The economic and environmental integrated analysis scheme - instrument for evaluating the power generation techniques

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ABSTRACT
In the context of the current economic and financial crisis, the costs reduction has a great importance in any sector of activity. Moreover, in order to comply with the environmental requirements a significant financial effort is needed. In such situation, the integrated analysis - environmental and economic - gains increasingly more ground worldwide for developing and selecting of viable scenarios for sustainable development. Within this work, the scheme of integrated analysis - economic and environmental - will be presented. This type of analysis might be an appropriate basis for evaluating the electricity production techniques, and finally for guiding the strategies in the energy sector.

Keywords: *energy, integrated analysis, indicators, algorithm*

INTRODUCTION
Optimizing decisions on policies and measures in the field of climate change through an integrated analysis – economic and environmental - becomes more and more important as a basis for developing and selecting of viable scenarios for sustainable development.

In this context, the proposed scheme might be used as a basis for the evaluation of the electricity production techniques, and finally for the guidance of the energy sector strategies.

For this scheme, qualitative and quantitative methods will be used to define the integrated analysis algorithm, and to establishing the relevant indicators and the evaluation criteria.

The stages of elaboration of the integrated analysis scheme are the following:

- Establishment of the classes of indicators;
- The establishment of the indicators for each of the classes;
- Assigning the weights for the classes and indicators;
- Assigning of scores to each indicator, and setting ranges of values associated with each score;
- Setting the compositing algorithm;
- Setting the final result interpretation procedure.

RELEVANT INDICATORS
A first step in the development of integrated analysis - economic and environmental - scheme is the establishment of the classes of indicators and their associated indicators.

The classes of indicators which are set out are the following: economic indicators, energy indicators and environmental indicators.

In the table no. 1 are presented the relevant indicators for each class of indicators.

Table no. 1: Classes of indicators and their associated indicators

Classes of Indicators	Indicator	Unit
Energy indicators	Unitary consumption	toe/MWh
	Energy efficiency	%
	Resource availability	years
Economic indicators	Investment costs	$ / kWh
	Operation costs	$ / MWh
	Fuel costs	$ / MMBtu
	Levelised cost (L.E.C.)	$ / MWh
Environmental indicators	Emission factor CO_2	tCO_2 / toe
	Emission factor CH_4	gCH_4 / toe
	Emission factor N_2O	gN_2O / toe
	Investment cost for CCS system	$ / kWh
	Investment cost for NOx control systems	$ / kWh
	Other pollutants with risk to health and the environment - significant emissions	Atmospheric pollutants emitted

In the following, the indicators for the three classes of indicators will be presented.

Energy indicators

Specific fuel consumption for power generation

Conventional fuel consumed for the production of 1,000 kWh electric energy is the quantity of fuel in oil equivalent (10000 Kcal/kg) consumed in the reference period, reported to the electricity produced during that period.[1]

In order to ensure a unified expression of this indicator, which allows comparison of fossil fuels in this respect, the indicator will be expressed in toe/MWh.

Energy efficiency

The energy efficiency is the percentage of the amount of energy consumed by an equipment for an effective activity, which is not used as heat.

Energy efficiency can be assimilated with the yield, respectively the ratio beetwen the effective energy and energy consumption, and hence also yield will always have a subunitary value. In the ideal situation, the energy efficiency has the value 1.

Usually, the energy efficiency is expressed in percentage.

Resource availability

Resource availability of fossil fuels is an increasing problem worldwide.

The specialists are estimating that the existing oil reserves would be able to support the current level of consumption only until the year 2040. For the world's natural gas reserves there is estimated the possibility to ensure the need at the present level of consumption by the year 2070, while coal reserves could guarantee consumption for a period of over 200 years, even in conditions of increased level of consumption with respect to the current one.

The indicator “resource availability" will be expressed in number of years.

Economic indicators

[1] National Statistics Institute, (2013), *Tempo-online database*, https://statistici.insse.ro/shop/index.jsp?page=tempo3&lang=ro&ind=IND116A, accesed at 12.03.2013

Investment costs

The cost of investment is an important parameter in assessing the expediency of building a plant. Investment costs vary depending on the technique used and the complexity of the installation, but also depending on the fuel used.

In order to ensure an uniform expression of this indicator, allowing the comparison of fossil fuels in this respect, the indicator will be expressed in \$/kWh.

Operation costs

This indicator incorporates the costs of operation and maintenance of installations for the production of electricity. Operating costs vary in a relatively narrow range, depending on the technique used, the fuel used and the power of the plant.

According to the estimates made by Risto and Aija[2], the operating costs for the plants most commonly in use in Europe, to produce electricity through the burning of fossil fuels, are in the range of 7-11 \$/MWh, at the price level in 2008.

In order to ensure a uniform expression of this indicator, allowing the comparison of fossil fuels in this respect, the indicator will be expressed in \$/MWh.

Fuel costs

The cost of fossil fuels is influenced primarily by the increasing energy consumption at the global level, but also by the natural process of continuous decrease of reserves.

Another important element that has influenced the evolution on a global basis of petroleum products prices was the deficit of the refining capacities, the issue requiring the identification of solutions, both on medium and long term. To all of these issues is added the tendency of certain states to supplement their own stocks to face the crisis.

These considerations have led to a general trend of increase in the world prices.

In order to ensure a uniform expression of this indicator, which allows the fossil fuels comparison in this respect, the indicator will be expressed in \$/MMBtu.

Levelised cost (L.E.C.)

The average cost per unit of electricity over the life of the plant (Levelised cost – LEC) is used as an indicator of global competitiveness for different types of techniques. This cost represents the cost in \$/MWh, of the construction and operation of an installation, throughout its life. The input indicators used for calculating this cost are the capital costs, fuel costs, operating costs, maintenance costs and financing, and the utilization rate for each type of installation.

The average cost per unit of electricity over the life of the plant (Levelised cost - LEC) is calculated using the following formula[3]:

$$\mathrm{LEC} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

in which:

LEC – The average cost per unit of electricity over the life of the plant (Levelised cost)

I_t – Investment costs in year *t*

M_t – Operation and maintenance cost in year *t*

[2] Tarjanne Risto, Kivistö Aija, C*omparison of Electricity Generation Costs* - Lappeenranta University of Technology, 2008: http://doria17-kk.lib.helsinki.fi/bitstream/handle/10024/39685/isbn9789522145888.pdf?seque Accessed at 12.11.2012

[3] U.S. Energy Information Administration, (2013), *Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013*

F_t – Fuel costs in year *t*
E_t – Electricity generated in year *t*
r – Utilization rate
n – Lifetime of the system

Environmental indicators

Unitary emission (Emission factor) for carbon dioxide (CO_2)

In order to compare the various techniques for the production of electricity through the burning of fossil fuels in relation to the amount of CO_2 emitted into the atmosphere, the unitary emission was chosen, expressed through the emission factor.

According to the definition given by the Guidelines for the Development of National Inventories of Greenhouse Gases, developed by the Intergovernmental Panel for Climate Change (IPCC), Edition 2006[4], "the emission factor is a factor which quantifies the emission of gas, generated by the activity unit". To ensure a representative estimate of the emissions generated by a given level of activity corresponding to a set of conditions for running the installation or the analysed activity, the emission factors are established through the mediation of a large amount of data obtained by measuring.

For the combustion of fossil fuels to produce electricity, the IPPC 2006 Guidelines, provide emission factors for carbon dioxide resulting from the combustion of various fuels used in large combustion plants - the category sources code NFR 1.A.1.a - expressed in t CO_2/TJ.

In the integrated environmental and economic analysis were taken into account national emission factors for CO_2 used for the category sources code NFR 1.A.1.a, in the National Environmental Protection Agency Annual Reports to the United Nations Framework Convention on Climate Change. The unit of measure selected for this indicator is tCO_2/toe.

Unitary emission (Emission factor) for methane (CH_4)

In the process of burning fossil fuels, other greenhouse gases are emitted into the atmosphere, in addition to CO_2. Although the emitted quantities are lower, these gases can contribute significantly to the equivalent amount of CO_2 resulting from combustion, due to their global warming potential, which is higher than that of CO_2.

The 2006 IPCC Guidelines present the emission factors for other greenhouse gases resulting from the combustion of fossil fuels, namely methane (CH_4) and nitrous oxide (N_2O), in volume 2 - stationary sources section.

In the case of methane (CH_4), in order to ensure uniformity of approach with regard to emission factors in order to obtain meaningful values, the measurement unit used will be gCH_4/toe.

Unitary emission (Emission factor) for nitrous oxide (N_2O)

As in the case of the methane emission factor, in the case of the nitrous oxide (N_2O), the emission factors used, were those provided for different techniques of electricity production, by the 2006 IPCC Guidelines.

In order to ensure uniformity of approach with regard to emission factors, in order to obtain meaningful values, the measurement unit used is gN_2O/toe.

The investment costs in systems of carbon capture and storage

This indicator refers to the cost of the installation of a system of capture and storage of carbon dioxide to a new plant, or to an existing one.

[4] Intergovernamental Panel on Climate Change, *2006 IPCC Guidelines for National Greenhouse Gas Inventories – Glossary*
http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/0_Overview/V0_2_Glossary.pdf Accessed at 14.09.2012

Immobilization of carbon by capturing and storing the carbon dioxide is a developing technology, released as a solution for the limitation of CO_2 emissions released by burning fossil fuels. Proponents of the idea say that this process will stop the spreading of noxes in the athmosphere, preventing air pollution, while detractors are protesting against the risk of leakage of landfill once buried, not being convinced of the effectiveness of the technology. A number of experts in environmental protection even draw attention to the fact that development in this direction can distract atention from the search and exploitation of renewable energy sources.

The cost of installation of such plants for the capture and storage of CO_2 vary from $ 25/kWh for the coal plants, up to 110-120 $/kWh for plants that use natural gas[5].

The investment costs in low NOx control systems

The indicator refers to the cost of the installation of a combustion control system which has the effect of a drop in nitrogen oxides (NOx) in the combustion gases, and is expressed in $/kWh.

The application of combustion control system leads to the reduction of up to 50% of NOx emissions as well as, through the increase of the efficiency of the combustion process, to the increasing of the plant efficiency.

The investment costs in this type of control systems can range from 25 to 52 $/kWh in the case of gas turbines, up to 84 $/kWh in the case of plants which burn lignite[6].

Other pollutants with risk to health and the environment

In addition to greenhouse gases, in the process of fossil fuels combustion to produce electricity, an extensive range of other pollutants that affect the population health and the environment, will be emitted in the atmosphere .

The types of pollutants and in particular the quantities emitted, depend on the fuel used and the installation type.

According to the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2009[7] in the combustion proces of fossil fuels the following pollutants are emitted in significant amounts in the atmosphere :

- ***Sulphur oxides*** – mainly sulphur dioxide (SO_2) – resulted after the oxidation of the sulphur content in coal, content that can vary from 0.3% for anthracite, to 8% in lignite, with an average of 2 – 3%[8];
- ***Nitrogen oxides (NOx)*** – resulted due to the oxidation of nitrogen in the air used for combustion;
- ***Suspended particulates*** – derived mostly from the ash, but also from the solid impurities in coals;
- ***Heavy metals*** – from the quantity of sterile contained by coal;
- ***Dioxins and furans*** – chlorinated compounds with high degree of toxicity.

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[5] U.S. Energy Information Administration, (2013), *Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013*

[6] European Commission, (2006), *Reference Document on Best Available Techniques for Large Combustion Plants (BREF-BAT 2006)*

[7] EMEP/EEA Air Pollutant Emission Inventory Guidebook, (2009), *Chapter 1.A.1 Combustion in energy industries* http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009 Accessed at 14.10.2012

[8] Schiopu E. C. (2011), *Research on flue gas desulphurisation from lignite combustion using absorbent solutions of calcium hydroxide and sodium hydroxide*, “C. Brâncusi” University, Târgu Jiu, Engineering Series, No. 1/2011, http://www.utgjiu.ro/revista/ing/pdf/2011-1/20_SCHIOPU_EMIL_CATALIN.pdf Accessed at 12.01.2013

This environmental indicator was introduced in the analysis in order to prioritise the techniques for producing electricity, after the intensity of the environmental impact, produced by different types of plants, depending on the type of fuel used.

ALGORITHM

The weights for indicators

The next stage in the procedure of drawing up the integrated scheme is the granting of weights for the classes of indicators and their respective indicators.

The indicators used in the scheme of environmental and economic integrated analysis are included in the three classes of indicators.

Weights were given to the classes of indicators and respective indicators, as follows:

Table no. 2: The weights of indicators used within the integrated analysis

Classes of indicators	Weight of the class of indicators	Indicator	Weight of the indicator
Energy indicators	34 %	Unitary consumption	13 %
		Energy efficiency	17 %
		Resource availability	4 %
Economic indicators	33 %	Investment costs	6 %
		Operation costs	8 %
		Fuel costs	8 %
		Levelised cost (L.E.C.)	11 %
Environmental indicators	33 %	Emission factor CO_2	10 %
		Emission factor CH_4	2 %
		Emission factor N_2O	2 %
		Investment cost for CCS system	8 %
		Investment cost for NOx control systems	8 %
		Other pollutants with risk to health and the environment - significant emissions	3 %

By examining the table it can be noticed that equal weighting was given to each class of indicators. We have to mention the fact that the weights given to each class may vary depending on the moment in which the analysis is performed and the objectives to which the decision must be taken.

The criteria by which the weights were given to the indicators are as follows:

- Relevance of the indicator;
- Complexity of the indicator;
- Accuracy with which the technological level and the status of the installation is reflected by the indicator;
- Number of elements contained by the indicator;
- Importance of the elements analyzed by the indicator.

Scores

Under the scheme of integrated analysis, there were awarded scores of "1" to "5", "1" representing the most unfavorable, and "5" being considered the most favorable.

In the table no. 3, are presented the scores given to indicators and the intervals associated with each score.

Table no. 3: Scores awarded to the indicators within the integrated analysis

Classes of indicators	Indicator	Measurement unit	Score				
			1	2	3	4	5
Energy indicators	Unitary consumption	toe/MWh	> 0.3	0.25 - 0.3	0.2 -0.25	0.15 -0.2	< 0.15
	Energy efficiency	%	< 40	40 - 45	45 - 50	50 - 55	> 55
	Resource availability	Years	< 15	15 - 25	25 - 35	35 - 45	> 45
Economic indicators	Investment costs	$ / kWh	> 1100	1000 - 1100	900-1000	800 - 900	< 800
	Operation costs	$ / MWh	> 20	15 - 20	10 - 15	5 - 10	< 5
	Fuel costs	$/MMBtu	> 20	15 - 20	10 - 15	5 - 10	< 5
	Levelised cost	$ / MWh	> 100	90 - 100	80 - 90	70 - 80	< 70
Environmental indicators	Emission factor CO_2	tCO_2 / toe	> 4	3,5 - 4	3 - 3,5	2,5 - 3	< 2,5
	Emission factor CH_4	gCH_4/ toe	> 170	45 - 170	30 - 45	20 - 30	< 20
	Emission factor N_2O	gN_2O/ toe	>150	50 - 150	25 - 50	10 - 25	< 10
	Investment cost for CCS system	$ / kWh	> 150	100 - 150	50 - 100	25 - 50	< 25
	Investment cost for NOx control systems	$ / kWh	> 150	100 - 150	50 - 100	25 - 50	< 25
	Other pollutants with risk to health and the environment - significant emissions	Atmospheric pollutants emitted	SO_2, NO_x, dioxins and furans, particles, HCl, heavy metals	-	SO_2, NO_x, particles	-	NO_x, particles

It can be mentioned that:

- For each score the ranges are set evenly (the intervals are relatively equal);
- The Scores "2", "3" and "4" contain fixed values intervals, and the scores "1" and "5" contain a more widespread interval;
- The score for the indicator "Other pollutants with risk to health and the environment " is assigned depending on the diverse range of pollutants.

Compositing algorithm

The objective of the scheme of integrated analysis is to evaluate two or more techniques of electricity production and to decide which is the best choice at a time or in a given situation. After choosing the techniques to be analysed, the values of the relevant indicators presented in the first part of the paper are identified and the matrix of performance is developed.

The compositing algorithm is the following:

1. In the case of each indicator, the interval for each value is identified, and the score is assigned.
2. Fiecare scor este înmulþit cu ponderea indicatorului aferent.
3. The values obtained are then added together, and the result represents the total score.

This algorithm corresponds to a cumulative linear model, described by the following formula:

$$AS_i = \sum_{J=1}^{n} W_j * r_{i,j}$$

in which: AS_i – total score for the technique i;

W_J – weight of indicator j;

$r_{i,J}$ – score of the indicator j for technology i.

INTERPRETATION OF THE RESULTS

As a result of the application of the proposed algorithm, to each alternative it is associated a total score. Based on this score, a techniques ranking is produced, in the descending order of total scores obtained by each technique.

In accordance with the manner in which the calculation algorithm was conceived, the technique with the highest total score is considered as optimal.

The purpose of this scheme is to review several techniques for the production of electricity at a particular point, in a certain area/region or in a specific situation, and finally, based on the results, solutions of orientation of the energy policies could be proposed .

EXAMPLE OF APPLICATION OF THE ANALYSIS ALGORITHM

For an easier understanding of the compositing algorithm, an example of application of the integrated analysis scheme is developed.

The techniques A and B, two techniques for the production of electricity are analysed.

In the table no. 4, the performance matrix is presented for the two techniques.

Table no. 4: Performance matrix for the techniques A and B

Technique	ENERGY INDICATORS Weight 34%			ECONOMIC INDICATORS Weight 33%				ENVIRONMENTAL INDICATORS Weight 33%					
	Unitary consumption	Energy efficiency	Resource availability	Investment costs	Operation costs	Fuel costs	Levelised cost	Emission factor	Emission factor	Emission factor	Investment cost for CCS system	Investment cost for NOx control systems	Other pollutants with risk to health and the environment - significant emissions
	toe/MWh	%	years	$/kWh	$/MWh	$/MMBtu	$/MWh	tCO_2/toe	gCH_4/toe	gN_2O/toe	$/kWh	$/kWh	Atmospheric pollutants emitted
Technique A	0,23	48,1	30	850	13,0	2,25	85,3	3,91	29	21	35	46	SO_2, NO_x, dioxins and furans, particles, hydrochloric acid, heavy metals
Technique B	0,18	46,7	15	990	8,5	7,75	154,0	2,32	167	42	28	65	NOx, particles

According to the methodology presented above, in the first stage the score corresponding to the interval in which the values for each indicator are situated will be assigned. These scores are presented in table no. 5.

Table no. 5: The scores assigned to each indicator

Technique	ENERGY INDICATORS Weight 34%			ECONOMIC INDICATORS Weight 33%				ENVIRONMENTAL INDICATORS Weight 33%					
	Unitary consumption	Energy efficiency	Resource availability	Investment costs	Operation costs	Fuel costs	Levelised cost	Emission factor	Emission factor	Emission factor	Investment cost for CCS system	Investment cost for NOx control systems	Other pollutants with risk to health and the environment - significant emissions
	toe/MWh	%	years	$/kWh	$/MWh	$/MMBtu	$/MWh	tCO_2/toe	gCH_4/toe	gN_2O/toe	$/kWh	$/kWh	Atmospheric pollutants emitted
Technique A	3	3	3	4	3	5	3	2	4	4	4	4	1
Technique B	4	3	1	3	4	4	1	5	2	3	4	3	5

Source: Author's calculations

According to the calculation algorithm, each score is multiplied with the weight of corresponding indicator, and the values obtained from this calculation are summed. The results are presented in the table no. 6.

Table no. 6: Application of the composing algorithm

Technique	ENERGY INDICATORS Weight 34%			ECONOMIC INDICATORS Weight 33%				ENVIRONMENTAL INDICATORS Weight 33%						Total score
	Unitary consumption	Energy efficiency	Resource availability	Investment costs	Operation costs	Fuel costs	Levelised cost	Emission factor	Emission factor	Emission factor	Investment cost for CCS system	Investment cost for NOx control systems	Other pollutants with risk to health and the environment - significant emissions	
	toe/MWh	%	years	\$/kWh	\$/MWh	\$/MMBtu	\$/MWh	tCO_2/toe	gCH_4/toe	gN_2O/toe	\$/kWh	\$/kWh	Atmospheric pollutants emitted	
Technique A	0,39	0,51	0,12	0,24	0,24	0,4	0,33	0,2	0,08	0,08	0,32	0,32	0,03	**3,26**
Technique B	0,52	0,51	0,04	0,18	0,32	0,32	0,11	0,5	0,04	0,06	0,32	0,24	0,15	**3,31**

Source: Author's calculations

It is noticed that, as a result of the application of the algorithm, the technique A has obtained a total score of 3,26 and the technique B a total score of 3.31.

For example, the ranking resulting from the application of the integrated analysis scheme is the following:

Table no. 7: The ranking of the proposed alternatives

Technique	Total score
Technique B	3,31
Technique A	3,26

It is noticed that the technique B can be considered to be the preferable alternative, because after the application of the algorithm of calculation a total score of 3.31 was obtained, in comparison with the technique A which obtained a total score of 3,26.

CONCLUSION

In conclusion, the objective of the integrated analysis scheme is to evaluate the various techniques for the production of electricity, and to decide on the basis of the results obtained, which between them represent the optimal solution to a specific situation or at a particular time.

This type of approach is not commonly used in Romania, and the potencial beneficiaries are the authorities and the experts from the energy sector and environmental protection.

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