USING *ECOLOGICAL FOOTPRINT* AS SUSTAINABLE DEVELOPMENT INDICATOR IN SCOPE TO EVALUATE A THERMO POWER PLANT'S ENVIRONMENTAL PERFORMANCE

Mădălina Silvia IGNATOV[1], Valeriu Nicolae PANAITESCU[2]

Implementarea Directivelor de mediu în cadrul unităţilor producătoare de energie din România, impune echilibrarea relaţiei dintre dezvoltarea industrială şi capacitatea productivă şi de suport a capitalului natural care o susţine, în vederea reducerii impactului de mediu asociat. Indicatorul cel mai concludent în evaluarea durabilităţii unui producător de energie este Ecological Footprint propus în 1992 de către Rees şi Wackernagel pentru sisteme socio-economice de scară macroregională. Autorii prezentei lucrări au dezvoltat un indicator complex fundamentat pe Ecological Footprint, prin introducerea unui număr considerabil de variabile, în scopul creşterii nivelului de încredere a estimărilor la scara mică (nivel regional).

Regarding the Environmental Directives' process as applied into Romanian industrial area, one must balance the relationship between the local industrial development and the carrying and productive capacity of the nearest natural capital, with the purpose of reducing the environmental impact. The most important sustainability indicator for power plant activity is the Ecological Footprint, initially developed in 1992 by Rees and Wackernagel at macro-regional level (national and European level). The authors of this paper developed a complex indicator, in order to estimate the associated Ecological Footprint of every producing unit, at a landscape level.

Keywords: sustainable development, ecological footprint, needed carrying capacity, productive area required, available carrying capacity, ecological deficit.

1. Introduction

After the release of the Brundtland Report (1987 WCED) followed by the design, development and implementation of sustainable development policies, it was necessary to develop indicators that are able to show the ¨measure¨ of economy/industry sustainability, including the thermo power plants [1].

The first sustainability indicator was designed in 1989 [2, 3] with important difficulties in achieving scale temporal-spatial forecasting and integration of multiple variables (size covering economic, environmental, technological and social).

[1] PhD. Eng., Hydraulics, Hydraulic Machines and Environmental Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: ignatov.madalina@rdslink.ro

[2] Prof., Hydraulics, Hydraulic Machines and Environmental Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: valp@hydrop.upb.ro

Most of these indicators - profit development stakeholders, respiratory disease statistics, water quality etc. - independently assess changes induced by the economic system (in particular the power plants) natural capital by proximity, not based on a holistic approach to environmental-economic relationship.

The main categories of indicators of sustainable development designed and tested in the period 1992-2001 can be grouped as [4]:

– indicators that assess the impact of economic activities on the environment (air quality, waste products, water quality etc.);

– impact indicators that assess evaluation of local population growth on natural capital (fragmentation of natural ecosystems, the rate of exploitation of natural resources etc.);– indicators that assess changes on the health of local population due to natural deterioration of the capital components;

– indicators that assess the monetary effects of damage components of natural capital (cost of ecological restoration of areas impacted, the rate of extinction of species etc.).

All the categories of "sustainability indicators" described above are characterized by a required limited approach to the relationship between industry and natural capital. The concept of *Ecological Footprint* set forth in 1989 by Wackernagel [5] and further developed in a comprehensive program of applied research at the landscape (circumscribed natural capital of Bacău Thermo Power Plant - TPP) by research team members who are also authors of this article [6], provides an important starting point in determination of the size and structural composition of natural capital (natural or half-natural ecological systems) which provides:

– processing product of the combustion process needed to produce electricity inside Bacău Thermo Power Plant;

– dilution of pollutants emitted into the atmosphere or discharged to surface aquatic ecosystems (river Bistrița, Bacău reservoirs I and II) and tailings storage support;

– Bacău Power Thermo Plant – support infrastructure.

The work of the research team focused on the following areas:

– foundation concepts necessary to assess the *Ecological Footprint* (*EF*) associated with Bacău Power Thermo Plant;

– characterization of the economic context in which the assessment of ecological foundation, in order to choose the most viable scenario for further development work on the Bacău Power Thermo Plant;

– compilation of a comprehensive database allowing subsequent generation of reports required by Bacău Environmental Agency and environmental audit reports;

– Bacău Thermo Power Plant associated *EF* assessment;

– development of a "best practice guide" for creating and improving a system of decision assistance support (SSAD) in Bacău Thermo Power Plant to reduce environmental externalities associated activity and compliance with mandatory legal requirements for obtaining and maintaining the integrated environment.

2. Conceptual frame

Bacău Thermo Power Plant began operation in 2005 after obtaining the integrated license of functioning from Bacău Environmental Agency.

Following critical review of the literature it could not be identified any environmental performance indicator that is able to express the "measure" of the power plant's sustainability. Under these conditions, the authors of this paper have developed a composite indicator (based on applied research initiated by Rees and Wackernagel in 1992) and The Systemic Ecology principles. According to these principles the environment is perceived as a hierarchy of ecological systems and humans, interrelated and subject to the law of entropy - (Figure 1).

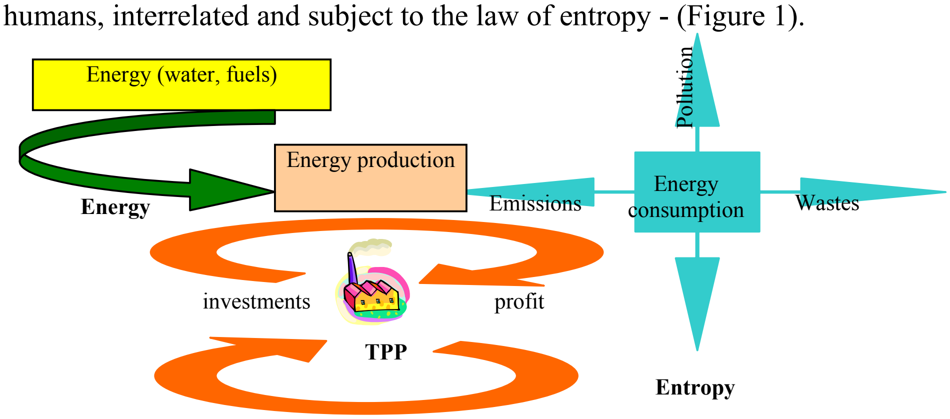

Fig. 1. Hierarchical organization of human systems (Bacău Thermo Power Plant - TPP)

Community environment policy aims to promote sustainable development principles in the economic development of Member States and its integration into national policies (including energy efficiency policy). This translates into the implementation of preventive actions, the principle of "polluter pays" by fighting environmental damage at source, and the internalization of environmental externalities.

A mean of quantifying the sustainable development of an energy producer must be associated with its ability to meet the standards and environmental directives.

These directives were ratified by Romania (Directive no. 96/61/EC on Integrated Pollution Prevention and Control, Directive no. 99/30/EC on limit values established for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air, Directive no. 99/296/EEC) on the monitoring mechanism of Community CO_2 and other greenhouse emissions, etc.).

Formulation and validation in practice need a viable indicator of sustainable development. This derives from the need to understand the functioning of ecological systems at landscape (man-made network systems - Bacău Thermo Power Plant regime in natural ecosystems - protected areas and ecosystems that are under half-natural - crops, artificial aquatic ecosystems, forest ecosystems). Also, with regard to the policy of regional socio-economic development and business strategy management, Bacău Thermo Power Plant really needs medium and long term predictions for the optimal efficiency scenario and establishes its own fair price of energy by internalising environmental externalities. Experimentally, this price is set at 3 cents for a MWh [7].

After trying to develop, adapt and test different indicators of sustainable development described so far in the literature, the authors concluded that none of them can address the need for permanent monitoring of the dynamics of relationship energy producer - natural capital. This relationship is necessary/indispensable (in order) to identify the actual position of a central electric heating model of sustainable development path.

The *Ecological Footprint* (*EF*) is only able to assess "the extent of sustainability" of an energy producing unit in relation to environmental changes induced by the operation. Thus, the *Ecological Footprint* is defined as the area of natural ecosystems and/or aquatic and terrestrial resources needed for the production involved in producing electricity and heat energy, but, at the same time, ensuring both assimilation/dilution of emitted pollutants and waste resulting from administrative processes and related combustion activities of Bacău Power Plant.

Rees and Wackarnagel initially tried to estimate surface of natural capital for supporting sustainable development of the national socio-economic system, without the need for imports of raw materials and energy. One can see this indicator has been designed for use only at the macro scale in order to estimate the character of "independence" of a state economy and production, exclusively based on natural resources. In this form, the *Ecological Footprint* is an indicator characterized by a high degree of generality, which cannot be used to demonstrate the environmental performance of a single production unit.

In a multidisciplinary research team, the authors of this paper have contributed to improv the performance indicator and correlation of the *Ecological Footprint* by introducing a number of new variables in order to increase the confidence levels of estimates at a small-scale (landscape level). This facilitates the use of this indicator for sustainable development and environmental performance evaluation of energy related activities of a power producer such as Bacău Thermo Power Plant.

3. The methodology for calculating *Ecological Footprint, EF*

To calculate the *Ecological Footprint* for Bacău *Thermo* Power Plant, the authors of this paper propose to estimate the *Necessary Productive Area* (*NPA*) energy producer support activities.

As a measure to prevent air pollution from large combustion plants (Directive no. 88/609/EEC), the productive area required to support Bacău Power Plant's activity is necessary to be included in an optimum level of environmental externalities, including:

– surface kinetic energy necessary to transform solar energy potential: crops, forests, protected areas, water surface (lakes Bacău I and II); – *building area;*

– surface absorption of pollutants resulting from the work needed at Bacău Power Plant.

For the *Necessary Productive Area* estimation the following formula is proposed

$$NPA_j = \sum_{i=1}^{n} \frac{Q_{ij}}{\overline{\overline{Z_{ij}^v}}} + \frac{I_{ij}}{\overline{\overline{Y_{ij}^v}}} - \frac{E_{ij} + \Delta S_{ij}}{\overline{\overline{X_{ij}^v}}} \quad (1)$$

NPA_j = the Necessary Productive Area [ha],

Q_{ij} = the internal yield [kg/ha], I_{ij} = import [kg/ha], E_{ij} = export [kg/ha],

$\overline{Y^c}$ = the global medium efficiency in the reference year [%],

$\overline{Y^v}$ = the global medium efficiency in the present (current) year [%],

$\overline{Z^v}$ = the national medium efficiency in the present (current) year [%],

$\overline{X^v}$ = the medium moderate efficiency in the present (current) year, calculated taking in account $\overline{Y^v}$ and $\overline{Z^v}$ [%],

ΔS = the stock difference between the end of the last year and the start of the current year [kg/ha]; i = the product, j = year.

Using the *EF* (Environmental Footprint) indicator to evaluate the relationship between the available natural capital and Bacău Power Plant sustainable development, two parameters must be estimated:

a) *Necessary Productive Area* (*NPA*) for the absorption of pollutants emitted into the atmosphere or discharged to surface water by Bacău Power Plant and

b) *Available Productive Area* (*APA*).

Regarding the estimation of *Available Productive Area* (*APA*) the following relationship is proposed:

$$APA_j = \sum_{k=1}^{n} (1-\omega) S_{kj}, \quad (2)$$

where: ω - weight area for biodiversity conservation,

S – land surface [ha], k – land type.

In order to be profitable, an energy production unit should be able to demonstrate its economic efficiency and to fit within optimal environmental externalities, so that the *APA* value would approximately be equal to the *NPA*. If The *NPA* value is greater than the *APA* (i.e. the value of ecological deficit increases), the unit is less efficient (including in terms of capacity to implement environmental provisions of the European Directives), evolving to progressive degradation of adjacent natural capital, the environmental externalities increasing exponentially with the cumulative effect of emitted pollutants.

Ecological Deficit (*ED*) is expressed by the difference between *Necessary Productive Area* (*NPA*) and *Available Productive Area* (*APA*), according to relation

$$ED = NPA - APA \tag{3}$$

4. ***Ecological Footprint*** advantages in assessing the trajectory of Bacău Thermo Power Plant to the sustainable development model

Regarding the calculation of *EF* indicator proposed by the authors of this paper a number of advantages could be identified, such as:

– calculation algorithm is easy to understand, based on practical approach;

– series is based on data from the statistical information database and results from research and monitoring (the most easily accessible);

– expressed in physical units, avoids the distortions induced by the price system;

– allows comparison with the available productive area and, being determined in this way, with the degree to overcome the local absorption basin (*Ecological Deficit*);

– ensures compatibility with other industrial units having similar technologies, in terms of natural capital relationship - industrial manufacturer. This facilitates standardization of best practice guide for other power plants.

5. ***EF*** and ***Ecological Deficit*** estimate for Bacău Power Plant

By entering in formulas (1) and (2) the data on production of the natural ecosystems that are adjacent to Bacău Power Plant (agro systems and forests), the following *Necessary Productive Areas* may be estimated

$$NPA_{corn\ 2010} = \sum_{i=1}^{n} \frac{Q_{ij}}{\overline{Z_{ij}^{v}}} + \frac{I_{ij}}{\overline{Y_{ij}^{v}}} - \frac{E_{ij}+\Delta S_{ij}}{\overline{X_{ij}^{v}}} = 654{,}441.12 \text{ ha}, \tag{4}$$

$$NPA_{wheat2010} = \sum_{i=1}^{n} \frac{Q_{ij}}{\overline{Z_{ij}^{v}}} + \frac{I_{ij}}{\overline{Y_{ij}^{v}}} - \frac{E_{ij}+\Delta S_{ij}}{\overline{X_{ij}^{v}}} = 2{,}432{,}063.44 \text{ ha}, \tag{5}$$

$$NPA_{sun\,flower\ 2010} = \sum_{i=1}^{n} \frac{Q_{ij}}{\overline{Z_{ij}^{v}}} + \frac{I_{ij}}{\overline{Y_{ij}^{v}}} - \frac{E_{ij}+\Delta S_{ij}}{\overline{X_{ij}^{v}}} = 15{,}966{,}255.20 \text{ ha}, \tag{6}$$

$$NPA_{wood\ 2010} = \sum_{i=1}^{n} \frac{Q_{ij}}{\overline{Z_{ij}^{v}}} + \frac{I_{ij}}{\overline{Y_{ij}^{v}}} - \frac{E_{ij}+\Delta S_{ij}}{\overline{X_{ij}^{v}}} = 2{,}266 \text{ ha}. \tag{7}$$

Summing the above values (associated with the different categories of productive areas) which were estimated for year 2010, one can calculate the *Ecological Footprint* indicator for Bacău Thermo Power Plant, expressed through the *Total Necessary Productive Area* (*TNPA*) as

$$TNPA_{2010} = 19\ 055\ 025.76 \text{ ha.} \tag{8}$$

Bacău Power Plant has integrated environmental authorization emitted by Bacău Environmental Agency and it must demonstrate a continuous environmental performance. In this conditions, the *Ecological Deficit* (*ED*) must tends towards zero. To calculate the *Ecological Deficit* (*ED*) is necessary to estimate the *Available Productive Area (APA)*, such

$$APA_{wood\,2010} = \sum_{K=1}^{n} (1-\omega) S_{kj} = 3{,}633.083 \text{ ha,} \tag{9}$$

$$APA_{protected\ areas2010} = \sum_{K=1}^{n} (1-\omega) S_{kj} = 12{,}687{,}499.74 \text{ ha,} \tag{10}$$

$$APA_{water\ bodies2010} = \sum_{K=1}^{n} (1-\omega) S_{kj} = 10\ 400 \text{ ha, .} \tag{11}$$

Summing the values estimated within relations (9), (10) and (11) one could be estimate the *Total Available Productive Area* (*TAPA*) around Bacău Thermo Power Plant, which amounts to

$$TAPA_{2010} = 12{,}701{,}775.87 \text{ ha.} \tag{12}$$

The *Ecological Deficit* is calculated with equation (3) by deducting the *Total Available Productive Area* from the *Total Necessary Productive Area,* as the value

$$ED = TNPA - TAPA = 6{,}353{,}249.89 \text{ ha.} \tag{13}$$

The *ED* value resulted from the relation (13) represents the natural and half-natural ecosystems (forest plantations, crops, aquatic ecosystems, wetlands) necessary for ensuring the capture and dilution of the entire quantity of pollutants and waste resulted form Bacău Power Plant's activity.

The estimated *Ecological Deficit* (*ED*) is then correlated with the dynamics of the health situation of local people (especially the dynamics of the respiratory diseases) [8] and introduced as parameters into ECOENERG v.0.

ECOENERG v.0 is a new software for environmental impact modelling proposed by the first author of this paper, as a result of her Ph.D. thesis, in order to identify the best management solutions for Bacău Thermo Power Plant sustainable development. With the help of this software, the decisison makers will be able to maintain the profitability of Bacău Thermo Power Plant with minimum damages on the environment [9].

The three packages of proposed solutions for reducing the value of *Ecological Deficit* estimated for Bacău Power Plant are referring to:

a. increase the *Available Productive Area* adjacent land cultivation, development of wetlands associated Bistrița River (along the impact zone generated by Bacău Thermo Power Plant) and Bacău reservoirs I and II;

b. development of a forest belt to take the emissions of greenhouse gases;

c. provide the necessary fuel combustion processes exclusively from domestic sources (Romania);

d. upgrade (to reduce volume and emissions of pollutants into the atmosphere) by purchasing and commissioning of a waste flue gas desulphurisation equipment.

6. Conclusions

The author's contribution to the development of the *Ecological Footprint* indicator ensures its adaptability to Romanian thermo power plants at the landscape level.

Assessment of the *Ecological Deficit* not only in land surfaces [ha], but also in its value in Euro helps the environmental managers to estimate the environmental externalities generated by Bacău Thermo Power Plant. By using the *Ecological Footprint* as a sustainable development indicator, the decision makers can identify and implement the best management strategies to make Bacău Thermo Power Plant capable of self-sustaining in a sustainable development way and to save it from insolvency and closure.

R E F E R E N C E S

[1] *P. Christensen*, Driving forces, increasing returns, and ecological sustainability in R. Costanza, (Ed.). Ecological economics: The science and management of sustainability*,* New York: Columbia University Press. 1991. pp: 362-390.

[2] *W. Rees & M. Wackernagel*, Ecological footprints and appropriated carrying capacity: Measuring the natural capital requirements of the human economy. In A-M. Jansson, M. Hammer, C. Folke, and R. Costanza (Eds.). Investing in natural capital: The ecological economics approach to sustainability. Washington: Island Press. 1994. pp: 255-257

[3] *W. Rees*, Ecological footprints and appropriated carrying capacity: What urban economics leaves out. Rev. Environment and Urbanization **vol. 4**. 1992. pp: 121-130

[4] *Madalina Ignatov (Botezatu) & Alejandro Lopez Lopez* (coord.), The Development and applying of some general socio-economical instruments for final users' analyse of The River Chatchment level. Universidad Complutense Madrid. Spain. 2002. pp: 3-30.

[5] *M. Wackernagel*, The ecological footprint and appropriated carrying capacity: A tool for planning toward sustainability. Unpublished PhD Thesis, University of British Columbia School of Community and Regional Planning. Vancouver: UBC/SCARP. 1994. pp: 343-361.

[6] *Madalina Ignatov (Botezatu) & Costel Negrei, (Coord.)*, Evaluation of The Romanian Socio-Economic System's Sustainability. Ed. University of Bucharest. 2002. pp: 2-49.

[7] *S.L. Boghiu, C. Stamatin-Michiu, M. Barbu, B. Achim* and *D. Theodorescu*, Internalization of The Environmental Costs in The Electricity Price at ELECTRICA's Level of Paper, *CCF International Conference Book.* 2004. pp. 4-5.

[8] *Madalina Ignatov, Valeriu Panaitescu,* EcoSense. A New Approach in Environmental Modelling, International Conference of Quality and Reliability. Sinaia. 2008. Pp: 433-438.

[9] *Madalina Ignatov,* Integrated pollution prevention and control from energy sector, in the context of accession to the European Union, *Ph.D. Thesis.* 2011. pp 187-195.