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SYSTEM OF EVALUATION OF THE ENVIRONMENTAL COSTS OF THE THERMAL GENERATION IN PERU

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Abstract—**It is necessary to analyze the advantages and disadvantages of the use of electricity generation with renewable energy resources and fossil fuels, that is, the environmental costs derived from greenhouse gas emissions emitted by thermal generation in Peru. Since when environmental, social and economic costs generated by thermal power plants begin to be quantified, we realize that damage to health and the environment is caused.**

In this context, a system for evaluating the environmental costs of thermal generation in Peru is necessary, whose result must be an integral part for the calculation of the variable costs of thermoelectric generation units allowing the internalization of environmental costs, mainly those associated with greenhouse gas emissions, which will make it possible to reorder the generation dispatch ranking of the thermoelectric generation units of the National Interconnected Electric System prepared by COES; for which, as an example of the study, the proposed evaluation system for thermal power plants using Camisea natural gas is applied.

In this way, the most polluting units will be displaced to lower places in the dispatch ranking, and if they are called in the dispatch, it will not be due to an economic dispatch but rather an emergency, thus contributing to reducing the damage to the environment.

Keywords- costos environmental costs, thermal power plants, atmospheric emissions, externalities and greenhouse gases

I. INTRODUCTION

The government, through Legislative Decree No. 1002-2008, promulgates the Investment Promotion Law for the Generation of Electricity with the use of Renewable Energies, published on May 2, 2008. By means of which it is declared of national interest and public need the development of new electricity generation through the use of renewable energy resources (RER), encouraging the promotion of investment and electricity generation from RER, to improve the quality of life of the population and protect the environment [1].

The third international auction for the supply of electricity to the National Interconnected Electric System (SEIN) with RER, carried out by the Supervisory Agency for Investment in Energy and Mining (OSINERGMIN), only considered RER generation projects with biomass and hydroelectric; leaving aside the participation of wind and solar generation projects.

This has led investors of RER generation projects, especially wind and solar, to question the cost of production of electricity generation plants with conventional resources, that is, fossil fuels and the pollution to the environment that these plants produce; The problem arises if the production costs of a thermal power plant is equal to or greater than the production cost of a generation plant with RER, if the environmental costs associated with greenhouse gas emissions are added to the former; emissions that generation plants with RER do not emit in electricity generation.

The System Economic Operation Committee (COES) is the entity in charge of preparing the programs for the short-term operation of the SEIN generation units, considering their efficient management for the best use of energy resources, as well as guaranteeing the operation SEIN economic.

On the other hand, the study prepared by the Glaciares Project, of the Swiss cooperation, revealed that by the year 2050 the deglaciation of the Cordillera Blanca, in Ancash, will generate economic losses of between 300 and 700 million dollars annually. It points out that the main cause of the accelerated deglaciation of the mountain ranges is the increase in global temperature, that said increase in temperature that we live today is mainly caused by humans, by CO2 emissions from vehicles, industries , thermal power plants and others [2].

For this reason, there is an urgent need to develop a system for evaluating environmental costs, specifically those associated with greenhouse gas (GHG) emissions from thermal power plants; Since the country does not have sufficient experience to determine these costs, the experience of other countries will be used.s

II. MATERIALS AND METHODS

1. REGULATORY FRAMEWORK

Peru has a vast environmental legal framework headed by the 1993 Constitution. The objective of the current environmental legislation is to ensure that any electricity generation activity is carried out in conditions that do not cause negative impacts on populations or ecosystems, nor that the established limits are exceeded, all in compliance with Law No. 28611 General Environmental Law; Law No. 27446 Law of the National System of Environmental Impact Assessment; Legislative Decree No. 757 Framework Law for the Growth of Private Investment, Decree Law No. 25844 the Electricity Concessions Law, Technical Guides of the Sector and other legal provisions, in marked in the concept of Sustainable Development.

A. Principle of Sustainable Development

This concept arises as a result of international concern about the use of limited natural resources, in the face of growing economic activity; and the serious and even irreversible environmental problems to which its indiscriminate use can lead.

As a result of the work of the United Nations World Commission on Environment and Development, created in the United Nations Assembly in 1983. This definition would be assumed in Principle 3 of the 1992 Rio Declaration, which states: The right to development must be exercised in a way that equitably responds to the development and environmental needs of present and future generations.

The objective of sustainable development is to define viable projects and reconcile the economic, social, and environmental aspects of human activities; three pillars that must be taken into account by communities, both companies and individuals.

B. Study of Environmental Impact in the Electricity Sector

The Supreme Decree No. 014-2019-EM, Regulation of Environmental Protection in Electric Activities, aims to promote and regulate the environmental management of the activities of generation, transmission and distribution of electricity, in order to prevent, minimize, rehabilitate and / or compensate the negative environmental impacts derived from such activities, within a framework of sustainable development [3].

A Competent Environmental Authority is established as the public entity in charge of the evaluation and, if applicable, the approval of Environmental Studies related to electrical activities.

Being some of the provisions for the preparation of the Environmental Study for electrical activities:

- Prepared on the basis of the project at the feasibility level
- Analysis of environmental impacts must respond to these characteristics and the type of environment where the project is to be developed.

- The main actions related to the gathering of information in the field must be identified.

- For the development of the electrical project design and the determination of the Baseline, the analysis of alternatives must be considered.

- The identification, characterization and assessment of the level of significance of the environmental impacts must be carried out on the main and auxiliary components of the investment project in an indivisible way in all its phases.

- The Baseline, identification and evaluation of the impacts, as well as the environmental management strategy, must be prepared by an Environmental Consultant registered in the National Registry of Environmental Consultants.

C. Maximum Permissible Limits in the Electricity Sector

MINEM has a project for the Approval of Maximum Permissible Limits (LMP) of Thermoelectric Generation Activities, which would be applicable to thermoelectric generation units whose installed power exceeds 500 kW.

D. National GHG Inventory:Infocarbon

In order to comply with the international commitments assumed by the Peruvian State, as well as to assist in the formulation of public policies on climate change, on December 19, 2014 Supreme Decree No. 013-2014-MINAM was published through which the preparation of the National Inventory of Greenhouse Gases (INFOCARBONO) was approved, in order to establish provisions for the preparation of INFOCARBON [4].

INFOCARBONO is established as a set of actions aimed at the compilation, evaluation and systematization of information related to the emission and removal of GHG. With this, the responsibility of the competent government sectors is assigned to collect relevant information and carry out periodic reports on GHG of the activities of their competence. MINAM is the entity that manages and conducts the INFOCARBONO, which will receive and review the reports of the sectoral GHG inventories to prepare the national inventory.

2. EXTERNALITIES IN THE ENERGY SECTOR

Externalities, that is, external costs or benefits, is defined as a side effect not valued and not compensated for by the operation of thermal power plants that directly affect other power plants [5].

Market failures or externalities occur when certain environmental costs of production are not reflected in the market cost of basic products, in this case, energy.

The determination of the environmental costs of thermoelectric generation units has increased its importance worldwide; since generation plants with RER have environmental advantages compared to generation plants that use fossil fuels; contributing to the reduction of GHG emissions.

However, these advantages have not been considered in the calculation of the variable costs of the thermal generation units for the dispatch of the power plants in the SEIN.

The magnitude of the unrecognized externalities in favor of generation plants with RER is a matter of debate; which brings with it another dispute about how to implement the necessary measures for the internalization of environmental costs.

Even in the energy planning models, the objective function is to minimize the economic cost of the entire system during planning, including fuel costs, environmental costs, among others; contributing to the formulation of economic and energy policies for the country [6].

In addition, having a system for evaluating the costs of the thermal generation units for the dispatch of the power plants in the SEIN, would allow evaluating the impact of electric vehicles on the electricity business [7].

3. SYSTEM OF EVALUATION OF ENVIRONMENTAL COSTS

The evaluation system presented aims to assess the environmental costs associated with the generation of electricity. Seeking to quantify the externalities of electricity, incorporating the external costs of greenhouse gases, that is, environmental costs to the cost of electricity production [8].

The generation of electricity leads to other types of externalities, as in public health, in the environment. Then, the economic valuation of environmental costs can be considered as the estimated cost of pollution for society that are not accounted for in the market price of the thermal power plants that produced the pollution [9].

The evaluation system is subdivided into five phases, in the first the thermal power plant is identified. In the second phase the generation of electricity for a period is determined, in the third phase the GHG emissions of the thermal power plant are determined, then in the fourth phase the economic valuation of the GHG emissions is carried out and finally in the fifth phase the environmental cost derived from the effects of climate change attributable to GHG emissions from the thermal power plant is valued.

A. Phase 1: Identification of the Thermal Power Plant

It consists of characterizing the thermal power plant, such as its location, the type of technology, type of fuel, installed power, among others.

B. Phase 2: Determination of Electricity Generation

It consists of calculating the total electricity generation of the thermal power plant according to the type of fossil fuel used during a year, using the equation (1).

$$Energy_{ct} = Capacity \text{ X hours of operation} \quad (1)$$

Where:
$Energy_{ct}$: Annual produced energy [MWh/year]
Capacity: Thermal power plant capacity [MW]
Hours of operation: Hours of operation of the plant [hours/year]

In the case of plants for which there are no historical data, due to the commercial operation of the thermal plant or repowering, the operation of said plant will be estimated.

C. Phase 3: Determination of GHG Emissions

Determine the GHG emissions per ton derived from each thermal power plant according to its electricity production by type of fossil fuel used during a year, using equation (2).

$$E_{gei} = Energy_{ct} \text{ x Fe} \quad (2)$$

Where:
E_{gei}: Estimated GHG Emissions [tn CO_2/year]
$Energy_{ct}$: Annual produced energy [MWh/year]
Fe: Emission factor of each fuel [kg CO_2/TJ]

In the case of plants for which there are no historical data, due to the commercial operation of the thermal plant or repowering, the GHG emissions associated with its generation will be estimated.

D. Phase 4: Economic Valuation of Emissions

The economic value of the GHG emissions of the thermal power plant must be determined, according to a reference value of the price of the ton of CO2.

The reference value is taken from the one-year historical series of the monthly average price of the European Carbon Dioxide Emission Rights Exchange (EUAs) and Carbon Credits (CERs). This series of euros is converted to Soles per ton, using the exchange rate of the last day of the month published by the Superintendency of Banking and Insurance; then the average of the resulting series is calculated in Soles per ton.

Finally, the economic value of the CO2 emissions in a year of the thermal power plant is the result of multiplying the GHG emissions by the price of the reference obtained.

$$VE_{ct} = E_{gei} \text{ x } P_{bolsa} \quad (3)$$

Where:
VE_{ct}: Economic value of emissions per plant thermal [S//year]

E_{gei}: Estimated GHG emissions [tn CO_2/year]
P_{bolsa}: Price of emissions [S//tnCO_2]

E. Phase 5: Assessment of the Environmental Cost

The unit monetary value of the environmental cost associated with the generation of electricity from a thermal power plant, results from the quotient of the economic value of the emissions between the energy generated per year from the thermal power plant.

$$CA_{ct} = (VE_{ct}) \div (Energy_{ct}) \quad (4)$$

Where:
CA_{ct}: Environmental cost [S//MWh]
VE_{ct}: Economic value of emissions per plant
thermal [S//año]
$Energía_{ct}$: Annual produced energy [MWh/year]

This environmental cost should be included in the variable costs of the thermal power plant to incorporate this externality in the comparisons between technologies in the short-term operation program of the SEIN generation units.

4. ANALYSIS OF THE ENVIRONMENTAL COST EVALUATION SYSTEM

The proposed evaluation system is applied to all thermal power plants; for the purposes of the study, the combined cycle power plants that use natural gas from Camisea have been chosen.

a. Phase 1: Identification of the Thermal Power Plant

There are three combined cycle thermal power plants located in the Chilca district, Cañete province, Lima department. Chilca 1 with four generation units, has an installed power of 851.80 MW, Kallpa has three generation units with an installed power of 979.00 MW and Fénix with two generation units that has an installed power of 575.00 MW.

b. Phase 2: Determination of Electricity Generation

The information on the energy produced in the year was obtained directly from the COES Operation Statistics 2018. The energy produced by the combined cycle thermal power plant is shown in table No. I.

TABLE I. ENERGY PRODUCED

Thermal power plant	**Produced energy [MWh/year]**
Chilca 1	3 403 600.00
Kallpa	3 974 300.00
Fénix	3 913 500.00

c. Phase 3: Determination of GHG Emissions

Once the type of fossil fuel used by the thermal power plant has been identified, it is necessary to estimate the associated GHG emissions. Table N ° II shows the emission factors by type of fuel [10].

TABLE II. EMISSION FACTOR BY TYPE OF FUEL

Fuel type	**Emission Factor [kg CO_2/TJ]**
Carbón	94 600
Diesel	74 100
Gas natural	56 100

Now, to estimate the GHG emissions associated with the thermal power plant, the natural gas emission factor from the previous table was used; the GHG emissions determined are shown in table N ° III.

TABLE III. EMISSIONS ASSOCIATED WITH THE THERMAL PLANT

Thermal power plant	**Produced energy [TJ/year]**	**Emission Factor [kg CO_2/TJ]**	**Emissions [tn CO2/año]**
Chilca 1	12 252.96	56 100	687 391.06
Kallpa	14 307.48	56 100	802 649.63
Fénix	14 088.60	56 100	790 370.46

d. Phase 4: Economic valuation of emissions

To determine the reference value of the ton of CO2, the monthly average prices of 2018 were taken from the European Carbon Dioxide Emission Rights Exchange (EUAs) and Carbon Credits (CERs). Since these prices are in Euros, it is converted to Soles using the exchange rate published by the Superintendency of Banking and Insurance, to obtain the price per ton in Soles. Table N ° IV shows the data used.

TABLA IV. HISTORICAL PRICES OF EMISSIONS

Date	Historical price [€/tn CO_2]	Exchange rate	Historical Price [S/./tn CO_2]
Jan-18	8.34	4.088	34.08
Feb-18	9.48	4.083	38.70
Mar-18	11.54	4.062	46.86
Apr-18	13.35	4.156	55.50
May-18	14.78	3.978	58.78
Jun-18	15.16	3.930	59.56
Jul-18	16.35	3.946	64.52
Aug-18	18.88	3.938	74.35
Sep-18	21.43	3.950	84.63
Oct-18	19.56	3.909	76.47
Nov-18	19.22	3.997	76.83
Dec-18	22.57	4.150	93.66
Average	**15.89**	**4.016**	**63.66**

The 2018 average price of the monthly historical series is 63.66 S // tn CO2. Finally, the economic value of the CO2 emissions in a year of the chosen thermal power plants is the result of the product of the emissions and the price of the ton of CO2, which is shown in table No. V.

TABLE V. ECONOMIC VALUE OF EMISSIONS

Thermal power plant	Emissions [tn CO_2/year]	Historical Price [S//tn CO_2]	Economic value [S//year]
Chilca 1	687 391.06	63.66	43 759 848.24
Kallpa	802 649.63	63.66	51 097 298.41
Fénix	790 370.46	63.66	50 315 597.04

e. Phase 5: Environmental Cost Assessment

The last phase of the evaluation system deals with the unit value of the environmental cost due to CO2 emissions; which is performed as the quotient between the annual economic value of emissions and the energy produced annually, the result of which is shown in table No. VI.

TABLE VI. ENVIRONMENTAL COST VALUATION

Thermal power plant	Economic value [S//year]	Produced energy [MWh/year]	Environmental Cost [S//MWh]
Chilca 1	43 759 848.24	3 403 600.00	12.86
Kallpa	51 097 298.41	3 974 300.00	12.86
Fénix	50 315 597.04	3 913 500.00	12.86

Table N ° VII shows the increase in the variable cost of the thermal power plant due to the inclusion of the environmental cost.

TABLE VII. VARIABLE COST INCREASE

Thermal power plant	Variable cost [S//MWh]	Environmental Cost [S//MWh]	Increase [%]
Chilca 1	27.95	12.86	46.01
Kallpa	29.74	12.86	43.24
Fénix	13.18	12.86	97.57

III. CONCLUSIONS

The external costs of greenhouse gases are externalities that need to be internalized in the variable cost of thermal power plants, to reorder the SEIN generation dispatch ranking, thus allowing greater electricity production with RER.

The proposed environmental cost evaluation system shows an objective and practical way of valuing externalities, quantifying CO2 emissions only during the operation of thermal power plants, providing policy makers with another perspective on the structure of the energy matrix..

The incorporation of environmental costs, the CO2 emissions associated with the generation park could be viewed in real time on the COES website, highlighting which are the sources responsible for said emissions; in this way to raise awareness of the relationship between CO2 emissions and electricity consumption, as well as the importance of achieving a more balanced consumption throughout the day.

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