Mass and energy flows in consequences of company environmental accounting

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Abstract

During the implementation of an environmental accounting system in a company, one of the most important pieces of information to obtain is a detailed understanding about material flows (raw materials, semi-finished products, final products and wastes) and flows of different types of energy inputs (buying, selling and wastage) when thinking about the consequences on the company. The authors, in the article: 1) study the question of the quantification of the flows, and the accuracy of their measurement, 2) provide an environmental accounting statement, with help of standards and indices, statistical trends analysis.

Introduction

In a company, there is n products (commodities) registered by accounting and statistics. For each product we can find (in subsistence units and monetary assessment):

- GT *gross turnover*...means total production
- CP *commodity production*...means output (good's selling and production)
- IT *internal turnover*...means intermediary product or stored material

The following formula (1) holds:

$$CP = GT - IT \tag{1}$$

To each GT of specified commodity (in physical units) there corresponds material or source consumption (in physical units) Q and waste amount (in physical units) W. The consumption standard (**a**) means proportion a = Q/GT; the proportion of amount of raw material consumption to calculating commodity unit. The waste normative (**w),** w = W/GT means proportion of amount of wastes for calculating commodity unit production. We obtain values Q and W from mass and energy flow's balances, which have to fulfil the condition (2):

$$\Sigma \text{ inputs} = \text{stocks} + \Sigma \text{ outputs} \tag{2}$$

These balances we make for a pre-defined system[4] and for a pre-chosen period (year, month, 24 hours, hour, etc.). Inputs, outputs and stocks we measure in physical units: in mass balances (kg/period, t, kt, Nm^3/period), in energy balances (J/period, kWh, tonnes of specific fuel/period etc.).

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[4] for example national economy-branch-field-company-workplace-equipment-process

Mass flows measurement

Material or source consumption (Q) value is found in operating practice by one of these ways:

1) Direct weighting or mass flow measurement;
2) Q = P. t. h, where **P** is profile of production line, **t** is time period, **h** is material density;
3) Q = P. t. h. c, where **c** is material concentration in media.

Weighting and measuring of all physical and chemical quantities in these formulas cause always these types of mistakes:

1) **Systematic** mistakes skew results in one direction. By comparing of the used measuring method with another method and with the help of calibration of appropriate standards systematic mistakes can be identified, and the measuring results rectified.
2) **Gross mistakes** are man's mistakes. They can be avoided by better work organization and better work discipline.
3) **Stochastic mistakes** have distribution around median value (Gauss distribution curve). They can be analyzed *ex post* using methods of mathematical statistics. Their dimension or frequency can be characterized on the base of analysis with satisfactory probability.

For technical-economical calculations we quantify standards as mean values or as point estimate. Only in *ex ante* risk assessment of bigger innovative projects with sensitivity analysis[5] we quantify standards and in calculation we use them as interval estimation.

Energy balances specials

Present equipments enable in mass balances measured all inputs and outputs flows inclusive wastes. Measurement's reliability and accuracy is only limited by amount of money for measuring equipment buying, operation and maintenance. In the case of energy balances, there is not possible to measure the so-called "heat waste"; heat, which increase surrounding's temperature (atmosphere, soil). These "heat wastes" we therefore quantify with calculation, as difference between heat amount of input and output flows.

Next, but trivial complication is a fact that in mass balances there is only one specific unit (kg and its multiples). Energy flows are measured ad hoc with different units: joules, kWh, calorie, the so-called specific fuel, oil equivalent and others.

In big production units and in national economics the comparison of their energy balances can be misrepresented by different type of calculation of so called primary electricity[6] to joules: with help of so called *physical equivalent* (1 GWh = 3,6 TJ) or by so called *displacement fuel* (for example 1 GWh = 9,08 TJ). Displacement fuel is agreed consumption of fossil fuel to electricity production in state-of-the-art equipments.

Balanced energy sources are different energy media, with different degree of grade, concentration and universality of usage. The balance resume sources from electricity (as the

[5] more details in [1]
[6] It is electricity from nuclear, hydro, wind and photovoltaic power stations, heat pumps and tidal power etc. These types of electricity are important in balances in Austria, Switzerland, France, Denmark, Norway etc.

noblest and the most universal resource) through different fuel types, low potential waste heat to the so called "heat waste". To quality of energy sources specification A. Gardel [4] used a category "*exergy*". It is proportion of energy transferable to mechanical work, respectively mechanical energy (definition: Z. Rant, 1953). "*Anergy*" is proportion of energy non-transferable to mechanical work.[7]

This formula is valid: exergy + anergy = constant, with a condition: exergy transforms only to anergy. In each energy flow in balanced system is determined with help of agreed coefficients (in state-of-the-art equipments) amount of exergy. The proportion of exergy of input and output energy flows then characterizes the qualitative part of using energy in balanced system. This type of balance is often used in the projects of manufacturing plants and apparatus, but in the state economic plan reflections is used meanwhile occasionally. But in the state economic plan reflections will its importance increase in consequences of reflections about higher usage of renewable energy sources.

Characteristics of standards development (normatives)

In present on the companies' level are observed consumption standard (a) and waste normative (w) mainly for:

1) planning and cost analysis for material buying, energy resources and for waste disposal
2) mass balances, how comply with pollutants emission's limits to natural compartments. The statistical office compiles on the level of state economic the fuel and power balance.[8] The company's balances and standards data make first data base for collection of the state economic mass balance (good aggregate) [5] and for the construction of derived so-called indicators of sustainable development.

In <u>short-term scale</u> we interest if technological process of a product is in the period of stochastic stability. It is usually in practice and in ISO standards (9000 and 14 000) the situation, where standard's values are situated in the interval ± 2 standard deviations around long time average. This is characteristic only for industrial technology. In agriculture and forest production standard's time series have seasonal variations; exploitability and standards are dependent on climatic cycles. We use time series with climatic similar periods to exclude too complicated models.

Standard's development between initial (t = 0) and usual time level (t = 1) characterizes the individual index $\mathbf{I = a_1/a_0}$. If we should make all standard's development assessment in bigger aggregated establishment (plant, company, enterprise), we will use summary index, where standard's weights capture weights **q** from initial period t = 0 (→Laspeyres index, IL) or from usual period t = 1 (Paasche index, IP).[9] As q value we often use GT values (amount of production). So we "weigh" standard by mass material consumption. We can use as weight the product **GT.p** (p...material costs). So we weigh standard by material costs.

[7] Electrical energy has high degree of transformation and the biggest "exergy".
[8] In the case of CR [2]
[9] It is not possible to justify preference of one index, because both are equivalent. "Therefore is often calculated the geometric average from both indexes" (Fisher index) [3]

$IL = \Sigma a_1.GT_0 / \Sigma a_0.GT_0$ (3)

$IL = \Sigma a_1.GT_0.p_0 / \Sigma a_0.GT_0.p_0$ (4)

$IP = \Sigma a_1.GT_1 / \Sigma a_0.GT_1$ (5)

$IP = \Sigma a_1.GT_1.p_1 / \Sigma a_0.GT_1.p_1$ (6)

Summary index is similar and with it we can characterise normative's wastes (w) development. Instead of p value we use amount of costs for utilization of waste's calculating unit.

In long term scale should be in the product the evidence of **a**, **w** value's decline. (This decline has a limit due to stechiometric chemical laws and II. Thermodynamic law.) Trend's determination of the time series is a task for regression analysis. Obviously is recommended to use *power function* Y = {(c.t) ↑2} and *exponential function* Y = {(c.e) ↑2t} + q.

$Y = q + c_1t + \{(c_2t) \uparrow 2\} + \{(c_3 t) \uparrow 3\} + \ldots + \{(c_{n-1}t) \uparrow (n-1)\} + \{(c_nt) \uparrow n\}$ (7)

Polynomial function (7) has quite good regression curve (with adequate degree of polynomial), but interpretation of coefficients in the formula (time power!) is forcible. In our article [6] we used the method of *Artificial Neural Networks* (ANN), in detail described in [7,8] for time series regression of standards of fuel and power economy (PEH).

In particular, the so-called Multilayer perceptron networks of different parameters have been used. In our case the network has one input and one output unit and one or more intermediate (hidden) layers of several units. Finding suitable network architecture is a matter of heuristics, experience and testing; the next phase of finding suitable network parameters (weights) is usually done by means of gradient based learning algorithms, such as *back propagation* or by a genetic algorithm.

The network consists of computational units of a perceptron type, which compute simple non-linear function:

$$f(x) = \sum \sigma(w_i x_i + b),$$

where x_i are inputs, b and w_i are unit parameters, and σ is a stepwise activation function (such as *logistic sigmoid*). The learning algorithm sets these parameters based on the available data by means of the *mean square error*.

For example for time series *NORMA 2* (amount of joules of technological losses for transfer 1 joule of PEH to final consumption) were obtained:

Table 1 Results of comparison within *NORMA 2*

Standard	Function's type	R^2
NORMA 2(1979-93), average 0,320546; standard deviation 0,019319 (6,03%)	Power, y = {(c.x)↑2}	0,8251
	Exponential, y = {(c.e)↑2}.x	0,6327
	Polynomial, n = 6	0,9228
	ANN (1-5-1)	0,8236
	ANN (1-5-3-1)	0,8195
	ANN (1-20-13- 1)	0,6327

R^2 is determination coefficient. Its values lie in the interval $0 \leq R^2 \leq 1$, and it measures suitability of used regression function. If all empirical values would be directly on regression curve, then would be $R^2 = 1$. Coefficient has such definition R^2=1– (SUM 1/SUM 2), where SUM 1=sum of squares of difference of (measured) values and "balanced" values (y_t), SUM 2=dispersion of data field of empirical values y_t.

Standards and planning

Standard's usage in a company management is multipurpose. Due to the manager's decision making phase the standards are: reached, assumed, planned, flexible and long time. These types of formulas include standards:

- buying source$_{\text{(natural units)}}$ = GT$_{\text{(natural units)}}$. m
- buying source$_{\text{(monetary units)}}$ = GT$_{\text{(natural unit)}}$. m . p$_{\text{(source cost)}}$

In explicit and implicit form are standards used in the structural balance of Leontiev type [x, y]. We have to first for all products quantified values GT, IT and CP to work with this type of balance:

MGT = GT. cost (8)
MIT = IT. standard. cost (9)
MCP = CP. cost (10)

We gradually compile:

- matrix I. quadrant (G type **n.n**), where is evidence about deliveries between subsystems in the value of internal turnover (MIT). Production of n products in horizontal direction means supplier, in vertical direction customer.

- **Y** matrix with n dimension, where is evidence of final products value – output (MCP)[10]

- **X** vector with n dimension, where is evidence of gross turnover value (MGT)

[10] In our model is made one simplification that final protection corresponds to goods production.

- matrix of technical coefficients A with dimension n.n, obtained by calculation $A = G.(D)^{-1}$, where **D** is diagonal matrix n.n, where non-zero elements (in diagonal curve) correspond to MGT values

- matrix of complex consumption coefficients with dimension n.n, obtained by calculations:

$B = (E-A)^{-1}$, where **E** is unit diagonal matrix.

The formula (11) uses balance calculations and different cases modeling.

$$X = B. Y \qquad (11)$$

Conclusion

Authors agree with [9]: "Focus in the environmental accounting system implementing is not in accountants, but in technicians, which have to obtained data of material and energy flows. It is job for company workers...External workers do not have completed idea about difficult connections within material and energy flows. And they have all the time problems with lack of data, which they have to ask for." In this context authors found useful to show problems connected with the mass and energy balances compilation and with their statistical application.

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