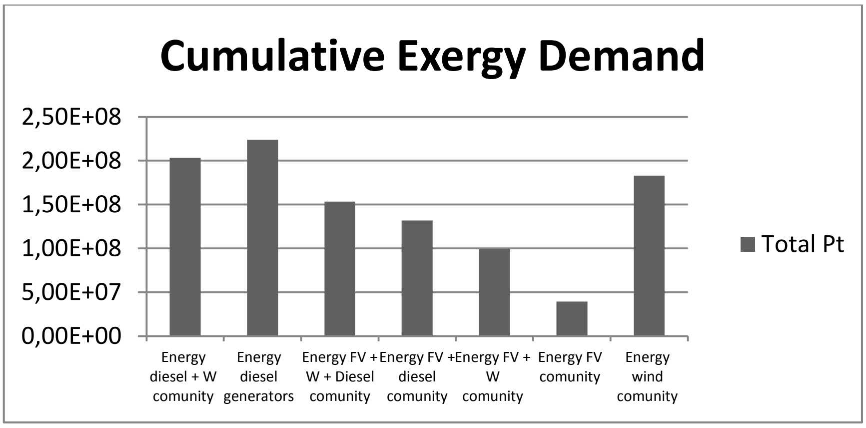

Fig 4 Total score of cumulative exergy demand.

All the variants that use resources of the nature, diesel, non renewable resource have major demands of accumulated exergy that those that use renewable resources (the two last ones) but in addition the consideration of infrastructure in alternatives imply the use of other not power resources as raw materials and additives been their chemical demands. If energy from wind and photovoltaic are comparing, then is evident the contribution of infrastructure to the cumulative exergy demand. in both case and major for wind energy.

In this case is useful to evaluate the relation between renewable and non renewable categories included in Cumulative Exergy Demand methodology by using the renewability factor (FR). See Fig.5

$$FR = \frac{Cumulative\ exergy\ demand\ for\ renewable\ categories}{cumulative\ exergy\ demand\ for\ non\ renewable\ categories} \quad (2)$$

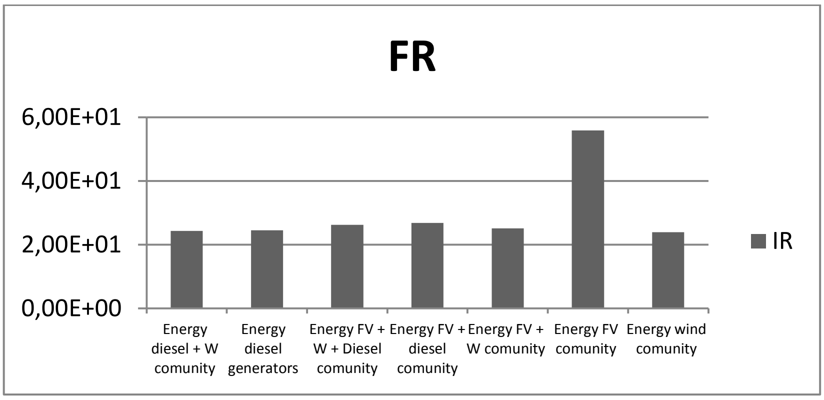

Figure 5 Relation between renowable and non renewables categories

The relation between renewable and non-renewable categories is mayor when the photovoltaic energy is used, (54, 57). If are compared the rest of the indexes, it is observed similar results with indexes below 30. This result is according with the cumulative exergy demand and reflect that when the infrastructure is considered in the exergetic analysis, the relations between renewable and non renewables resources is similar in this study case for all alternatives excluding photovoltaic alternative.

### *3.3 Economic evaluation combined with Exergetic Life Cycle Assessment*

The last step is to select the best alternative according with economic and environmental aspect, for this reason was necessary to establish the compromise between the total investment and the Cumulative Exergy Demand. (Fig. 6)

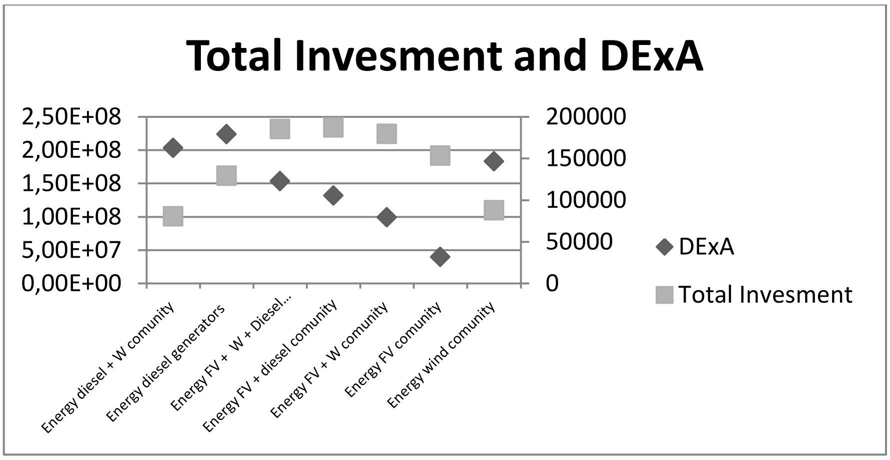


Fig. 6 Total Investment and DExA for each alternative evaluated.

The alternative that use diesel generator alone, combined with wind energy and photovoltaic + wind, have high cumulative exergy demand. These were excluded. According with the DExA and FR the best alternative is the use of photovoltaic energy, but if the production cost are considered the alternative that included the use of photovoltaic and wind energy can be selected. In this case the enviromental impact is considerably menor than other.

## 4. Conclusions

1. The Life cycle Analysis in the selection of energetic sources for isolated communities must include the construction and operation stage.

2. The use of Cumulative Exergy methods allow to found the exergetic loss of electricity generation sources and to establish the relation between non renewable and renewable resources.

3. The combination of economic and exergetic analysis by using Exergetic Life Cycle Assessment allow to select the best alternatives for generating electricity in the communities isolated from the system.

4. It is necessary to improve the inventories for system generator with the incorporation of infrastructure data for Latin American.

5. The result showed that in this case the best alternatives are the use of photovoltaic energy and the combination photovoltaic and wind.

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