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INDUSTRIAL SYMBIOSIS, ECOEFFICIENCY, SUSTAINABILITY A CASE STUDY

Cristian Teodorescu[1], Mirela Danubianu [2],

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Abstract In the last decade, international organizations have expressed their concern about the capacity of classical economical indicators to encompass the whole story of the developing processes, especially in their relationship with the environment. A comprehensive environmental metrics has been adopted (states and organizations reports indicators like greenhouse gas emissions, ozone concentrations, surface of contaminated land, number of threatened species, etc.) and operates in parallel with the traditional industrial indicators. But it seems not enough since this complementary metrics does not illustrate the entire complexity of development processes, in the 21st Century. Recent EU documents stress the importance of sustainable development, of the importance of industrial symbiosis as a tool to better manage material, energy and human resources and evaluate the possibility of generating and reporting new, synthetic, composite indicators that could include both the information in the classical economical indicators but also the environmental impact and the quality of life.

The paper is a contribution in this respect and, starting from the results of the implementation of the Industrial Symbiosis paradigm in the case of a power plant, it presents how the EU recommendations about a more sophisticated metrics of ecoefficiency works, for the first time at the level of a Romanian enterprise. An original, new metrics is generated, that takes into account whether and how the technological and economical processes are accompanied by a favourable trend for the environment, A new, composite index for ecoefficiency and sustainability is presented in its structure and dynamic evolution, enabling local managers not only to assess their sustainable development trend, but also to identify where should their action be directed in the short term to correct unfavourable trends. The study was a part of the PAZEWAIA Project financed by Innovation Norway.

[1] GEC-Bucovina, Suceava, christit@gmail.com

[2] ”Ştefan cel Mare” University-Suceava, mdanub@eed.usv.ro

1. Metrics for development

The growing concern about a bunch of indicators difficult to infer but telling almost nothing to common people led, in the last decade, EU structures, as well as EU states to initiate a critical evaluation of existing indicators for economic development and suggest possible approaches to a new metrics that should include also the environmental concerns and the quality of life (Beyond GDP, 2014; GDP&Beyond, 2009; Stiglitz et al, 2008, EU-JRC, 2010). Essential findings are presented below.

The gap between traditional measures of socio-economic variables (GDP, productivity, growth, inflation, inequalities etc.) and their perception by the general public becomes wider and wider and cannot be explained only on a monetary basis, by education or by cultural differences.

Cited documents do not recommend a *tabula* rasa of the existing metrics of socio-economic development but try to identify complementary measures, more complex indicators that goes beyond the economic performance.

The main objective is to devise indicators that could include all the three perspectives of the sustainable development (economic, environmental, and social sustainability). A critical analysis of the limits of the existing system of indicators and their public perception points to several possible causes:

a. The metrics could be fundamentally correct, but the characteristics of the measuring processes are flawed;

b. Errors and misjudgments in the conceptual framework can be also accepted, sending economists to the drawing board. As long as GDP says nothing about atmospheric pollution or water quality, aspects that confronts general public at every moment, the GDP and other statistical measures that does not include pollution are intrinsically biased and may become irrelevant;

c. Industrial performance and products available on the market must be accompanied by some more information than the price of the goods (does this furniture or this book come from sustainably managed forests? Has children work been used to produce these cloths? Production of this car has led to increasing pollution of soil, water and air?);

d. Adding eco-indicators (air or water quality, rate of waste generation, resource availability, ecosystems under risk, etc.) to the existing metrics, though having its merits, complicates the statistics and make it more confusing and less straightforward and understandable;

e. Sustainability must govern and be monitored not only inside companies themselves but also in their interaction in the competition process (Schwab, 2014);

f. Successive economic crisis led to a dramatic increase in inequalities and this reduces the relevance of statistical averages. GDP *per capita*, productivity, average income and other intensive indicators can neither produce a fair account of the world, at the beginning of the 21st Century.

g. What if the construction of a new, better metrics would start not from the central administration and national statistical institutes (top-down) but from the industry, business community or even from common people (bottom-up)? In this respect, some encouraging results are already available. The business community already uses more complex metrics for assessing the performance of companies demonstrating not only financial success but also strong environmental, social and governance sustainability (FTSE4GOOD, 2014; DJSI, 2014).

The paper has no ambition to challenge the business community or already established metrics like the mentioned Financial Times of Dow Jones approaches. It intends to demonstrate that complex metrics may be devised at enterprise level to monitor its progress toward sustainability. Complex metrics can be easily devised starting from existing company metrics and from available documents detailing best practices.

The study is a part of the *Partnerships with Zero-Waste Industrial Activities* (PAZEWAIA, 2014) Project financed by the Norwegian Government through Innovation Norway. The Norwegian partner (International Development Norway) involvement in the Project with technical and scientific support, expertize in calculus and analysis is hereby graciously acknowledged.

2. The case of the termica power plant

Previous papers (Danubianu et al, 2013, 2014) have detailed the sustainability analysis for the TERMICA Power Plant in Suceava.

The Company applied the principles of Industrial Symbiosis (Agarwal and Strachan, 2008) in trying to better manage its environmental footprint and a special appointed multi-disciplinary team carried out a thorough benchmark and material and energy flow accounting analysis, along the lines of ISO14051-2011. Main conclusions:

a. Some 30000tons of virgin soil were preserved by using inert demolition waste to cover the ash field of the power plant;

b. modern techniques like data-mining prove useful to analyze data existing at the Company, recorded in many years of operation; updated databases can show to managers, in real time, what are the trends in the technological processes but also in the environmental footprint;

c. external facilitators (Norwegian, Romanian) and Company's specialists derived more objective estimates for their environmental costs that amounted even to 18-24% of total Company expenses, in the period analyzed, 2007-2011;

d. more important, the intrinsic structure of these costs indicated points where costs are excessively high (more specific, internal consumption of electric power generated and the costs associated to flue gas);

e. The material and energy flow cost accounting should remain in place as it ascertain best what the environmental footprint of TERMICA is. Measures should be directed to reduce this footprint by acting where the environmental costs are the higher;

f. correlation analysis showed what operational parameters correlate best. Acting upon one of them will result in a corresponding improvement in all other strongly correlated parameters;

g. an internal benchmarking analysis was carried out and indicated the year 2008 as the best one in the recent history of the power plant. By simply reproducing the conditions valid in 2008, TERMICA could improve by 6-12% level of efficiency, without any additional investment.

h. Using regression analysis showed that, excepting the internal electric energy consumptions, all other important operational parameters tend to approach the levels specified by the best available techniques documents, in the short or medium term.

3. A composite index to assess sustainability

The team of Norwegian and Romanian experts working with the local specialists have concluded that such an index should include:

a. Technical performances of the power plant. E.g.:

1. Internal losses of electric energy produced
2. Internal losses of thermal energy produced
3. Heat losses with the flue gases

b. Environmental consequences of the plant operation in all 3 media. E.g.:

- Ash management costs (soli pollution)
- Greenhouse gases (carbon dioxide) emitted (atmospheric pollution)
- Water losses (loss of water resources).

Table 1 includes the relative dynamics of these parameters in the period 2007-2011.

As the table shows, in the 5 year period studied, there is a decreasing trend in negative products (as defined by ISO14051). This qualitative remark should be turned into a quantified, numerical value and this will be done by using a Composite Index measuring the power plant performance.

Table 1. Dynamics of parameters measuring technological and environmental performance. (2007=100)

Performance indices	***Year of operation***				
	2007	***2008***	***2009***	***2010***	***2011***
Internal losses of electrical energy produced	100	105	101	94	95
Internal losses of thermal energy produced	100	99	101	97	94
Ash management costs	100	111	118	115	110
Amount of greenhose gases (CO_2) emitted	100	90	91	88	87
Heat losses with flue gases	100	99	97	95	94
Water losses	100	98	96	95	96
TOTAL Negative products	100	98	94	94	90
Rate of negative products in annual	21	22	24	20	18

The 12 performance indices of the power plant were selected to assess the progress toward sustainability are included in Table 2.

The 12 indices are extremely heterogeneous and in order to bring them to a common scale, their actual reported (and averaged, where need be) values for each year in the period (2007-2011) were compared to those in reference documents (LCP, 2006).

Table 2. Indices used in devising a composite index.

	Indices	***Symbol***	***Acronym***	***Weight, %***
1.	Internal consumption of electric energy produced	I_1	*ICEE*	*9*
2.	Internal consumption of thermal energy produced	I_2	*ICTE*	*9*
3.	Boiler efficiency	I_3	*BE*	*4*
4.	Specific fuel consumption (amount of coal/1MWh energy produced)	I_4	*SFC*	*12*
5.	Specific water consumption (m^3 fresh water/1MWh energy produced)	I_5	*SWC*	*14*
6.	Excess air to boiler	I_6	*EAB*	*5*
7.	Ash generated per 1MWh electric energy produced	I_7	*AEE*	*5*
8.	Ash generated per 1Gcal thermal energy produced	I_8	*AET*	*5*
9.	Greenhouse gases (CO_2) to stack	I_9	*GG*	*7*
10.	NOx in flue gases	I_{10}	*NOX*	*12*
11.	Volatile Organic Compounds (VOC) in flue gases	I_{11}	*VOC*	*12*
12.	Heat losses with the flue gases sent to stack (their temperature was used as performance indice)	I_{12}	*HLFG*	*6*

Fig.1 illustrates how some of these indices compare to the Best Available Reference Documents (BAT) levels (relative values: BAT level=1.00; acronyms used are those in Table 2)

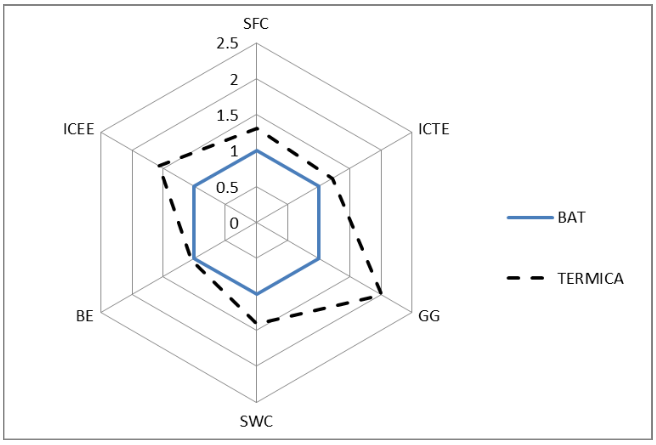

Fig. 1. Power plant performances in 2010 against Best Available Techniques documents.

The structure of a Composite Index for sustainability is inspired by the well-known aver-all mass and heat transfer coefficients (series of resistances to transfer and an analytical form of such a Composite Index is:

$$CI_{analyitical} = \frac{1}{\frac{1}{\frac{(ICEE)_{BAT}}{(ICEE)_{Termica}}} + \frac{1}{\frac{(ICTE)_{BAT}}{(ICTE)_{Termica}}} + \frac{1}{\frac{(BE)_{Termica}}{(BE)_{BAT}}} + \cdots + \frac{1}{\frac{(HLFG)_{BAT}}{(HLFG)_{TERMICA}}}}$$

The sum at the denominator has 12 terms, one for each of the 12 indices mentioned in Table 2. The denominator of each fraction at the denominator of the expression is less than unity and should be increased in order that the power plant performances align to those in BAT documents. This can be achieved by reducing power plants consumptions, losses or increasing the boiler efficiency. The most important property of such a calculation is that the resulting analytical Composite Index is less than the smallest of the ratios ($I_{k,BAT}/I_{k,Termica}$) and remains so as long as this smallest ratios is not increased. In this way, managers have an indication of where to act with priority in order to increase the power plant performance.

A synthetic version of the Composite Index is obtained by attaching to each index from the 12 indices set mentioned above, a weight, as shown in Table 1. These weights illustrate the relative importance of each particular indicator. The formula proposed for inferring a synthetic Composite Index of Company sustainability is:

$$CI_{synthetic} = \frac{100}{\sum_{k=1}^{12} w_k \times \left(\frac{I_k}{I_{BAT,k}}\right)^{\alpha}}$$

The following notation is used:

$CI_{synthetic}$: synthetic Composite Index for sustianability

w_k : weight associated to each ratio ($I_k/I_{BAT,k}$)

I_k : indices (see notation in Table 1)

$I_{BAT,k}$: BAT level for indices I_k;

α : exponent (+1 for those indices that are higher than their BAT correspondents and should be lowered, e.g., consumptions, losses; -1 for those indices that are lower than their BAT correspondents and should be increased, e.g., boiler efficiency).

It is important to note that the selection of indices to be included in the Composite Index and their associated weights were the result of consultation of Company's managers and external facilitators. They are subject to different structure, if the Company Management decides so. Nevertheless, the objective was to device a comprehensive Composite Index that for the long-term, one that will keep its structure unmodified, enabling comparison and trend identification in the Company's performances.

The weight selected for greenhouse gas emissions was selected arbitrarily low because there is a market for CO_2 in Romania and the Company currently takes advantages of it to turn its savings in CO_2 emitted into profit, by selling CO_2 certificates.

Other indices have also a weight that could seem low (e.g., 4% weight for boiler efficiency). This is because there is little room for improving such indices without investing in new boilers and advanced power generating technologies.

If all ratios ($I_k/I_{BAT,k}$) are equal to unity (in the case that performances of the studied power plant are identical to those mentioned in BAT reference documents), the value of the Composite Index is 100. This value is lower than 100 in the case of poorer performances of the power plant, in comparison to BAT.

Such a Composite Index has the following advantages:

1. It includes only measures familiar to the Company's managers since they are monitored permanently and, some of them, reported to the local Environmental Protection Agency;

2. It uses BAT documents for reference, also accessible and familiar to managers since the power sector in Romania must align to the stringencies of cleaner production and BAT, as soon as possible;

3. By studying each separate ratio ($I_k/I_{BAT,k}$), managers straightforwardly identify where is the lowest performance of the Company (highest than unity ratio that should be decreased in all cases, with the exception of the ratio of boiler efficiencies that is currently lower than unity and should be increased);

4. The dynamics of this composite index show, if it increases the favorable progress of the company toward sustainability and eco-efficiency. Fig. 2 illustrates this dynamics.

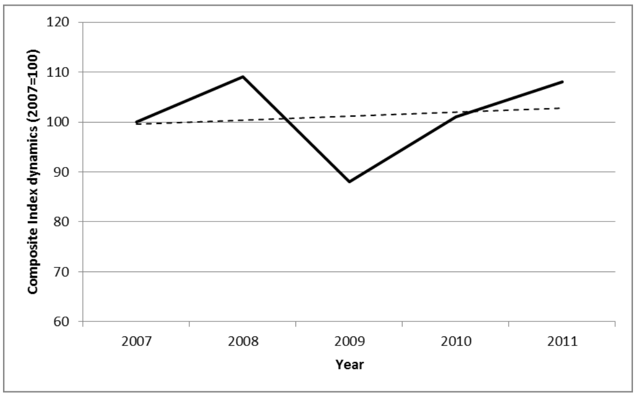

Fig. 2. Dynamics of the Composite Index (relative values; 2007=100).

Fig. 2 indicates, again, the year 2008 as the best in the recent history of the power plant (result obtained also via the internal benchmarking analysis). Yet it is clear that the power plant has recovered from the economic crisis period and it is on a good, uphill trend, as shows the regression line in the figure.

Conclusions

The paper presents a continuation of exploiting on a scale as large and comprehensive as possible the operating data existing at a Romanian power plant.

Previous implementation of the Industrial Symbiosis principles has reduced dramatically the costs of ecologization of the ash deposit of the power plant.

This is of particular importance since Romania has a poor performance in waste recycling (ANPM, 2014). Material and energy flow cost accounting along the lines of ISO 14051 has also showed, in a previous study, the importance of having a correct image of what the real environmental costs of a company are.

Further developments (e.g., use of Life Cycle Assessment) will further deepen the knowledge the power plant system structure and behavior (Teodorescu, 2010)

In the present study, managers were given a tool to assess the sustainability of the power plant from the technological and environmental perspectives, by devising a Composite Index.

It includes only measures and indices already familiar to the Company's managers (including reference to Best Available Techniques) but aggregates all this indices into a single, synthetic value, easy to monitor. The structure of the Composite Index enables managers to identify where the managerial action should be directed, where to allocate resources with priority in order to improve the power plant performances in the short term. Once the Composite Index shows a limit in its evolution, it could be an indication that further improving the performances requires something more than good housekeeping or professional maintenance (probably investments in new technology is needed).

The Composite Index adopted includes 12 indices (technological but also environmental and resource-connected), turn them into dimensionless ratios by using BAT reference values and allocates specific weights to each such ratios.

The set of indices and the associated weights were discussed and approved by the Company's managers and experts and they could be subject of further improvement.

The evolution of the Composite Index shows a favorable, increasing trend in the last 3 years of operation, in the period under scrutiny.

Coupled with the Industrial Symbiosis approach and the ISO14051 material and energy flow cost accounting, the generation of the Composite Index constitutes a pattern of assessing the sustainability of a Company and showed the following benefits:

- Industrial Symbiosis is a valuable tool to turn waste into resource and to reduce environmental costs;
- Material and energy flow cost accounting should become a permanently used tool to monitor Company's performances and to direct action toward hot points;
- Together with other economic analyses, the material and energy flow cost accounting lead to an objective evaluation of investments needed for a better technology and reduced environmental footprint;
- By calculating the components of the suggested Composite Index, the personnel is motivated to improve the value of a given component – if this has an

unfavorable value – by preventive maintenance and good housekeeping, by strictly observing operational procedures. Losses are reduced and consumptions are lowered;

During the study, a set of recommendations were suggested to Company's managers, Excerpts:

1. A better selection of fuel providers;
2. An optimal fuel management system;
3. A permanent study of the BAT documents by all Company's managers;
4. Implement preventive maintenance procedures at every working place, for every equipment;
5. Critical analysis of internal processes that consumes excessive electric and thermal energy;
6. A cost-benefit analysis to reduce the temperature of flue gases sent to stack. Reducing their temperature would lead to better plant efficiency;
7. Reducing water losses at the cooling tower (by taking into account even investing in a closed water circuit);
8. Better ash management. Selling ash to cement and concrete producers, in a symbiotic partnership, could be a solution to reduce waste to landfill.

The study generated expertize at Company's level, enabling local managers to carry on the procedures for monitoring environmental costs, for calculating the Composite Index and to identify potential symbiotic partnerships in order to turn plant's waste into resources.

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