Methods of ecological and economic evaluation of technology

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Introduction

Comprehensive evaluation of a manufacture process should include, above all, an analysis of the technological process (existent or designed), a balance of resource and processing aid flux, apparatus and equipment, and a balance of produced and emitted waste. An important step in the evaluation is identifying potential sources of waste production [1÷5].

To perform a comprehensive technology evaluation it is important to choose the appropriate method, among those, which are specifically designed for economical evaluation, or others adapted for this cause. An overview and examples of methods used can be found in multiple publications [2÷8]. A complete and valid evaluation of environmental impact of a manufacture technology concerns existent manufacture processes, as well as those updated and newly designed.

Using methods of joint technical, ecological and economic evaluation of manufacture processes is critically important for a comprehensive assessment of a given production. Evaluation methodics may have a quantitative character (process balance and technical-economic factors), qualitative character (subjective evaluation methods, expert evaluation) or may possess a mixed character. Evaluations may be either partial or comprehensive. The diversity of methods for a multilateral assessment of manufacture processes; however, the choice of optimal methods of assessment may substantially influence the validity of results obtained. This work describes the main methods of ecological and economic evaluation [2,4,8÷10], while chosen methods have been associated with examples of application. Table I summarises methods of technology evaluation.

Cleaner productions as the main element of balanced development and preventing environmental pollution

Every manufacturing activity influences the environment, so there is no ecologically clean production. However we can discuss *Cleaner production*, i.e. one that reduces negative influence on the environment to the minimum. Using cleaner productions enables reaching a higher level of ecological production development and product use. It remains one of the basic elements qualifying for a balanced development of the society (*Societal Sustainability Development*). Cleaner productions require developing even better technologies, with little or no waste produced in the process and consuming less energy, which must have positive economical impact, when introduced. Such an ascertainment has changed the approach to ecological factors. The lasting effect is the introduction of more optimal methods for preventing waste production or waste management. Such actions are currently being undertaken by single manufacturing sites, whole corporations or even on nationwide and global scale [3, 9, 11, 12].

Cleaner production, production management, which prevents and limits environmental impact on all stages of an article's life cycle - from resource extraction to final storage of spent product. The aims of cleaner production are not only achieved through modifying technology, but also through changes in the way ecological problems are perceived, as well as the connection of ecology and economy [3, 4, 11]. Using techniques (options) of cleaner production, especially on the stage of research and development as well as design (Fig.1), allows for a pro-ecological direction for newly developed technologies.

Balanced development (ecodevelopment) is a form of economical development, which takes into account all the needs of environmental conservation. It is a process, in which the exploitation of natural resources, investment and technology development directions, as well as institutional changes proceed in perfect harmony with the current and future potential used for fulfilling human needs and aspirations [3, 13, 14]. Environmental protection in the model of balanced develop-

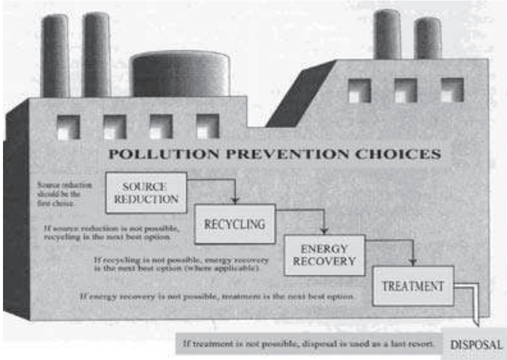

Fig. 1. Hierarchy of options for pollution prevention [3]

Table I

Technology evaluation methods

Methods	Material absorbance	Energy absorbance	Calculation of cost production	Cleaner production	Cumulative account	Schaltegger and Sturm	Implementation option	Fuzzy logic	BAT	LCA	Quality technological
quantitive	+	+	+	+	+	+					
qualitive				+			+	+	+	+	
Quantitative-qualitative				+				+		+	+
technical	+	+		+				+		+	
eclogical				+	+	+		+		+	
economical			+	+				+			
Technical-ecological-economics				+			+	+	+		+
Technical-ecological				+	+					+	
Ecological-economic				+							

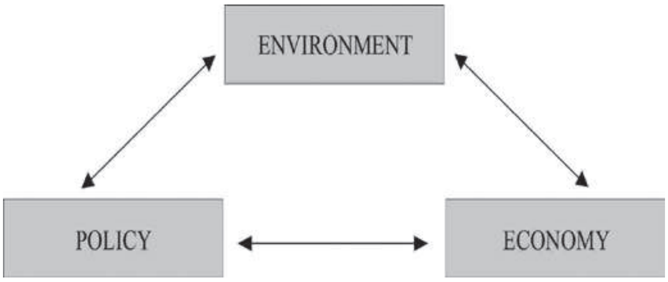

Fig. 2. Feedback loops within the society between politics, economy and the environment

ment is strictly intertwined with economy and politics. How to connect elements of economy, politics and ecology into one consistent, operational system? An answer to this question could help protect the environment more effectively (Fig. 2)

Comparative analysis of various methods for producing pasturage calcium phosphates using process analysis in terms of accumulative analysis and LCA techniques

Different techniques for producing pasturage phosphates using thermal method and low-temperature endothermic method (two separate installations in "Bonarka" Cracow and "Fosfory" Gdańsk) were compared [2, 3, 15].

The method of process analysis, in terms of cumulative analysis based on mass balance of the process, describes the emission of dust and gases, as well as the removal of sewage and solid waste. Evaluation methods introduce the following terms [2, 15]:

- accumulated risk (*ZS*), the sum of emissions (*E*) or discharges (*O*) of a given substance within steps of the process (f = 1 … n):

$$ZS_E = \sum_{f=1}^{n} E \qquad (1)$$

- accumulated risk factor (*WS*) as quotient of accumulated risk (ZS) and production size (*P*):

$$WS = \frac{ZS}{P} \qquad (2)$$

- accumulated risk factor including toxicity factor (*K*):

$$WSk = WS \cdot K \qquad (3)$$

- the sum of these factors – global accumulated risk factor (*GWS*):

$$GWS = \sum_{f=1}^{n} WSk \qquad (4)$$

- relative environmental risk factor (*WZZ*), comparing GWS^P of the initial process and of the modified process(GWS^N):

$$WZZ = \frac{\sum GWS^P - \sum GWS^N}{\sum GWS^P} \cdot 100\% \qquad (5)$$

Comparing techniques for pasturage phosphate production using this method has shown, that *WZZ* of the low-temperature endothermic process (DCP "Bonarka") is 21,25% lower compared to that of the thermal process (DFP "Bonarka") [15].

Ecological Life Cycle Assessment is a technique, through which a given process or article can be analysed during its entire life cycle - "from cradle to the grave" so to speak, which means from resource extraction, through production, use up to the point of spent product disposal (Fig. 3). LCA takes into account the responsibilities and influence of manufacturer – on the local, regional and global level [3, 16-19].

LCA may be used to evaluate the overall environmental impact of a product, or for designed alternatives [15]. LCA therefore allows for choosing a design alternative or appropriate components/materials [18].

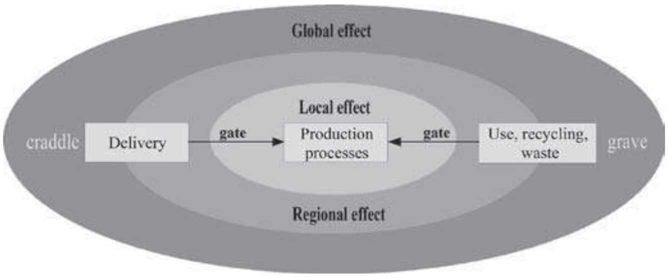

Fig. 3. Figurative representation of LCA

LCA also simplifies finding the most important process elements influencing the environment. Therefore set of primary objectives, to be fulfilled first, can be established.

Analysing bar charts (Fig. 4 and 5) [15] it can be concluded, that the best method (according to such an analytical method) is the low temperature endothermic method used in "Fosfory", Gdańsk. It seems puzzling, that the more recent production method of DCP "Bonarka" obtains results worse than the older method (DFP "Bonarka") even more surprisingly, the DCP was built based on and updated DFP installation. This stems from the fact, that the LCA method [15, 8] takes into account resource consumption much more than it does energy consumption.

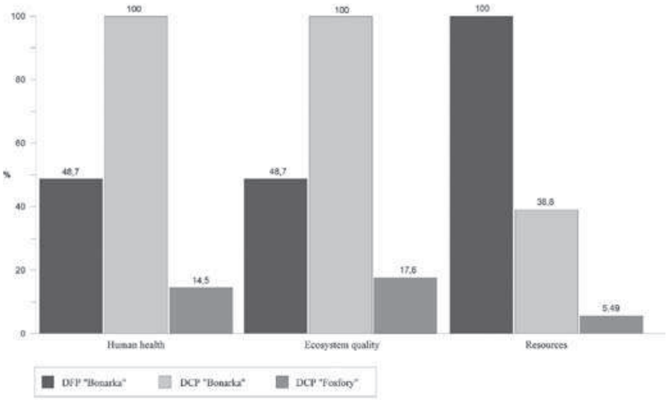

Fig. 4. Comparison between three processes of phosphate production (risk assessment depending on area of influence)

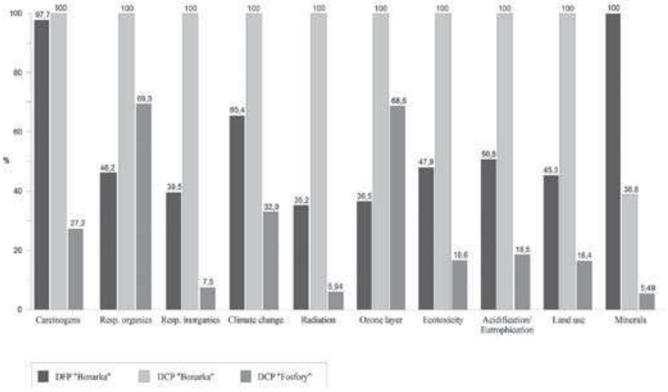

Fig. 5. Comparison between three processes of phosphate production (risk assessment depending on categories of influence)

Ecological process evaluation using Schaltegger&Sturm method

This method has been developed by the Swiss corporation Ciba-Geigy [3]. The basis of evaluation is the allowable substance concentration. Calculation methods are as follows:

- the concentration of a give substance expressed in mg/mol of given environmental medium, which allows data comparison,
- carbon dioxide is a reference point, while the calculated environmental impact factor determines the multiplier, by which a given substance is more dangerous to the environment than CO_2.

The environmental impact factor is expressed using EIU/kg of substance, where EIU (*Environmental Impact Unit*), is unit influence

Table 2

Final evaluation of technological apparatus Best Available Technologies in using self- setting fillings in ZG Trzebionka

Lp.	Proposed solution of technological apparatus	Total score of proposed solution, points										
		Technical reality			Environmental efficiency			Economic efficiency			Average Q_{ev}	The possibility of better solutions
		A_1	W_1	$a_1 W_1$	a_2	W_2	$a_2 W_2$	a_3	W_3	$a_3 W_3$		
1	Production of self-setting fillings mixture using adhesives silica	1	2,5	2,5	3	1,7	5,1	2	1,3	2,6	3,4	0
2	Production of self-setting fillings mixture using cement	1	1,8	1,8	3	1,7	5,1	2	1,5	3,0	3,3	1
3	Production of self-setting fillings mixture using volatile ash from thermal-electric power station	1	2,2	2,2	3	1,9	5,7	2	2,2	4,4	4,1	1
4	Production of self-setting fillings mixture using modified ash	1	2,2	2,2	3	1,8	5,4	2	1,7	3,4	3,7	1
5	Production of self-setting fillings mixture using gelling agent	1	2,2	2,2	3	1,8	5,4	2	1,0	2	3,2	1
6	Existing technology using slushing filling	1	1,6	1,6	3	0,9	2,7	2	1,5	3,0	2,4	1

of natural environment. The calculated EIU factor is multiplied by the size of the load of given pollutant. Individually calculated environmental influences produced in the analysed process are summed up. The Schaltegger&Sturm method is practical, it can be used to operate on a large number of factors and allows for summaries of results of multiple evaluations. One drawback to the method is, however, the basis in allowable substance concentration, due to the fact, that this criterion has a qualitative character and may be sometimes subject to influence from social factors.

Methods for evaluating manufacture process modernisation

Methods of evaluation of ecological and economic effects of modernisation options for technical processes [3, 4, 20], or new manufacture methods contain a number of steps. They contain specifically:

- assessment of topics and field of action and assembling a problem group,
- assessing implementable options, their description and evaluation;

Problem groups may include up to several people. The set of information presented to problem groups before they start searching for solutions should include operating procedures, thermodynamic and mass balance, characteristics and sizes of waste flux, specifications of resources and final product as well as any documents pertaining to the predicted process modifications based upon laboratory and industrial research results. The main objective of the group is choosing a method of proceeding from among the options. When the group agrees upon the final number of options, it is tasked with creating a set of criteria by which the options are evaluated and compared. Often such an assessment is enriched with specific criteria, attuned to a given industrial site.

Evaluation of best available Technologies (BAT) for reusing flotation tailings of zinc and lead ore processing for producing optimal filling mixtures.

Best Available Technologies (BAT) are solutions ensuring minimum risk for the natural environment and simultaneous cost-effectiveness of production. BAT include manufacture techniques as well as environmental protection techniques. The term of BAT, not entailing excessive costs (BATNEEC) has also been introduced [21, 22].

Propositions are listed concerning criteria and methods of BAT evaluation for new technological and apparatus solutions, concerned with the development and implementation for a self-setting filling mixture, produced from flotation tailings of zinc and lead ore enrichment processes carried out in ZG Trzebionka [21,22]. Assessment of technical, ecological and economic effectiveness of these solutions has become the base of choosing the best available technology of reusing flotation tailings (Table 2). For the sake of comparison, the current filling technology, using sand fillings, was evaluated using the same set of criteria.

Individual criteria describing solution level were evaluated using a four-stage scale: as level: 0 – zero, 1 – low, 2 – medium, 3 – high. The arithmetical average of points awarded for individual criteria amounted correspondingly to partial technical, ecological and economical marks.

The evaluation of individual solutions using the method of complex quality, which includes n qualitative properties, where n may be any number. Complex quality is therefore a function of qualitative characteristics' variables:

$$Q = f(W_i) = f(W_1, W_2, \ldots, W_n) \tag{6}$$

The arithmetical average of marks (technical, ecological and economical) resulted in the average mark of a specific technological apparatus solution (BAT). The final mark was evaluated by complex quality method using the equation:

$$Q_{\acute{s}r} = (a_1 \cdot W_1 + a_2 \cdot W_2 + a_3 \cdot W_3)/3 \tag{7}$$

Average results for technical grade of new technological apparatus solutions analysed largely exceeded the boundary mark of 1.5 pt. The lowest mark obtained amounted to 1.8 pt, while the highest reached 2.5pts. Average results for ecological evaluations ranged from 5.1 pt to 5.7 pt. The economical evaluation marks ranged between 2.6 and 4.4 pt.

The cumulative mark is also largely satisfying. Individual solutions were marked in range of 3.2 to 4.1 pt. Thus the technical, ecological and economic applicability of the new proposed solutions was confirmed.

Methods for evaluating technological quality

Indicators of ecological and economic manufacture methods may be the base of comprehensive evaluation of manufacture methods assessed using the technological quality methods. In a comprehensive evaluation of development for a given technology, global indicators of cumulative risk are taken into account - $Q_{ED,}$ (ecological quality indicator), production costs - Q_K, energy consumption - Q_E, material consumption - Q_M, partial technological quality indicator – Q_J.

Calculating the technological quality indicator [2÷4,23] includes adding up mentioned partial indicators according to equation:

$$Q_T = Q_{ED} + Q_E + Q_M + Q_K + Q_J \tag{8}$$

Individual partial indicators are calculated using equation:

$$Q_J = F / Wc * Ai \tag{9}$$

Where: Q_J – partial indicator of technological quality, *F* – absolute value of analysed indicators, *Wc* – value criterion, *Ai* – importance grade. Value grades (*Wj*), importance grades (*Ai*) and value criteria (*Wc*) are determined subjectively (expert analysis).

Table 3

Comprehensive evaluation of technological quality of Sodium Chromate production variants. Listing of partial indicators

Technology quality rating	Sodium Chromate production variants indicator (F)					
	Dolomite methods	Wariant				
		A1	A2	A3	B1	B2
Global risk indicator accumulated GWS	126,6065	37,0705	-1,9938	-15,5419	-32,9642	-44,8778
The net cost, PLN/t	2512,43	1836,11	1590,10	1668,37	1083,11	1230,61
Energy consumption, GJ/t	32,93	17,30	15,63	10,62	10,29	10,29
Material consumption, kg/t	4111,2	2098,8	1522,7	1316,9	658,5	658,5
Labour consumption, m-h/t	70	40	40	38	38	38
Noise, %	100	62	50	45	45	45

Table 4

Comprehensive evaluation of technological quality of different variants of Sodium Chromate production. Technological quality calculation

Partial technological quality indicator Q_j	Assesment of quality technology			Quality technological, points Qt=F/Wc*Ai					
	Value indicator	Range of value	Importance grade	Dolomite methods	New methods-variant				
	Wc (1points=)	Wi, points	Ai		A1	A2	A3	B1	B2
Global risk indicator accumulated GWS	1,3	0-100	5	486,9	142,6	-7,7	-59,8	-126,8	-172,6
The net cost, PLN/t	25,1	0-100	4	400,4	292,6	253,4	265,9	172,6	196,1
Energy consumption, GJ/t	0,3	0-100	3	329,3	173,0	156,3	106,2	102,9	102,9
Material consumption, kg/t	41,0	0-100	1,5	150,4	76,8	55,7	48,2	24,1	24,1
Labour consumption, m-h/t	0,7	0-100	1	100,0	57,1	57,1	54,3	54,3	54,3
Noise, %	1,0	0-100	1	100,0	62,0	50,0	45,0	45,0	45,0
Technology quality rating, points				1567,0	804,1	564,9	459,8	272,1	249,8
% in relation to dolomite methods				100,0	51,3	36,0	29,3	17,4	15,9

In a comprehensive evaluation of the level of technological advancement of Sodium Chromate production (Tables 3,4) [23] included global cumulative risk indicators (Q_{ED}), production costs (Q_K), energy consumption (Q_E), material consumption (Q_M), labour consumption (Q_P) and noise emission level (Q_{Ho}).

The analysis of ecological and economic effects of technical apparatus modernisation in the manufacture processes of sodium chromate (especially the introduction of chrome waste recycling) using the method of technological quality evaluation [12, 25] confirms a substantial reduction in environmental risk caused by the process, as well as a substantial production cost reduction. Introducing the A1 variant (sodium chromate production with recycling chromic waste) allowed the increase in technological quality by 48.7% compared to the standard dolomite method. Indicators of technical quality improvements for other variants ranged from 64% to 86.1%. Effects of this magnitude result from a complete change of production structure for Sodium Chromate and using the most up-to-date technological apparatus solutions in future variants, as well as the low level for the classical dolomite method. When further variants are evaluated, the differences become less drastic, although remain on a significant level of increase in technological quality-from a few up to several percent.

Summary

In the course of evaluating a given technology, it is important to choose appropriate evaluation methods of technical, ecological and economic characteristics of manufacture processes. Evaluation methods may be of quantitative, qualitative or mixed character, and the evaluations may be partial or comprehensible. The diversity of such methods allows, on one hand, a multilateral assessment of manufacture processes, while on the other hand the choice of evaluation methods may influence the validity of results obtained.

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