Sustainability Assessment, Case of Study: Geothermal Power Plant

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I. INTRODUCTION

Sustainable development can be defined in various ways, depending on the analytical standpoint. The most common accepted guidelines were introduced by the United Nations in 1987 (Brundtland Report), and extended in 1992 by the Rio Declaration on Environment and Development [1]. According to these documents, development is deemed sustainable when it satisfies present needs without compromising the capacity of future generations. Moreover, integral or global sustainability goes beyond purely environmental aspects; social and economic factors, as well as ethical and cultural concerns must be considered [2].

The accelerated global energy demand together with declining global reserves of fossil fuels and the growing effects of global warming have turned eyes to alternative energy sources. One example of these are geothermal resources, which consist of the usage of thermal energy from the Earth's interior stored in both rock and trapped steam or liquid water for generation of heat or electricity. Even though the geothermal resource is considered sustainable by itself, a sustainability assessment of the power plant should be performed as well to ensure that the overall project satisfies the sustainability criteria [3]. Unlike conventional practices, current alternative energy projects must consider sustainability assessments to serve as a framework for sustainable development, in order to achieve a balance between environmental, economic and social aspects in addition to encourage the development of best practices and technologies.

In this article we will perform a sustainability assessment study using two ideal scenarios of geothermal power plants projects for comparison. A set of sustainability indicators were compiled after an extensive review of the literature taking into account important aspects of geothermal power plants construction and operation while integrating the sustainability criteria. First, a background on geothermal power plants will be presented. Second, the environmental, economic and social indicators will be presented pointing out the relevance of each aspect in this particular case of study. Finally, a sustainability assessment for two ideal cases of geothermal power plants will be performed and the results will be presented.

II. BACKGROUND ON GEOTHERMAL POWER PLANTS

Geothermal systems as they are currently exploited occur in a number of geological environments where the temperatures and depths of the reservoirs vary accordingly. Many high-temperature (> 180 °C) hydrothermal systems are associated with recent volcanic activity and are found near plate tectonic boundaries (subduction, rifting, spreading or transform faulting), or at crustal and mantle hot spot anomalies. Intermediate- (100 to 180 °C) and low-temperature (< 100 °C) systems are also found in continental settings, where above-normal heat production through radioactive isotope decay increases terrestrial heat flow or where aquifers are charged by water heated through circulation along deeply penetrating fault zones. Under appropriate conditions, high, intermediate and low temperature geothermal fields can be utilized for both power generation and the direct use of heat [4].

The basic types of geothermal power plants in use today are steam condensing turbines and binary cycle units. Steam condensing turbines can be used in flash or dry-steam plants operating at sites with intermediate and high-temperature resources (≥ 150 °C). The power plant generally consists of pipelines, water steam separators, vaporizers, de-misters, heat exchangers, turbine generators, cooling systems, and a step up transformer for transmission into the electrical grid. The power unit size usually ranges from 20 to 110 MW [5], and may utilize a multiple flash system, flashing the fluid in a series of vessels at successively lower pressures, to maximize the extraction of energy from the geothermal fluid. The only difference between a flash plant and a dry-steam plant is that the latter does not require brine separation, resulting in a simpler and cheaper design [4].

Binary cycle plants, typically organic Ranking cycle (ORC) units, are commonly installed to extract heat from low

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and intermediate-temperature geothermal fluids (generally from 70 to 170 °C), from hydrothermal and EGS type reservoirs. Binary plants are more complex than condensing ones since the geothermal fluid (water, steam or both) passes through a heat exchanger heating another working fluid. This working fluid, such as isopentane or isobutene with a low boiling point, vaporizes, drives a turbine, and then is air cooled or condensed with water. Binary plants are often constructed as linked modular units of a few MW in capacity [4]. There are also combined or hybrid plants, which comprise two or more of the above basic types, such as using a binary plant as a bottoming cycle with a flash steam plant, to improve versatility, increase overall thermal efficiency, improve load-following capability, and efficiently cover a wide resource temperature range.

Geothermal energy is classified as a renewable resource because the tapped heat from an active reservoir is continuously restored by natural heat production, conduction and convection from surrounding hotter regions, and the extracted geothermal fluids are replenished by natural recharge and by injection of the depleted (cooled) fluids. Geothermal fields are typically operated at production rates that cause local declines in pressure and/or in temperature within the reservoir over the economic lifetime of the installed facilities. These cooler and lower-pressure zones are subsequently recharged from surrounding regions when extraction ceases [4].

The total thermal energy contained in the Earth is of the order of 12.6 x 10^{12} EJ and that of the crust of the order of 5.4 x 10^{9} EJ to depths of up to 50 km [6]. The main sources of this energy are due to the heat flow from the Earth's core and mantle, and that generated by the continuous decay of radioactive isotopes in the crust itself. Heat is transferred from the interior towards the surface, mostly by conduction. The result is a global terrestrial heat flow rate of around 1,400 EJ/yr. Continents cover ~30% of the Earth's surface and their terrestrial heat flow has been estimated at 315 EJ/yr [7]. In practice geothermal plants can only utilize a portion of the stored thermal energy due to limitations in drilling technology and rock permeability. Commercial utilization to date has concentrated on areas in which geological conditions create convective hydrothermal reservoirs where drilling to depths up to 4 km can access fluids at temperatures of 180 °C to more than 350 °C [4].

According to [4], the annual average growth of geothermal electric installed capacity over the last 40 years is 7%, spanning from 720 MW during 1970 to 10,715 MW in 2010. The enormous potential of geothermal energy makes a sustainability assessment relevant to enable right decision making about a holistic feasibility of new power plants, trying not to make the mistakes of the past while using other resources and technologies.

III. SUSTAINABILITY INDICATORS FOR A GEOTHERMAL POWER PLANT

The indicators here presented have been selected based on an extensive literature review about enhanced geothermal systems (EGS), binary and flash technologies. Every indicator is rated from 1 to 5 and considers that all indicators have the same weight; therefore, it is possible to have an overall rate as a sustainability assessment.

The information of the scenarios that will be used for the sustainability assessment comparison were extracted from the U.S. Department of Energy's Geothermal Electricity Technology Evaluation Model (GETEM) [8], which provides useful information about geothermal power plant technologies and is presented here in Table I for reference.

A. *Environmental indicators*

The starting point of our research was a life cycle assessment for geothermal power plants as it is a well-known study and is practically the environmental aspect of a

TABLE I

Geothermal Power Plant Technologies

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Geothermal Technology	EGS	EGS	Hydrothermal	Hydrothermal
Net Power Output, MW	20	50	10	50
Producer-to-injector Ratio	2:1	2:1	3:1 and 2:1	3:1 and 2:1
Number of Turbines	Single	Multiple	Single	Multiple
Generator Type	Binary	Binary	Binary	Flash
Cooling	Air	Air	Air	Evaporative
Temperature, °C	150-225	150-225	150-185	175-300
Thermal Drawdown, % per year	0.3	0.3	0.4-0.5	0.4-0.5
Well Replacement	1	1	1	1
Exploration Wells	1	1 or 2	1	1
Well Depth, km	4-6	4-6	< 2	1.5 < 3
Flow Rate per Well, kg/s	30-90	30-90	60-120	40-100
Gas/Brine Ratio, scf/stb	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Pumps for production	Submersible	Submersible	Lineshaft or Submersible	None
Distance between wells, m	600-1000	600-1000	800-1600	800-1600
Location of Plant in Relation to Wells	Central	Central	Central	Central
Plant Lifetime, years	30	30	30	30

sustainable assessment. The life cycle of a geothermal power plant can be summarized by the life stages of the power plant as: exploration, construction, operation and dismantling [9].

The life cycle of geothermal binary power plants is characterized by large material and energy inputs, especially during construction of the subsurface plant component. Successful exploration and access to the reservoir with minimum drilling and completion efforts referring to a specific site is hence the precondition for low environmental impacts. Due to the large influence of the auxiliary power required for delivering the geothermal fluid from the reservoir on the net power output, a sufficient reservoir productivity is required in order to make up for the large material and energy inputs during construction. The enhancement of the reservoir productivity by means of technical measures is, therefore, a key aspect for the improvement of the environmental performance of geothermal binary power plants [10].

Power supply systems will soon need to switch entirely to low-carbon resources and technologies on a global scale. The energy supply sector emitted 25.9% of worldwide anthropogenic CO2 equivalent emissions in 2004. The low-carbon options selected should also be robust enough to with stand intensifying climate change impacts such as droughts, floods, water scarcity, and storms [11].

Considering local environmental impacts, the construction phase is associated with many impacts on the environment. Due to the existing experience from the oil- and gas-industry however, the resultant effects are not of concern because of respective regulations and directives. It has to been considered though that the requirements of environmental protection are closely associated with the surrounding and that hydro-geothermal power plants will often be constructed near the public [9].

1) Global warming (E1)

With the current patterns of generation and consumption, plus our dependence to fossil fuels, the average temperature of earth's climate is increasing.

The main GHG emitted by geothermal operations is CO2. Geothermal fluids contain minerals leached from the reservoir rock and variable quantities of gas, mainly CO2 and a smaller amount of hydrogen sulfide. The gas composition and quantity depend on the geological conditions encountered in the different fields. Depending on technology, most of the mineral content of the fluid and some of the gases are re-injected back into the reservoir. The gases are often extracted from a steam turbine condenser or two-phase heat exchanger and released through a cooling tower. CO_2, on average, constitutes 90% of these non-condensable gases [12]. A field survey of geothermal power plants operating in 2001 found a wide spread in the direct CO_2 emission rates. The average weighted by generation was 122 g CO_2/kWh, with values ranging from 4 to 740 g CO_2/kWh [12]. In closed-loop binary-cycle power plants, where the extracted geothermal fluid is passed through a heat exchanger and then completely injected, the operational CO_2 emission is near zero [13].

The indicator that here will represent the global warming is measured in grams [g] of equivalent carbon dioxide (CO_2) per kWh. The rating is considered as shown in Table II.

2) Wasted generation (E2)

Includes energy used for logistics, production, operation and maintenance, as a kind of indicator of efficiency. Based on [14], the indicator is measured as a percentage of wasted [kWh] per generated [kWh] of the power plant. The rating is considered according to Table II.

3) Land use (E3)

Good examples exist of unobtrusive, scenically landscaped developments (e.g., Matsukawa, Japan), and integrated tourism/energy developments (e.g., Wairakei, New Zealand and Blue Lagoon, Iceland). Nonetheless, land use issues still seriously constrain new development options in some countries (e.g., Indonesia, Japan, the USA and New Zealand) where new projects are often located within or adjacent to national parks or tourist areas. Spa resort owners are very sensitive to the possibility of depleted hot water resources. Potential pressure and temperature interference between adjacent geothermal developers or users can be another issue that affects all types of heat and fluid extraction, including heat pumps and EGS power projects. Good planning should take this into account by applying predictive simulation models when allocating permits for energy extraction [4].

Power plants may use vast tracts of land that's could be used for other purposes, which implies the existence of marginal cost in land use. Based on [4, 15-16] this impact will be measured in square meters [m^2] per megawatt [MW] and

TABLE II
ENVIRONMENTAL INDICATORS RATINGS

Ratings	Global Warming, (E1) [g CO_2/kWh]	Wasted generation, (E2) [kWh/kWh]	Land Use, (E3) [m^2/MW]	Aggregated Water for Construction, (E4) [gal/kWh]	Aggregated Water for Operation, (E5) [gal/kWh]	Material Consumption (E6), [Metric tons/MW]
5	0	≤ 1 %	≤ 1,000	≤ 0.0010	≤ 0.005	≤ 20
4	200	2 %	2,000	0.0033	0.250	50
3	400	3 %	5,000	0.0066	0.500	100
2	700	4 %	7,000	0.0100	0.720	150
1	> 700	> 5 %	> 7,000	> 0.0100	> 0.720	> 150

rated according to Table II.

4) *Aggregated water consumption (E4 and E5)*

For the geothermal scenarios, the water consumption for the enhanced geothermal systems (EGS) construction stage is much greater than the other geothermal scenarios. This is primarily due to the additional requirement of reservoir stimulation for EGS. No stimulation was assumed for the other scenarios. Stimulation volume is assumed to be dependent on the desired water volume flow rate (a function of plant capacity) and to be independent of depth. The water volume required for stimulation contributes approximately 60–80% of total upfront water requirements for the evaluated well depths. Water requirements for stimulation can vary from the estimate presented here according to the number of stimulations required for successful circulation and the reuse of water for multiple stimulations. When water consumption is normalized across the life cycle, the contribution of stimulation is small, and the vast majority of water consumption for all geothermal technologies occurs during the operations phase [8]. Measured in gallons per kWh [gal/kWh] the aggregated water consumption will be evaluated in qualitative manner according to Table II. Only construction and operation stage information about aggregated water consumption is significant and available.

5) *Material consumption (E6)*

Considers aluminum, concrete, cement, bentonite, diesel, iron and steel due to the long pipes and wells, and it was based on information gathered in [17]. The indicator it is measured in metric tons per MW, and it is rated as shown in Table II.

B. *Economic indicators*

Power generation options are studied in a dynamic context. We learn from past experiments and experiences in order to improve technologies and practices. A new technology is adopted for development when its future cost price is expected to decline because of learning. Access to electricity is a condition for sustainable development. Examples of basic goods are light, medicine and food cooling, and the availability of driving power for productivity and comfort. The electricity supply systems of the future must be affordable for the majority of countries in the world. If they are too capital and high-tech intensive, they cannot be used worldwide and are less suitable for sustainable development. Electricity supply is considered secure when users are guaranteed continuous delivery at affordable prices. It is reliable when black-outs and brown-outs happen only occasionally. The value of security and reliability depends on the end uses of electricity and on users' willingness to pay [11].

1) *Cost (N1 and N2)*

Geothermal projects typically have high upfront investment costs due to the need to drill wells and construct power plants and relatively low operational costs. Operational costs vary depending on plant capacity, make-up and/or injection well requirements, and the chemical composition of the geothermal fluids. Without fuel costs, operating costs for geothermal plants are predictable in comparison to combustion-based power plants that are subject to market fluctuations in fuel prices.

One additional factor affecting the investment cost of a geothermal electric project is the type of project: field expansion projects may cost 10 to 15% less than a greenfield project, since investments have already been made in infrastructure and exploration and valuable resource information has been learned from drilling and producing start-up wells.

For construction stage, considering condensing flash power plants estimated to be USD_{2005} 1,780 to 3,560/kW, and for binary cycle plants USD_{2005} 2,130 to 5,200/ kW [18], this indicator is measured in USD_{2005} per kilowatt [kW] of the power plant capacity. The rating is considered according to Table III.

For operation stage, each geothermal power plant has specific O&M costs that depend on the quality and design of the plant, the characteristics of the resource, environmental regulations and the efficiency of the operator. The major factor affecting these costs is the extent of work-over and make up well requirements, which can vary widely from field to field and typically increase with time [19]. In terms of installed capacity, current O&M costs range between USD_{2005} 152 and 187/kW per year, depending of the size of the power plant. In New Zealand, O&M costs range from $US_{cents2005}$ 1.0 to 1.4/kWh for 20 to 50 MW plant capacity [20], which are equivalent to USD_{2005} 83 to 117/kW per year. The rating is considered according to Table III.

2) *Capacity factor (N3)*

Another performance parameter is the capacity factor (CF). The net capacity factor of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time. The evolution of the worldwide average CF of geothermal power plants since 1995 is considered for this indicator, calculated from the installed capacity and the average annual generation as

TABLE III
ECONOMIC INDICATORS RATINGS

Ratings	Construction Cost (N1), [USD_{2005} / MW]	Operation Cost (N2), [USD_{2005} / MW-year]	Capacity factor (N3), [0-1]	Incentives (N4), [% of the Cost]
5	≤ 2,000	≤ 75	> 90	> 8 %
4	3,000	100	90	8 %
3	4,000	150	80	6 %
2	6,000	200	70	4 %
1	> 6,000	> 200	≤ 60	≤ 2 %

reported in different country updates gathered by [21], in which is based the rating of this indicator in Table III.

3) *Incentives (N4)*

Success of geothermal development in particular countries is closely linked to their government's policies, regulations, incentives and initiatives. Successful policies have taken into account the benefits of geothermal energy, such as its independence from weather conditions and its suitability for base-load power. Another important policy consideration is the opportunity to support the price of geothermal kWh.

For example, in the United Stated, the Renewable Portfolio Standard (RPS) places an obligation on electric supply companies to produce a specified fraction of their electricity from renewable energy sources and enumerates mechanisms that are permitted to achieve compliance, such as renewable energy credits (RECs). Currently no federal RPS legislation has been enacted. A total of 29 states and the District of Columbia have an RPS. The states include Arizona, California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Indiana, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, Texas, Washington and Wisconsin [22].

This indicator includes all the financial advantages that a power plant can have. Incentives are measured in form of percentage of the cost depending and the rating is considered according to Table III, for all stages of the life cycle. We propose this table based on Darajat III geothermal power plant where incentives reduced the life cycle cost of geothermal energy by 2 to 4 % [23].

C. *Social indicators*

Affordable electricity bills pave the way to increased access to electricity-based services. The "polluter pays" principle is solid and fair when assigning environmental responsibilities. In power generation systems, the final electricity users should be liable for the full costs and risks inherent to particular technologies and plants. Power plants are acceptable only when free of major hazards. Core changes for sustainable development include the exploitation of other natural resources with new technologies and investments that meet the needs of developing countries [11].

Compared to other technologies, odor, noise, pollution and visual impacts is very low for geothermal plants [14].

1) *Employment generation (S1 and S2)*

The successful realization of geothermal projects often depends on the level of acceptance by local people. Prevention or minimization of detrimental impacts on the environment, and on land occupiers, as well as the creation of benefits for local communities, is indispensable to obtain social acceptance. Public education and awareness of the probability and severity of detrimental impacts are also important. The necessary prerequisites to secure agreement of local people are: prevention of adverse effects on people's health, minimization of environmental impacts, and creation of direct and ongoing benefits for the resident communities [24]. Geothermal development creates local job opportunities during the exploration, drilling and construction period (typically four years minimum for a greenfield project). It also creates permanent and full-time jobs when the power plant starts to operate since the geothermal field from which the fluids are extracted must be operated locally [25]. This can alleviate rural poverty in developing countries, particularly in Asia, Central and South America, and Africa, where geothermal resources are often located in remote mountainous areas. Some geothermal companies and government agencies have approached social issues by improving local security, building roads, schools, medical facilities and other community assets, which may be funded by contributions from profits obtained from operating the power plant [26].

Based on [24-26] this indicator considers the direct and indirect employment generated per year. The units of measurement are workers per MW of installed power and rated is considered according to Table IV.

2) *Population displacement (S3)*

An electric power plant can be built in an uninhabited or sparsely populated area, which then grows in population, or the opposite effect may happen. Multiple land use arrangements that promote employment by integrating subsurface geothermal energy extraction with labor intensive agricultural activities are also useful. In many developing countries, geothermal energy is also an appropriate energy source for small scale distributed generation, helping accelerate development through access to energy in remote areas [4]. Measured in people displaced per MW is rated according to Table IV.

3) *Social benefits (S4)*

It measures the possibility of setting up a plant in zones far from highly industrialized areas. This helps assess the economic boost for less developed areas, decentralizing

TABLE IV
SOCIAL INDICATORS RATINGS

Ratings	Employment generation during construction, (S1) [Employees / MW]	Employment generation during operation, (S2) [Employees / MW]	Population displacement (S3), [People displaced/MW]	Social benefits (S4), [Location]
5	> 16	> 8	≤ 5	Middle of nowhere
4	16	8	10	Outside a town
3	12	6	15	Town
2	8	4	20	Outside a city
1	4	2	> 20	In a city

energy production and resulting in equality and development. This indicator also includes the benefits derived from the construction of schools, sports centers and other infrastructures financed by the electrical company. The rating is considered according to Table IV.

4) Risks (S5)

Local hazards arising from natural phenomena, such as micro earthquakes, hydrothermal steam eruptions and ground subsidence may be influenced by the operation of a geothermal. As with other (non-geothermal) deep drilling projects, pressure or temperature changes induced by stimulation, production or injection of fluids can lead to geo-mechanical stress changes and these can affect the subsequent rate of occurrence of these phenomena [27]. A geological risk assessment may help to avoid or mitigate these hazards.

Routine seismic monitoring is used as a diagnostic tool and management and protocols have been prepared to measure, monitor and manage systems proactively, as well as to inform the public of any hazards [27]. In the future, discrete-element models would be able to predict the spatial location of energy releases due to injection and withdrawal of underground fluids. During 100 years of development, although turbines have been tripped offline for short periods, no buildings or structures within a geothermal operation or local community have been significantly damaged by shallow earthquakes originating from geothermal production or injection activities.

With respect to induced seismicity, ground vibrations or noise has been a social issue associated with some EGS demonstration projects, particularly in populated areas of Europe. The process of high pressure injection of cold water into hot rock generates small seismic events. Induced seismic events have not been large enough to lead to human injury or significant property damage, but proper management of this issue will be an important step to facilitating significant expansion of future EGS projects.

TABLE V
RISKS RATING

Depth [km]	≤ 1.5	3	5	10	>10
Rating	5	4	3	2	1

Based on how deep is need to be drilled according to [28-30] the rating for risk is rated according to Table V.

IV. SUSTAINABILITY ASSESSMENT RATE

After each indicator is measured an overall sustainability assessment rate can be obtained simply as follows:

$$SAR = \frac{\sum_{i=1}^{6} E_i + \sum_{i=1}^{4} N_i + \sum_{i=1}^{5} S_i}{Total\ number\ of\ indicators} \tag{1}$$

It is important to remember that all indicators were considered to have the same weight. Therefore, (1) is simply the average of all the indicators under study.

The sustainability assessment (SAR) will serve as a reference frame for the selection of an optimal project in terms of sustainability rather than on a specific aspect.

In order to apply the sustainability assessment rate in two fictional geothermal power plants, information from scenarios 1 and 4 from Table I as well as data from [4] and [8] were used as shown in Table VI.

The sustainability assessment rate for scenario 1 is 2.73 and for the scenario 4 is 3.2; that means that the scenario 4 is a more sustainable power plant.

V. CONCLUSIONS

It is clear that geothermal electric market appears to be accelerating compared to previous years, as indicated by the increase in installed and planned power capacity. Of course its

TABLE VI
CASE OF STUY: SUSTAINABILITYY ASSESSMENT OF TWO GEOTHERMAL POWER PLANTS

CODE	**INDICATOR**	**MEASURE**	**SCENARIO 1**		**SCENARIO 4**	
			Value	**Rate**	**Value**	**Rate**
E1	Global warming	g CO_2/kWh	390	4	0	5
E2	Wasted generation	%	4	2	1	5
E3	Land use	m2 / MW	5,500	2	1,500	4
E4	Water consuption (construction)	Gal / kWh	0.005	3	0.005	3
E5	Water consuption (operation)	Gal / kWh	0.600	2	0.200	4
E6	Material consumption	Metric tons / MW	30	4	35	4
N1	Cost (construction)	USD_{2005} / MW	5,000	2	3,500	3
N2	Cost (operation)	USD_{2005} / MW-yr	175	2	125	3
N3	Capacity factor	%	85	4	65	2
N4	Incentives	%	8	4	2	1
S1	Employment generation (construction)	Employees / MW	10	3	10	3
S2	Employment generation (operation)	Employees / MW	7	4	3	2
S3	Population displacement	People / MW	16	2	25	1
S4	Social benefits		1	1	3	3
S5	Risks	Depth km	6	2	1.5	5
SAR	**Sustainability assessment rate**			**2.73**		**3.20**

exploitation is regionalized as not all the countries in the world have the geothermal resource. However, as geothermal power plants have many similarities to well-known steams power plants we decide to use it as a case study for a sustainability assessment of projects of this kind. We consider that all types of projects, such as civil structures, waste management, power plants, etc., should be designed and constructed following a sustainability assessment study as it will provide an optimal structure regarding sustainability.

In this investigation, extensive reviews were made to define indicators and develop ratings for the most representative environmental, economic and social aspects of a geothermal power plant.

Regarding the environmental indicators, the global warming is the most representative aspect to considerer when evaluating renewable technologies; also, wasted generation was used as a kind of efficiency indicator considering that the nonrenewable energy used for the plant construction and operation affects the environment. Finally the land, material and water used were considered as they could have being used for other purposes in this populated world.

Regarding the economic indicators, the cost of the construction stage is the main barrier for renewable energies power plants. The capacity factor was considered even though it depends on the specific project, and the incentives play an important role in the world scene. Finally, the social indicators were the hardest to fine and define. They consider the jobs created, social benefits, risks and a possible population displacement during the entire life cycle of the plant.

We present a sustainability assessment (SAR) case study that will serve as reference for the optimal selection of projects in terms of sustainability rather than economical or environmental aspects by themselves.

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