Journal of Business and Economics, ISSN 2155-7950, USA
October 2014, Volume 5, No. 10, pp. 1773-1784
DOI: 10.15341/jbe(2155-7950)/10.05.2014/005

http://www.academicstar.us

Practical Aspects of Pre-evaluation of Eco-efficiency of Environmental Technologies

Włodzimierz A. Sokół
(Central Mining Institute, Plac Gwarkow 1, 40-166 Katowice, Poland)

Abstract: The development of each company operating in the global market and its competitiveness depends on the effectiveness in achieving strategic and operational objectives that are closely related to the use of eco-efficient technologies. In these times of increasing social awareness of protection against industrial pollution, decisions on the choice of technology should subside in the appropriate stage of the company environmental management system. Decisions regarding the selection of eco-efficient technologies follow from the identification of significant environmental aspects of the company's activities and their impact on the environment. On this basis, long- and short-term objectives and specific projects are determined. These projects are implemented by using environmentaly friendly technologies. There are hundreds technology offers from different countries on the market. For that reason, potential buyers will expect recommendations relating to eco-efficiency technology offers being submitted by suppliers, in order to know which one is better than another without extended and very expensive analysis. For that reason, a simplified pre-evaluation approach was developed for the assessment of the eco-efficiency of a given technology, often based on very limited numerical data. The methodology was tested on more than four hundred offers of environmental technologies submitted by suppliers from seven Baltic Sea Region countries. The results of pre-evaluation of eco-efficiency enhancement depend on the efficient use of resources, energy and reduction of emissions into the air, water and soil are presented on example of searching for clean coal technology offers for heating of buildings.

Key words: eco-efficiency; environmental technology; risk management; environmental management
JEL codes: L21, O14, Q51

1. Introduction

The development of each company operating in the global market and its competitiveness depends on the effectiveness of achieving the strategic and operational objectives of development adopted by its top management. This is closely related to the use of ecologically and economically efficient technologies. These technologies should be socially acceptable, and thus also socially efficient. In these times of increasing social awareness of protection against industrial pollution, decisions about the choice of technology should subside in the appropriate stage of company management, which greatly facilitates the establishment and functioning in an environmental

---

Włodzimierz Antoni Sokół, D.Sc.Eng, Manager of International Projects, Director of the National Contact Point, for Eco-efficient Technologies and Management Systems, Central Mining Institute; research areas/interests: sustainable development, regional environmental management, risk management, environmental technologies, power engineering, energy efficiency, resource and eco-efficiency. E-mail: w.sokol@gig.eu.

management system (EMS) that meets the requirements of international standards such as ISO 14001 (ISO 14001, 2004) or better still EMAS (EMAS, 2009). Businesses can take advantage of ready-made tools in this regard, e.g., those available through a network model and e-REMAS software (Sokół, 2011), supporting integrated environmental management at the regional and local level, but also groups of companies and individual enterprises. It is because of the exchangable internal database (Reviewing sheet) and a set of indicators relevant for any company's activity and structure. An important component of the e-REMAS model (Figure 1) is the management of business risk associated with achievement of the objectives of the organization, because every decision (especially those related to investments) is accompanied by the risk of not achieving the company objectives-ecological, economic and social.

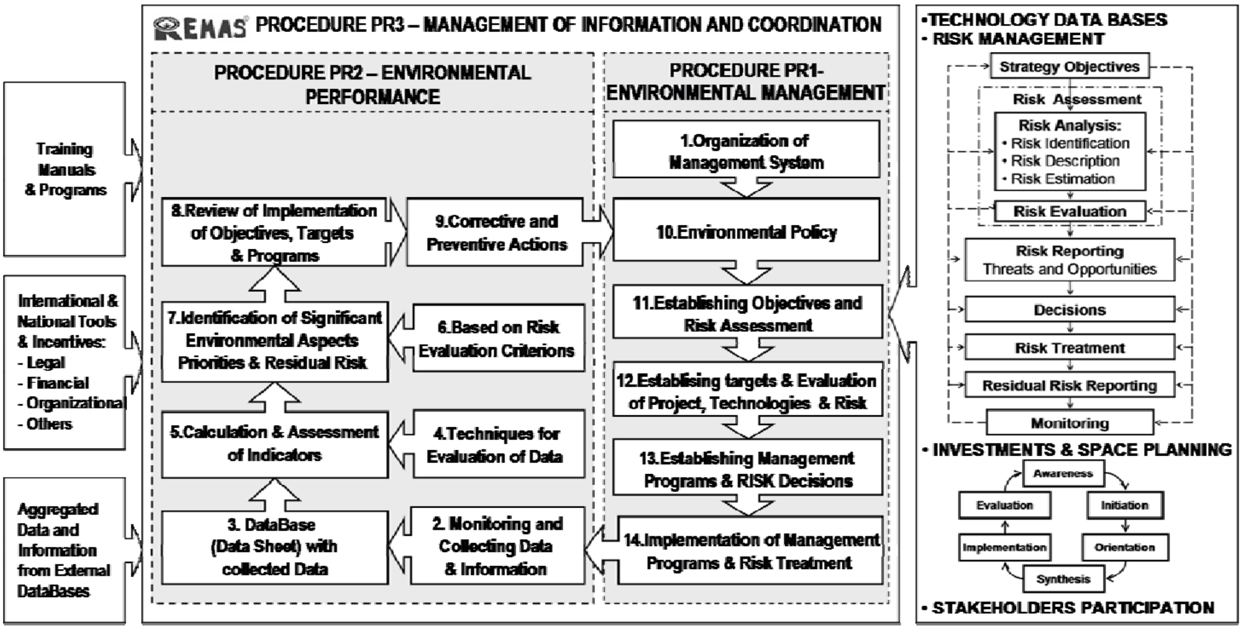


Figure 1 The e-REMAS Model (Sokół, 2013)

In a properly functioning environmental management system, decisions regarding the selection of efficient technologies are adopted as a result of the identification of significant environmental aspects of the company's activities and their impact on the environment (points 6 and 7 in Figure 1) based on collected and evaluated data (points 2-5 in Figure 1). On the basis of the fact, the environmental policy shall be determined (point 10 in Figure 1); long-and short-term objectives (point 11 in Figure 1) and specific tasks (point 12 in Figure 1). The tasks (projects) are implemented by means of specific technologies, which will enable the company to achieve its goals, including improvement of its environmental performance. They should be innovative and characterized by the highest eco-efficiency of the solutions offered on the market. The next course of action in the EMS is to develop a program of implementation for the tasks (point 13 in Figure 1) and their implementation (point 14 in Figure 1) and monitoring of the environmental performance of the company during implementation of the technology (points 2-5 in Figure 1) to allow possible corrective actions (points 8-9 in Figure 1).

Business risk is inherent in environmental management, and this risk must also be managed according to existing schemas (like AIRMIC, 2002; ISO 31000, 2009); however in e-REMAS the AIRMIC approach is applied. The selection process for the implementation of the tasks should be assessed and only those technologies which give a high probability (confidence) that the objectives (including environmental ones) of the organizations will be achieved shall be selected. Assessment of the probability and impact of a selected technology on the improvement of the environmental performance of the company and its competitiveness provide the basis for risk assessment, and whether the objectives established in the EMS will be achieved, because the technology will ensure success or otherwise, and so there is a risk of failure. Linking of risk management with the environmental management system is presented in Figure 1 and in Sokół (2013), including an example of revitalization of post-industrial site.

Conducting assessments of eco-efficiency of the technology provided for implementation leads to the success of the company. There are thousands of technologies from different countries offered on the market. Let us consider only the Polish market for environmental technologies (COM, 2004; UN AGENDA 21, 1992; Lonsdale J. et al., 2011; ETV, 2003). According to the GreenEvo report (GreenEvo, 2010), the Polish market for environmental technologies consists of about 1280 producers and distributors and is under development, searching for new areas for export and innovative solutions for new investments. The main directions of export and import of these technologies in are presented Figure 2 and Figure 3).

Figure 2 Export of Polish environmental technologies. (GreenEvo, 2010)

Figure 3 Import of pro-environmental technologies to Poland. (GreenEvo, 2010)

Evaluation of eco-efficiency is mainly available for mass products (Saling et al., 2002; Guinee, 2002; Michelsen et al., 2006; JEMAI, 2004; ISO 14045, 2012). Appropriate methodologies are still being sought for technology assessment. Many evaluation efforts have failed because they lacked important data relating to the life cycle assessment (LCA) of the technology and relied upon simplified assumptions to overcome this lack of sufficient data for an eco-efficiency analysis. Moreover, a full LCA depends on assumed system boundaries and on features of the tools applied, such as ecoindicator 99 (Goedkoop, Effting & Collignon, 2002; ISO 14044, 2006) and others. Meanwhile, potential buyers (very often small, medium and micro companies (in Poland over 1 700 000 are SMEs and 96% are micro-enterprises)), will expect quick recommendations relating to the eco-efficiency of technology offers being submitted by the suppliers, in order to know which one seems to be better than the others, without extended and highly costly analysis. For that reason, a simplified pre-evaluation approach was developed for assessment of the eco-efficiency of a given technology, often based on limited numerical data from the beginning in the framework of the international project SPIN, presented in Kaunus (Sokół, 2011). This was then tested as a task of the EFFECT project (EFFECT 2012) on examples of over 400 technology offers from Baltic Sea Region countries and LONGLIFE-INVEST (LONGLIFE INVEST 2012) for a new investment: an energy efficient dormitory building for Klaipeda University in Lithuania. Examples of implementation of the methodology for sustainable revitalization of post-industrial sites are presented in Sokół (2013). The methodological details and its practical aspects are discussed more extensively in this paper and illustrated by means of the example of searching for clean coal technology offers as option for heating systems for buildings.

2. Pre-evaluation of Eco-Efficiency of Environmental Technologies

Pre-evaluation of the probability that the technology offers are suitable is a part of the project evaluation. Depending on the importance of the technology for the project, coupled with product knowledge which is provided with the technology offer, the technologies are categorized into different "bins" because of the probability of achieving the efficiency declared by the supplier. The probability that the project is able to achieve the expected objectives after implementation of the selected technology (in the framework of a given investment project) influences the allocation of a technology to a specific bin. Putting a technology offer in a selected bin is valid, assuming the supplier describes the technology in sufficient detail. If the supplier submits numeric data on the technology, with a confirmed efficiency in comparison to the situation before implementation of the technology, or to reference solution, then the eco-efficiency of the technology eco-efficiency is pre-evaluated.

Inspired by JEMAI (2004), a simple approach to the enhancement of eco-efficiency of an improved technology developed is illustrated as follows (Sokół, 2013):

$$\Delta E[\%] = 100 \cdot (E_{new} / E_{old} - 1) = 100\left\{\sqrt{3} / \sqrt{\sum_{i=1}^{3} I_i^2} - 1\right\} \tag{1}$$

Where: $$I_i = \sqrt{\frac{1}{n_i}\sum_{j=1}^{n_i} I_{ij}^2}, \quad i = 1\text{-}3,\ j = 1\text{-}n_i \tag{2}$$

$$I_{ij} = \sqrt{\frac{1}{n_j}\sum_{k=1}^{n_j} I_{ijk}^2}, \quad i = 1\text{-}3,\ j = 1\text{-}n_i,\ k = 1\text{-}n_j \tag{3}$$

$$E_{new} = \frac{V_{new}}{I_{new}} = \frac{1}{(I_{new}/V_{new})} = 1/\sqrt{\sum_{i=1}^{3} I_i^2} \quad \text{and} \quad E_{old} = \frac{1}{\sqrt{3}} \tag{4}$$

In Equations (1) to (4) $\boldsymbol{I_{ij}}$, $\boldsymbol{I_{ijk}}$ and $\boldsymbol{I_i}$ are the relative environmental impact of a new technology (improved):

$$I_{ijk} = \left(\frac{I_{ijk,new}}{V_{new}}\right) / \left(\frac{I_{ijk,old}}{V_{old}}\right) \tag{5}$$

and:

$\boldsymbol{I_1}$ – Efficiency of resources, i.e., the degree of reduction in raw material consumption, e.g., water, fossil fuels etc.,

$\boldsymbol{I_2}$ – Efficient use of energy that includes the degree of the reduction in the consumption of primary energy,

$\boldsymbol{I_3}$ – Emissions released, i.e., the degree of reduction of emissions into air, water and soil and the content of environmentally harmful substances etc.,

$\boldsymbol{n_i}$ – quantity of the parameters $\boldsymbol{I_{ij}}$ in the framework of the environmental impacts $\boldsymbol{I_i}$,

$\boldsymbol{n_j}$ – quantity of the parameters $\boldsymbol{I_{ijk}}$ in the framework of the environmental impacts $\boldsymbol{I_{ij}}$,

$\boldsymbol{E_{new}}$, $\boldsymbol{E_{old}}$ – the eco-efficiency of the new and old technologies, respectively,

$\boldsymbol{V_{new}}$, $\boldsymbol{V_{old}}$ – technology value of the new and old solutions, respectively,

$\boldsymbol{I_{ij,new}}$, $\boldsymbol{I_{ij,old}}$ – environmental impact of the new and old solutions, respectively.

In Equation (1), it is assumed that for an old technology (before implementation of improvements), each component of the environmental impact is represented by $I_i = 1$. If the new technology does not show improvement in a component, the value remains equal to 1. Equations (2) and (3) (i.e., the average sum of squares) is used when a few improvements I_{ij} were implemented relating to one environmental impact I_i, or a few improvements I_{ijk} were implemented relating to one environmental impact I_{ij}; however Equation (3) is an option for grouping specific impacts under the term I_{ij} for example those relating to waste, emissions into the air, materials etc., if relevant.

Pre-assessment of the eco-efficiency enhancement (ΔE) assumes that the system boundaries apply to the technology only and that external changes are negligible. The accuracy of this evaluation depends on the numerical data submitted by the technology supplier. This approach can motivate a potential buyer to ask for more detailed data to allow assessment of eco-efficiency for the full life cycle.

3. Results of Testing the Methodology

The methodology was tested on 415 selected offers for environmental technologies submitted by suppliers from seven Baltic Sea Region (BSR) countries: Denmark, Estonia, Finland, Germany, Lithuania, Poland and Sweden, being considered for the SPIN and ACT CLEAN databases (www.actclean.gig.eu). The suppliers of these technology highlights have marked 102 offers as energy efficient, 22 as renewable energy resource technologies, and 16 as remediation offers. Results of a pre-evaluation of the eco-efficiency ΔE [%] of selected energy-efficient technology offers from BSR are presented in Sokół (2013); however, with giving an extended description of site remediation technology. For that reason, this description is developed in this paper for four selected clean coal technology options identified while searching for technology offers for heating systems for dormitory building in Klaipeda (LONGLIFE INVEST 2012) to increase energy efficiency and to reduce CO_2 emission.

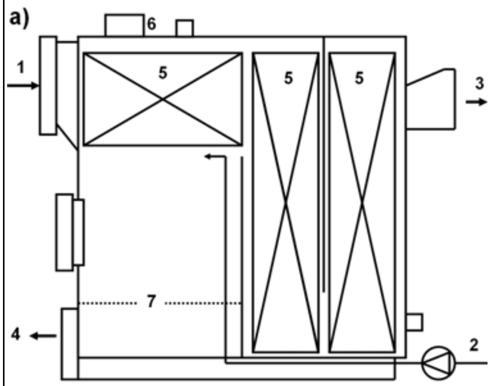
The data of the technology offers for clean use of coal in buildings for heating are presented in Tables 1-4 (Czaplicka, Sciazko, 2004). In this example, the offers contained a lot of data, because they were collected for research purposes, however not coal but wood pellets were finally selected for heating a building in Klaipeda. In general, technology offerings include only a single datum or only a description without any numerical figures.

In the case, the data relate to the following: a boiler with a culm chamber (a), a boiler with a fixed grate (b), a boiler with a moving grate (c) and a boiler retort furnace (d). The basic parameters, relevant units and values are given in columns 1-3. The technology parameters are ranked in four groups: technology value V_1, resource efficiency I_1, energy efficiency I_2 and efficiency in reduction of emissions I_3. Columns 5 and 6 present the relative values, i.e., I_{ijk}/V_1 and their units. The energy efficiency section I_2 includes external consumption of electricity I_{21} for use within the system for driving fans, feeders and powering the control panel; thermal losses I_{22} are also included because the process efficiency $\eta < 1$.

In this case, Equation (2) is used to calculate I_2 as average sum of squares of I_{21} and I_{22}.

Efficiency in the emission reduction section I_3 include: the release of ash I_{31} and emissions into the air I_{32} that include five emissions I_{321} - I_{325} namely SO_2, CO_2, NO_x, CO and dust, respectively. In this case, Equation (3) is used to calculate the impact I_{31} as the average sum of squares of I_{31} and I_{32}; however impact I_{32} is calculated using Equation (3) as the average sum of squares of I_{321} - I_{325}. This approach is a useful option because it permits assessment of the separate impacts of ash release and emissions into the air; however, application of Equation (2) only for all six parameters is acceptable, and in that case leads to the same conclusions in relation to the efficiency of the pre-evaluated technologies.

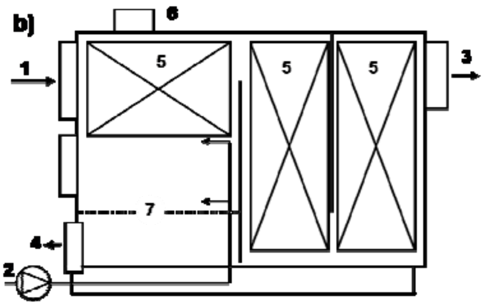
Table 1 Technology T1-Boiler with Culm Chamber



1- solid fuel, 2 – air, 3 – outlet gasses, 4 – ash, 5 – heat exchangers, 6 – control panel, 7 – furnace

Parameter	**Unit**	**A**	**B**	**Unit**	**A/** V_{11}
1	2	3	4	5	6
Technology value-V_1					
Energy production	kW	12	V_{11}	kW/kW	1
1. Resource efficiency-I_1					
Fuel consumption	kg/h	2.1	I_{11}	kg/kWh	0.175
2. Energy efficiency–I_2					
Energy consumption	kW	0.12	I_{21}	kW/kW	0.01000
Energy losses	kW	2.8380	I_{22}	kW/kW	0.23650
3. Efficiency in emission reduction–I_3					
3.1. Wastes–I_{31}					
Ash release	kg/h	0.497	I_{31}	kg/kWh	0.04142
3.2. Emissions to air–I_{32}					
Emission-SO_2	kg/h	0.0125	I_{321}	kg/kWh	0.00104
Emission-CO_2	kg/h	3.3	I_{332}	kg/kWh	0.27500
Emission-NO_x	kg/h	0.0153	I_{343}	kg/kWh	0.00128
Emission-CO	kg/h	0.1134	I_{344}	kg/kWh	0.00945
Emission-Dust	kg/h	0.0014	I_{365}	kg/kWh	0.00012

Table 2 Technology T2-Boiler with Fixed Grate



1- solid fuel, 2 – air, 3 – outlet gasses, 4 – ash, 5 – heat exchangers, 6 – control panel, 7 – fixed grate

Parameter	**Unit**	**A**	**B**	**Unit**	**A/** V_{11}
1	**2**	**3**	**4**	**5**	**6**
Technology value -V_1					
Energy production	kW	20	V_{11}	kW/kW	1
1. Resource efficiency -I_1					
Fuel consumption	kg/h	3.2	I_{11}	kg/kWh	0.16000
2. Energy efficiency -I_1					
Energy consumption	kW	0.15	I_{21}	kW/kW	0.00750
Energy losses	kW	5.6027	I_{22}	kW/kW	0.28013
3. Efficiency in emission reduction –I_3					
3.1. Wastes –I_{31}					
Ash release	kg/h	0.51	I_{31}	kg/kWh	0.02550
3.2. Emissions to air –I_{32}					
Emission - SO_2	kg/h	0.0323	I_{321}	kg/kWh	0.00162
Emission - CO_2	kg/h	12.4	I_{322}	kg/kWh	0.62000
Emission - NO_x	kg/h	0.0106	I_{323}	kg/kWh	0.00053
Emission - CO	kg/h	0.1743	I_{324}	kg/kWh	0.00872
Emission - Dust	kg/h	0.0283	I_{325}	kg/kWh	0.00142

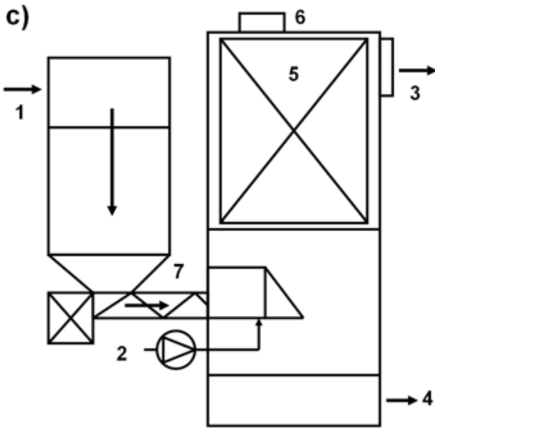
In Equations (1), (2) and (3), I_{ij}, I_{ijk} and I_i respectively refer to the relative environmental impact of a new technology (improved) or to a reference solution, and not absolute values. This means that we have to define which technology has to be considered as the reference for pre-evaluation of the eco-efficiency enhancement ΔE of other technologies.

Identifying the reference solution is essential because the eco-efficiency enhancement ΔE is not calculated by taking direct the values from column 6 of Tables 1 to 6 to the Equations (2) or (3), but by using Equation (5).

If technology T1 (Boiler with culm chamber) is selected as the reference and the aim is the evaluation of the eco-efficiency enhancement ΔE for technology T2 (Boiler with fixed grate), then applying Equation (5), for example for $\boldsymbol{I_{11}}$, we obtain:

$$I_{11}(T2) = \left(\frac{I_{11}(T2)}{I_{11}(T1)} \right) = \frac{0.160}{0.175} = 0.914 \tag{6}$$

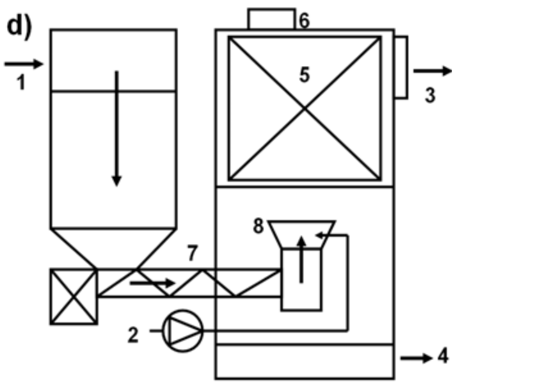
Table 3 Technology T3-Boiler with Moving Grate



1- solid fuel, 2 – air, 3 – outlet gasses, 4 – ash, 5 – heat exchangers, 6 – control panel, 7 – feeder

Parameter	**Unit**	**A**	**B**	**Unit**	**A/V_{11}**
1	**2**	**3**	**4**	**5**	**6**
Technology value –V_1					
Energy production	kW	35	V_{11}	kW/kW	1
1. Resource efficiency - I_1					
Fuel consumption	kg/h	5.6	I_{11}	kg/kWh	0.16000
2. Energy efficiency-I_2					
Energy consumption	kW	0.35	I_{21}	kW/kW	0.01000
Energy losses	kW	9.8047	I_{22}	kW/kW	0.28013
3. Efficiency in emission reduction - I_3					
3.1. Wastes - I_{31}					
Ash release	kg/h	0.73	I_{31}	kg/kWh	0.02086
3.2. Emissions to air-I_{32}					
Emission - SO_2	kg/h	0.0549	I_{321}	kg/kWh	0.00157
Emission - CO_2	kg/h	22.4	I_{332}	kg/kWh	0.64000
Emission - NO_x	kg/h	0.0511	I_{343}	kg/kWh	0.00146
Emission - CO	kg/h	0.0270	I_{344}	kg/kWh	0.00077
Emission - Dust	kg/h	0.0062	I_{365}	kg/kWh	0.00018

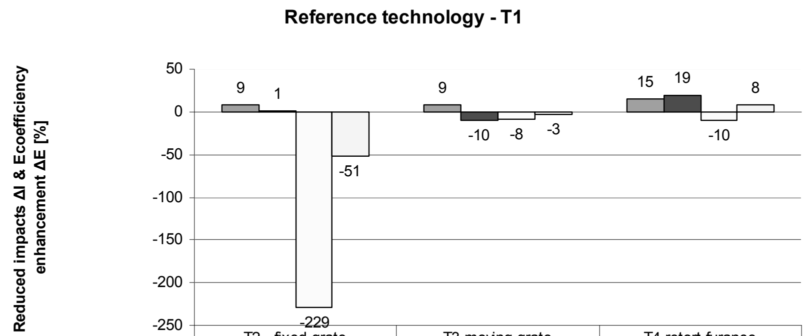
Table 4 Technology T4–Boiler with Retort Furnace



1- solid fuel, 2 – air, 3 – outlet gasses, 4 – ash, 5 – heat exchangers, 6 – control panel, 7 –feeder, 8 – retort furnace

Parameter	**Unit**	**A**	**B**	**Unit**	**A/ V_{11}**
1	**2**	**3**	**4**	**5**	**6**
Technology value - V_1					
Energy production	kW	25	V_{11}	kW/kW	1
1. Resource efficiency – I_1					
Fuel consumption	kg/h	3.7	I_{11}	kg/kWh	0.14800
2. Energy efficiency – I_2					
Energy consumption	kW	0.21	I_{21}	kW/kW	0.00840
Energy losses	kW	4.6031	I_{22}	kW/kW	0.18412
3. Efficiency in emission reduction – I_3					
3.1. Wastes – I_{31}					
Ash release	kg/h	0.5	I_{31}	kg/kWh	0.02000
3.2 Emissions to air – I_{32}					
Emission - SO_2	kg/h	0.0557	I_{321}	kg/kWh	0.00223
Emission - CO_2	kg/h	12.3	I_{332}	kg/kWh	0.49200
Emission - NO_x	kg/h	0.0297	I_{343}	kg/kWh	0.00119
Emission - CO	kg/h	0.0169	I_{344}	kg/kWh	0.00068
Emission - Dust	kg/h	0.0053	I_{365}	kg/kWh	0.00021

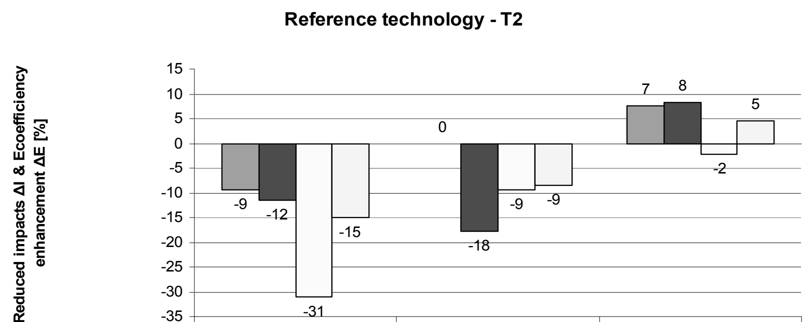
This means that technology T2 reduced the impact $\boldsymbol{I_1}$ (i.e., consumption of fuel) by $\boldsymbol{\Delta I_1}$ = 8.6%. This result is presented in Figure 4 as well as results for $\boldsymbol{I_2}$ and $\boldsymbol{I_3}$ and the eco-efficiency enhancement $\boldsymbol{\Delta E}$. Figures 5, 6 and 7 present the same results if technologies T2, T3 and T4 are taken as reference technologies for the others.



	T2 - fixed grate	T3-moving grate	T4-retort furance
ΔI1 - Resources	9	9	15
ΔI2 - Energy	1	-10	19
ΔI3 - Emissions	-229	-8	-10
ΔE [%]	-51	-3	8

Technology No

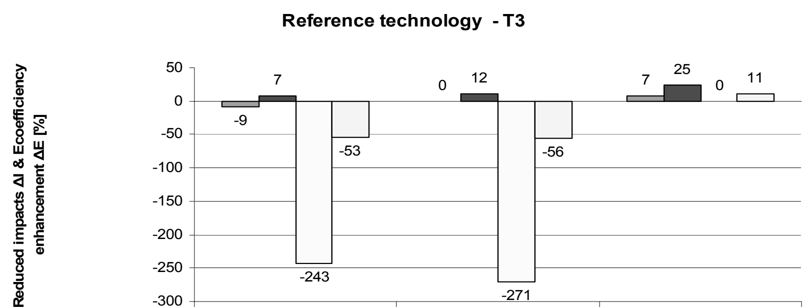
Figure 4 Eco-efficiency Enhancement *ΔE* of Technologies T2, T3 and T4 if the Reference Technology Is T1



	T1-culm chamber	T3-moving grate	T4-retort furance
ΔI1 - Resources	-9	0	7
ΔI2 - Energy	-12	-18	8
ΔI3 - Emissions	-31	-9	-2
ΔE [%]	-15	-9	5

Technology No

Figure 5 Eco-efficiency Enhancement *ΔE* of Technologies T1, T3 and T4 if the Reference Technology Is T2



	T1-culm chamber	T2 - fixed grate	T4-retort furance
ΔI1 - Resources	-9	0	7
ΔI2 - Energy	7	12	25
ΔI3 - Emissions	-243	-271	0
ΔE [%]	-53	-56	11

Technology No

Figure 6 Eco-efficiency Enhancement *ΔE* of Technologies T1, T2 and T4 if the Reference Technology Is T3

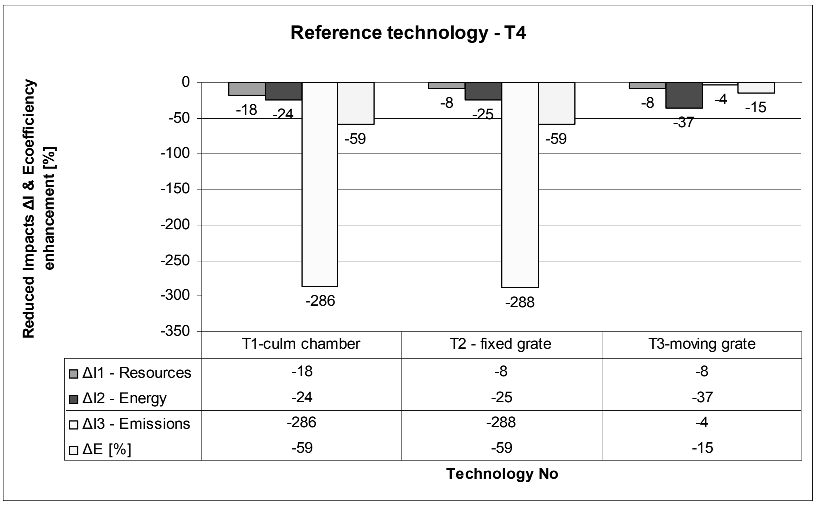


Figure 7 Eco-efficiency Enhancement *ΔE* of Technologies T1, T2 and T3 if the Reference Technology Is T4

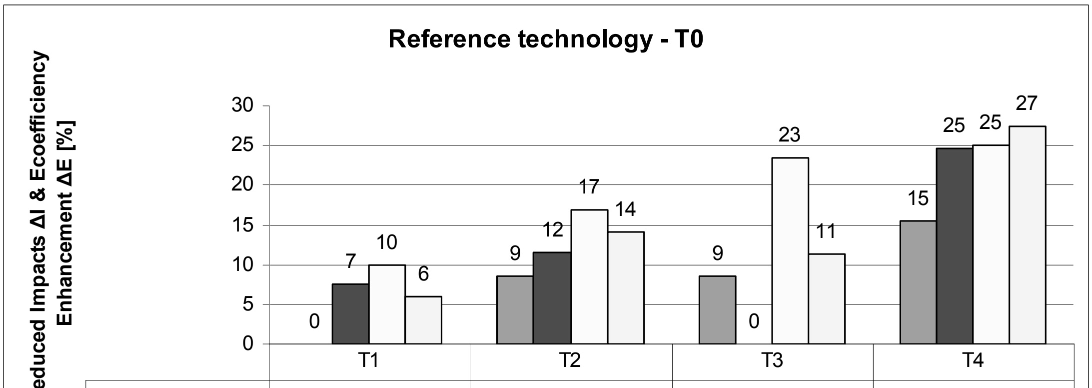
The positive values of I_i in Figures 4, 6 and 7 indicate a reduction of environmental impact I_i (and conversely for negative values). Positive values of ΔE indicate that the eco-efficiency has increased compared with the reference technology; negative values indicate a decrease. Analysis of Figures 4 to 7 leads to the conclusion that technology T4 (boiler with retort furnace) is the most ecoeffective in comparison with the reference technology (T1) and the other technologies (T2 and T3).

For benchmarking of technology offers it is best to use a different technology as a reference instead of one of these four. It has to be less eco-efficient. It should be the least effective in relation to the other options. For that reason in Table 5 reference technology T0 having the worst performance of all four technologies is proposed, i.e., the worst parameters of Tables 1, 2, 3 and 4 are chosen.

Table 5 Reference Technology T0

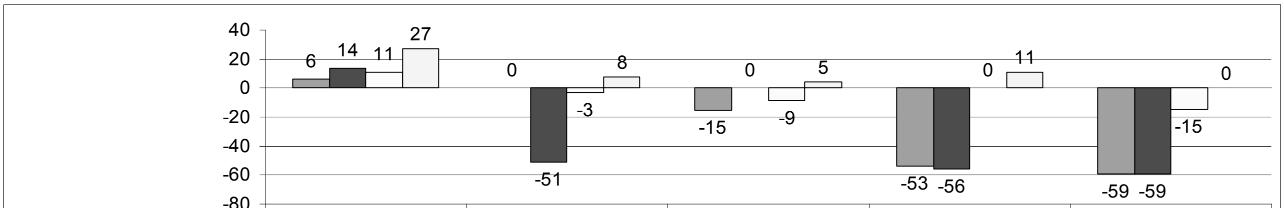
Parameter	No	Unit	Max Value
Technology value-V_1			
Energy production	V_{11}	kW/kW	1
1. Resource efficiency-I_1			
Fuel consumption	I_{11}	kg/kWh	0.17500
2. Energy efficiency–I_2			
Energy consumption	I_{21}	kW/kW	0.01000
Energy losses	I_{22}	kW/kW	0.28013
3. Efficiency in emission reduction–I_3			
3.1 Wastes–I_{31}			
Ash release	I_{31}	kg/kWh	0.04142
3.2 Emissions to air–I_{32}			
Emission-SO_2	I_{321}	kg/kWh	0.00223
Emission-CO_2	I_{332}	kg/kWh	0.64000
Emission-NO_x	I_{343}	kg/kWh	0.00146
Emission-CO	I_{344}	kg/kWh	0.00945
Emission-Dust	I_{365}	kg/kWh	0.00142

The resulting eco-efficiency enhancement ΔE of technologies T1, T2, T3 and T4 if the reference technology is T0 is presented in Figure 8. Eco-efficiency enhancement ΔE of technologies T1, T2, T3 and T4 depends on which technology is selected as the reference, as shown in Figure 9.



	T1	T2	T3	T4
ΔI1 - Resources	0	9	9	15
ΔI2 - Energy	7	12	0	25
ΔI3 - Emissions	10	17	23	25
ΔE [%]	6	14	11	27

Figure 8 Eco-efficiency Enhancement *ΔE* of Technologies T1, T2, T3 and T4 if the Reference Technology Is T0



	Reference - T0	Reference -T1	Reference - T2	Reference - T3	Reference -T4
DE1 for T1-culm chamber	6	0	-15	-53	-59
DE2 for T2-fixed grate	14	-51	0	-56	-59
DE3 for T3-moved grate	11	-3	-9	0	-15
DE4 for T4-retort furnance	27	8	5	11	0

Figure 9 The Eco-efficiency Enhancement *ΔE* of Technology Options Depends on which Technology Is Used as the Reference

The use of reference technology T0 is better at presenting the environmental impacts and eco-efficiency enhancement with respect to each technology. The conclusion is the same: that technology T4 (Boiler with retort furnace) is the most ecoeffective in comparison with the reference technology and the other technologies (T1, T2, T3 and T4).

The question is how to proceed if the technology offer includes as technology value $\boldsymbol{V_1}$ more than one component, i.e., $\boldsymbol{V_{11}}$, $\boldsymbol{V_{12}}$, etc? In this case, the best approach is to calculate the eco-efficiency enhancement separately for each component of $\boldsymbol{V_1}$, i.e., $\boldsymbol{\Delta E_{11}}$, $\boldsymbol{\Delta E_{12}}$, etc. However, the average sum of squares can be used for evaluation of the combined $\boldsymbol{\Delta E}$, but in practice a potential buyer likes to know the eco-efficiency related to each technology value.

The next question relates to the economic and social efficiency of the technology. The methodology is general (see Equations (1) to (5)) and different technology values and different impacts can be considered, but assessment of the technology's economic and social efficiency during relevant steps of company environmental management system is recommended (see Figure 1), taking into account existing and potential risks. In this case, not only the technology offer is evaluated, but the whole project (the task, or tasks). How this is done for the case of sustainable revitalization of post industrial sites can be seen in Sokół (2013).

Eco-efficiency evaluations always consider the whole life cycle (ISO 14045:2012; JEMAI, 2004; Goedkoop, Effting & Collignon, 2002; etc.). Eco-efficiency pre-evaluation is a relative (not absolute) assessment, assuming changes in the technology system, which is why the boundaries of the system mainly include the use of technology. In the cases considered for pre-evaluation of technology offers for clean use of coal for heating in buildings, this assumption is reasonable because changes may involve negligible fuel preparation and transportation of the same from afar. Good practice would be to assess the risks posed by the real emission changes throughout the life cycle of the technologies analyzed. If the supplier provides data on the remaining life cycle stages of the technology (such as the extraction of raw materials and fuels, transportation and disposal) then these impacts will be evaluated. In practice, technology offers include only fragmented data. In the case of the more than 400 technology offers reviewed within the framework of the EFFECT project (EFFECT, 2012), less than 56% included any numeric data and none related the full life cycle. The data contained in offers frequently describe selected technical characteristics of the technology and are not compared with earlier solutions, competitors' solutions or reference technologies.

4. Conclusions

The methodology presented is an easy and useful tool for initial assessment of the eco-efficiency of environmental technologies offered by their respective suppliers. Moreover, the methodology facilitates assessments of how the solutions reducing consumption of resources and energy and emissions into air, water and soil will improve the environmental performance of the purchasing company after the application of the technology in relation to the system previously used or a competitor's system.

The technology's impact on economic and social efficiency has to be evaluated during the relevant steps of the company environmental management system, taking into account existing and potential risks and rather separately (not by aggregation with eco-efficiency of environmental impacts) to better see all influents.

Eco-efficiency pre-evaluation means a relative (not absolute) assessment performed assuming that the boundaries of the system mainly include the use of technology, however, it is worth assessing the risk of that simplification. It does not preclude a full LCA and eco-efficiency analysis for the selected solution within the environmental management system, if the supplier provides sufficient data.

References:

AIRMIC (2002). "Risk management standards", *ALARM*, IRM: 2002.

COM (2004). "Final: Communication from the commission to the council and the European Parliament", *Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union*, Brussels, 28.1.2004.

Czaplicka K. and Sciazko M. (2004). "Model of prognosis of environmental and economic extraction and using clean coal", Part 2, *Eco-Efficiency of Clean Combustion of Coal*, Central Mining Institute, Katowice, 2004. (in Polish)

EMAS (2009). Regulation (EC) No 1221/2009 of The European Parliament and of The Council of 25 November 2009 on the voluntary participation by organizations in a Community eco-management and audit scheme (EMAS), repealing Regulation (EC) No 761/2001 and Commission Decisions 2001/681/EC and 2006/193/EC.

EFFECT (2012). "Dialogue platform on energy and resource efficiency in the Baltic Sea Region", available online at: http://www.cbss.org/environment-and-sustainability/baltic-21-lighthouse-projects/.

Environmental Technology Verification (ETV) Program (2003). "Case studies: Demonstrating program outcomes", *EPA/600/R-06/001*.

Goedkoop M., Effting S. and Collignon M. (2002). *The Eco-indicator 99: A Damage Oriented Method for Life Cycle Impact Assessment—Manual for Designers* (2nd ed.).

GreenEvo (2010). "Rynek polskich technologii środowiskowych (Polish market of environmental technologies)", *GreenEvo*, September 2010

Guinee J. B. (2002). "Handbook on life cycle assessment: Operational guide to the ISO standards", *Int. J LCA*, Vol. 7, No. 5.

ISO 31000 (2009). "Risk management—Principles and guidelines".

ISO 14001 (2004). "Environmental management systems—Requirements with guidance for use".

ISO 14044 (2006). "Environmental management—Life cycle assessment—Requirements and guidelines".

ISO 14045 (2012). "Environmental management—Eco-efficiency assessment of product systems—Principles, requirements and guidelines".

Japan Environmental Management Association for Industry (JEMAI) (2004). *Eco-Efficiency and Factor Handbook for Products*: *Japan Environment Public Release Draft*, January 2004.

LONGLIFE-INVEST (2012). "The implementation of the planned Lithuanian Long life pilot project as a dormitory for Klaipeda University", accessed on 30 March 2014, available online at: http://longlife-invest.eu/jml/.

Lonsdale J. et al. (2011). "Detailed assessment of the market potential, and demand for, an EU ETV scheme", *EPEC*, June 2011.

Michelsen O., Magerholm Fet A. M. and Dahlsrud A. (2006). "Eco-efficiency in extended supply chains: A case study of furniture production", *Journal of Environmental Management*, Vol. 79, pp. 290-297.

Saling P., Kicherer A., Dittrich-Kramer B. and Wittlinger R. et al. (2002). "Eco-efficiency analysis by BASF: The method", *Int. J LCA*, Vol. 7, No. 4, pp. 203-218.

Sokół W. A. (2011). "Biogas in regional environmental management system: Eco-energetics-biogas and syngas", in: Gdanska Wyższa Szkoła Administracji, *Technologies, Legal Framework, Policy and Economics in Baltic Sea Region*, Gdańsk, pp. 40-41.

Sokół W. A. (2011). "Pre-evaluation of eco-efficiency of environmental technologies", in: *International Conference "Sustainable Consumption and Production 2011"*, Kaunus, 30 September 2011.

Sokół W. A. (2013). "A methodology for pre-evaluation of ecoefficiency of environmental technologies for sustainable revitalization of post-industrial sites", in: *Contaminated Soils, Sediments, Water & Energy*, Vol. 19, *Proceedings of the 29th Annual International Conference on Soils, Sediments, Water & Energy*, Amherst, October 21-24 2013. pp. 132-155, accessed 30 March 2014, available online at: http://www.aehsfoundation.org/ecc-proceedings.aspx.

UN AGENDA 21 (1992). *United Nations Conference on Environment & Development Rio de Janerio*, Brazil, 3 to 14 June, 1992.