POLITYKA ENERGETYCZNA
Tom 15 ✧ Zeszyt 1 ✧ 2012
ISSN 1429-6675

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Abiotic depletion in energy and waste management systems

ABSTRACT. Abiotic resources are defined as natural sources (including energy sources), such as iron ore and crude oil, which are regarded as "non living". Abiotic depletion is one of the impact categories to be taken into account in Life Cycle Assessment. It is also one of the most frequently discussed impact categories. Energy generation is usually linked with the consumption of natural resources. Abiotic depletion is strongly dependent on used forms of electricity generation.

On the other hand, waste management systems could be treated as a source of "negative emission", as well as a significant means of conserving natural resources. Combining both systems in abiotic depletion terms would be interesting.

The LCA analysis presented in the paper focuses on natural resource usage calculated for power systems in different countries of the EU, and compared with possible conservation of natural resources linked with different recycling options. The paper also discusses the influence of waste management systems on mineral resource management, and the promotion of different types of waste recycling and other forms of waste utilization on a national scale.

KEY WORDS: abiotic depletion, LCA waste management, energy

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Introduction

Life Cycle Thinking (LCT) is an approach that takes into consideration all the aspects of the life cycle of products and services before they are even planned, produced and distributed (Baldo 2000; Bauer et al. 2008; UNEP SETAC 2007). The most important tool of the LCT approach is Life Cycle Assessment (LCA). Proper environmental evaluation is a crucial issue that should always be taken into consideration in order to insure sustainable development in practice (Pikoń, Gaska 2010; Pikoń 2008, 2008a, 2003).

LCA is a technique to assess the potential environmental impacts associated with a product or service throughout its life cycle using the following process:

- Goal and scope definition: defining suitable goal and scope for the LCA study.
- Inventory analysis: compiling an inventory of relevant inputs and outputs of a production system.
- Impact assessment: evaluating the potential environmental impacts associated with the selected inputs and outputs.
- Interpretation: interpreting the results.

LCA considers the potential environmental impacts throughout a product's life cycle (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. Examples of categories of environmental impacts included in commercial LCA software tools are resource use, human health, acidification, eutrophication, photo-oxidants formation and others. The limitations of the LCA technique can be overcome by complementing it with other tools and methods, e.g. Environmental Risk Assessment. The International Standards ISO 14040-14043 provides principles, a framework, and methodological requirements for conducting LCA studies.

The methodology used to perform this task is largely based on Life Cycle Analysis methodology. Available published information on impact categories, methods and indicators includes, for instance, CML guidelines (Guinée et al. 2001). CML is a method developed in the Centre of Environment Science of Leiden University in The Netherlands.

Following the ISO 14042 requirements, first a list of impact categories has to be defined, and characterisation factors for relating the environmental loads to suitable category indicators for these impacts have to be selected. Next, the results of applying those factors are calculated and then normalised to indicate the share of each of them in a regional total. Finally, the normalisation results are grouped and weighted to include societal preferences toward the various impact categories.

The result of applying this methodology is a final score for each technology analyzed, allowing for a well-balance comparison among them, including a comparison of time periods [needs clarification].

In the impact assessment phases, the results of the inventory analysis are translated into contributions to relevant impact categories which have to be predefined. The inventory analysis has consisted of defining all of the inputs from the environment (raw materials, fuels) and outputs to the environment (energy, emissions), which enter and go out of a power generation facility.

One of the impact categories used in standard CML evaluation is Abiotic Depletion.

Abiotic resources are natural resources (including energy resources), such as iron ore and crude oil, which are regarded as non-living. Several optional methods for the assessment of abiotic resource depletion are used. Depending on the definition, different methodologies have been developed, including different definitions of impact categories. In some cases, abiotic resource depletion encompasses both the use of non-renewable and renewable abiotic resources (wind, flowing water etc.). This study is focused on abiotic resource depletion according to the definition given in the classic LCA methodology, where only non-renewable sources are taken into consideration (Guinee et al. 2001).

The characterisation model is a function of natural reserves of resources combined with their rates of extraction. The natural reserves of these resources are based on ultimate reserves. The characterisation factor is the Abiotic Depletion Potential (ADP). This factor is derived from each extraction of elements and fossil fuels and is a relative measure with the depletion of the reference element. In this example, antimony is used as a reference element. Mass flow of an element or fossil fuels used is multiplied with the characterisation factor (ADP given in kg of antimony equivalents/kg used material, for instance, fuel) to obtain the Abiotic Depletion Indicator (ADI) given in kg of antimony equivalent (related to functional unit). It can be described by the following equation:

$$ADI = \sum_{i=1}^{n} ADP_i \cdot m_i$$

where: *ADI* – abiotic depletion indicator [kg of antimony eq./Functional Unit],
ADP – characterization factor – Abiotic Depletion Potential [kg of antimony eq./kg of *i* substance],
n – of sample substances or fuels,
m – mass of sample element or fuel *i* [kg of *i* substance/Functional Unit].

The Abiotic Depletion Potential can be calculated using the following equation (Ministry of Environment, Netherlands 2002):

$$ADP_i = \frac{\frac{DR_i}{(R_i)^2}}{\frac{DR_{ref}}{(R_{ref})^2}}$$

where: *ADP* – Abiotic Depletion Potential of resource *i,*
R_i – ultimate reserve of resource *i* [kg],
DR_i – extraction rate of resource *i* [kg/year],
R_{ref} – ultimate reserve of the reference resource, antimony [kg],
DR_i – extraction rate of reference resource, antimony [kg/year].

The analysis is usually made using relative values. All values should be related to Functional Unit. The functional unit is a key element of LCA which has to be clearly defined. The functional unit is a measure of the function of the studied system, providing a reference to which the inputs and outputs can be related. This enables the comparison of two different systems.

The values of ADP could be found in several sources, such as inventory databases.

Abiotic depletion is one of several environmental impact indicators used to asses the overall environmental preference of the evaluated process. In order to cerate the single score, weighting factors can sometimes be applied. Weighting factors may be chosen by expert panels. As there is no recommended set of weighting factors, we have used those resulting from a social panel approach (Guinée et al, 2001):

- Abiotic depletion: 0.01
- Global warming: 2.4
- Human toxicity: 1.1
- Fresh water aquatic ecotoxicity: 0.2
- Marine aquatic ecotoxicity: 0.2
- Terrestrial ecotoxicity: 0.4
- Photochemical oxidation: 0.8
- Acidification: 1.3
- Eutrophication: 1.0

Surprisingly – so far abiotic depletion is treated as the least important environmental impact indicator in the whole LCA analysis.

Energy production

The non-renewable sources of energy are usually: hard coal, lignite, crude oil, natural gas or nuclear processes.

The energy systems usually use not one but many different sources. The energy mix in EU countries is shown in table 1.

The structure of energy source utilization is different in different EU countries. It is determined mainly by each country's existing resources. For instance, the UK previously used crude oil and natural gas as a source of energy mainly because this country is an important producer of those fuels. Similarly in Poland, the main source of energy is coal because this country is the largest producer of this fuel in Europe. Nuclear power is a very important source of energy in many countries. For instance, France is able to cover 40% of all energy needs form this source. A similar situation can be fount in Sweden (37%), Lithuania (37%), Slovakia (23%), Bulgaria (22%) or Belgium (22%).

As a consequence, usage of 1 kWh of electric energy is linked with different consumption of natural resources – depending on the system of energy production. As shown in table 2, the differences can be significant.

TABLE 1. Total energy consumption mix in 2008 in different EU countries (Energy Mix 2008)

TABELA 1. Udział poszczególnych źródeł energii w całkowitym zapotrzebowaniu na energię w różnych krajach Unii Europejskiej

	Fossil fuels [%]	Crude oil [%]	Gas [%]	Nuclear [%]	Renewable [%]	Other [%]
Austria	12	42	23		21	2
Belgium	11	37	27	22	2	1
Bulgaria	36	22	13	22	5	2
Cyprus	2	94	0	0	4	0
Czech Republic	42	20	17	15	3	3
Denmark	21	41	23	0	14	1
Estonia	56	18	13	0	10	3
Finland	20	29	10	16	23	2
France	5	33	14	40	6	2
Greece	30	57	7	0	5	1
Spain	15	49	18	12	6	0
Holland	11	38	45	1	3	2
Ireland	15	59	23	0	2	1
Lithuania	2	25	23	37	7	6
Luxemburg	2	64	26	0	2	6
Latvia	1	30	29	0	36	4
Malta	0	100	0	0	0	0
Germany	25	36	23	12	4	0
Poland	58	24	13	0	5	0
Portugal	13	57	13	0	15	2
Romania	23	26	35	4	12	0
Slovakia	24	19	29	23	4	1
Slovenia	21	36	12	19	11	1
Sweden	6	29	2	37	26	0
Hungary	13	24	44	12	4	3
UK	16	35	38	9	2	0
Italy	9	45	36	0	7	3

TABLE 2. Average relative resources consumption (given in kg/kWh) during electricity generation according to energy mix in different countries (den Boer E. at al. 2005a)

TABELA 2. Średnie względne zużycie surowców [kg/kWh] w procesie wytwarzania energii elektrycznej w różnych krajach Unii Europejskiej (den Boer E. at al. 2005a)

	Poland	Czech Rep.	Holland	Germany	Finland	UK	Sweden	France
chromium (ore)	8,90E-06	1,50E-05	1,20E-05	2,30E-05	2,60E-05	1,80E-05	2,60E-05	4,50E-05
coal hard	3,60E-01	8,80E-02	1,50E-01	1,50E-01	6,90E-02	1,80E-01	1,10E-02	2,90E-02
coal soft, lignite	4,70E-01	6,00E-01	5,70E-02	3,10E-01	2,80E-02	2,60E-03	1,00E-03	1,70E-03
copper (ore)	1,20E-05	1,00E-05	1,30E-05	1,70E-05	1,00E-05	8,50E-06	5,60E-06	5,90E-06
iron (ore)	1,20E-03	8,20E-04	9,70E-04	8,10E-04	7,00E-04	8,70E-04	3,70E-04	4,70E-04
manganese (ore)	3,70E-06	2,00E-06	2,10E-06	2,30E-06	2,40E-06	2,00E-06	2,20E-06	1,70E-06
molybdenum (ore)	4,80E-07	2,60E-07	2,60E-07	3,00E-07	3,00E-07	2,60E-07	2,80E-07	2,00E-07
natural gas	8,80E-03	1,70E-02	1,40E-01	2,60E-02	2,90E-02	8,70E-02	2,10E-03	5,50E-03
nickel (ore)	2,80E-05	3,10E-05	2,90E-05	4,40E-05	4,70E-05	3,60E-05	4,40E-05	7,10E-05
oil crude	7,60E-03	3,70E-03	1,10E-02	6,10E-03	5,40E-03	9,90E-03	3,10E-03	4,80E-03
tin (ore)	7,00E-09	1,50E-08	1,40E-08	9,20E-09	1,20E-07	1,60E-08	2,50E-08	8,40E-09

Of vital importance (and linked with the previously quoted information) to every environmental analyses is the technology of power generation. Each technology has its own emission characteristics. Some examples are shown in table 3. The analysis presented here is made on the basis of the LCA approach. As a result, all commonly called "zero emission" technologies are shown to create their own environmental impact – including for instance photovoltaic cells. This technology, treated as extremely clean, in fact is not as clean as we might have expected. It is linked with positive environmental impact categories including abiotic depletion. The same type of installation (for instance, a coal power plant) could have a different environmental impact due to differences in emissions (note for instance NOx emission in the Bayswater hard coal power plant and Lindell). The abiotic depletion could also be different, due for instance to differences in efficiencies.

An analysis of table 1, 2 and 3 indicates that the localisation of the installation consuming energy (which, in fact, each one does) is a crucial issue in each environmental evaluation. The energetic [energy?] system used to power each installation is an issue of paramount importance for environmental impact evaluation.

So far, energetic systems are designed on a national level. That is why it is reasonable and convenient to assume that energy consumed in one country is a mix of energy sources and

TABLE 3. Environmental impact due to technology of electricity generation technology (Wibberley et al. 1999)

TABELA 3.Wpływ na środowisko różnych technologii wytwarzania energii elektrycznej (Wibberley et al. 1999)

	NO_x [kg/GJe]	SPM [g/GJe]	GHG [Mg CO_{2eq}/GJ]	SO_x [kg/GJe]	Energy consumption [GJ/GJe]	Fresh water consumption [m^3/GJe]
Coal power plant – Liddell	0,8	27	0,28	1,3	3,1	0,02
Biomass – co-combustion	0,8	26	0,25	1,19	2,8	0,005
mCoal power plant – Bayswater	0,63	23	0,26	1	2,9	0,49
Natural gas	0,57	0,3	0,18	0	3	0
Photovoltaic cell	0,38	5	0,04	0,15	0,3	0,05
Biomass IGCC	0,18	7	0,01	0,07	0,15	0,38
Nuclear power plant	0,07	0,3	0,01	0,08	0,02	0,49
Wind turbine Crookwell	0,01	0,53	0,001	0,05	0,02	0,002
Hydro power plant – Eildon Weir	0,01	0,47	0,069	0	0,01	0,002

technologies which is fairly easy to determine. If we go further, we could gain complex data about all environmental impacts in all impact categories including abiotic depletion. Results of the LCA analysis of that issue on an EU scale is presented in fig. 1.

The same technology or installation consuming electric energy could consume a different amount of natural resources depending on the location where it is operating, and could be treated as an extremely environmentally friendly and sustainable technology, or devastating for the environment. For instance, introducing electric car engines in Norway could be treated as a part of a sustainable program because of the very low consumption of natural resources linked with it. The same program introduced in Greece could have quite a different effect on the environment. The equivalent consumption of natural resources in Greece is 212 times higher than in Norway.

We must remember that the energy mix is not stable and is gradually changing.

While thermal generation totalling over 430 GW, combined with substantial hydro and nuclear power, has long served as the backbone of Europe's power production, Europe is steadily making the transition away from conventional power sources and towards renewable energy technologies. Between 2000 and 2007, total EU power capacity increased by 200 GW to reach 775 GW. The most notable change in capacity is the near doubling of gas capacity to 164 GW. Wind energy more than quadrupled from 13 GW to 57 GW. The growth of natural gas and wind power has taken place at the expense of fuel oil, coal and nuclear

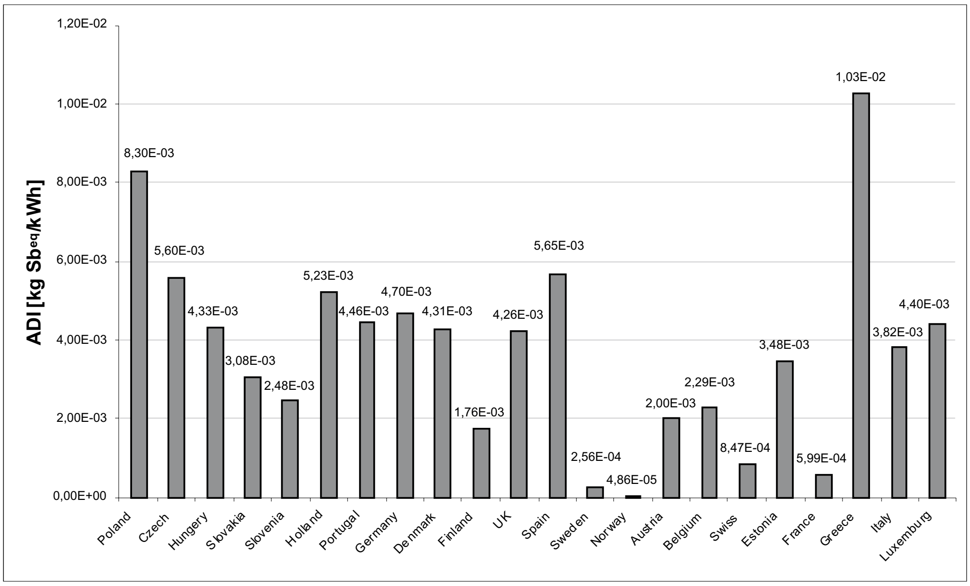

Fig. 1. ADI for electric energy production in different EU countries given in kg Sb eq/kWh

Rys. 1. Wskaźnik ADI (wyczerpywanie surowców mineralnych) produkcji energii elektrycznej w różnych krajach Unii Europejskiej wyrażony w kg Sb eq/kWh

power. In 2007, 21.2 GW of new capacity was installed in the EU-27, of which 10.7 GW was gas (50 percent) and 8.6 GW was wind power (40 percent) (EWEA 2011).

Waste Management

Originating in the concept of the so-called "waste hierarchy", prevention of waste production constitutes the basis of current European policy on waste. Ideally, in the first place, we should not produce waste. If this is not possible, waste must be reused, recycled, and recovered, to limit landfill as much as possible (European Commission 2006). This hierarchy should not be seen to be a rigid prescription because the environmental impacts of a waste management system depend on a great number of geographic, economic, social and technological factors. Different waste treatment solutions can cause different environmental impacts (Buttol et al. 2007; McDougall et al. 2001).

A waste management system is usually complex. There is no single, "optimal" waste utilization technology. Because of the variety of waste types, we are forced to use many types and technologies of waste processing. Each of them has a different environmental impact. For instance, recycling is suspected to have a positive influence on the environment. Recovered materials from household wastes that are reprocessed can be used to replace virgin materials, possibly resulting in overall savings in raw materials, energy consumption and emissions to air, water and soil. As a result, some environmental relief can occur (table 4). It is represented by a negative ADI. If the ADI is positive, it means that we face an environmental burden – or, in other words, some portion of abiotic resources, given in Sb equivalents, are consumed. A negative ADI indicates that some natural resources are saved as a result of the action taken.

TABLE 4. Abiotic Depletion Indicators of various recycling types

TABELA 4. Wskaźnik wyczerpywania surowców mineralnych (ADI) dla różnych typów recyklingu

Type of recycling	ADI [kg Sb_{eq}/Mg]
Glass	-1,45E+00
Paper	3,08E+00
Cardboard	-4,32E-01
Aluminium	-2,36E+01
Metals (tinplate)	-9,54E+00
PET	-2,59E+01
Other plastics	-1,26E+01

The values presented in table 4 are interpreted on the basis of the LCA approach. It shows the difference of obtaining the material from recycling and from virgin material. They therefore show the real effect of recycling. The calculations were made on the basis of data normalised for Europe (den Boer E. et al. 2005a).

Data placed in table 4 show that nearly all types of recycling could have a positive influence on natural resource consumption. The only exception is paper recycling, which makes the additional consumption of 3,08 kg Sb_{eq}/Mg of recycled paper.

Different waste management systems could save different quantities of natural resources.

As an example, the analysis of 4 different scenarios is given. In each scenario, waste could be treated using recycling technologies, landfilling and incineration. Landfilling could create environmental relief due to biogas utilisation for energetic purposes. The assumed acquisition rate of biogas is 50%. As a result, some portion of energy created in normal power plants (based on the energy mix in Poland) could be replaced. Incineration results in a similar situation. Its major objective at present is to produce energy. In each scenario, the ratio of application of those technologies is different. This is shown in table 5. General information about the assumed fraction composition of waste is given in table 6. Unfortunately, not all materials can be recycled. The reasonable maximum threshold was applied in scenario 3.

Results of the analysis are given in table 7. Notably, quantities of Sb equivalent due to waste utilization can be quite large, but different in different systems. The lowest is in scenario 0, which is based on landfilling only. If we change this situation and introduce a system based on scenario 1, the difference per Mg of waste would be as high as 5,85 kg Sb_{eq}.

TABLE 5. Description of scenarios under analysis

TABELA 5. Charakterystyka analizowanych scenariuszy

	Recycling	Incineration	Landfilling
Scenario 0	0%	0%	100%
Scenario 1	6%	46%	49%
Scenario 2	0%	46%	54%
Scenario 3	26%	0%	74%

TABLE 6. Fraction composition of waste and ration of fractions directed into different forms of utilization in scenario 1

TABELA 6. Skład frakcyjny odpadów oraz oraz udział frakcji kierowanych do różnych form utylizacji w scenariuszu 1

	Waste composition [%]	Recycling ratio of single fraction [%]	Incineration ration of single fraction [%]	Landfilling ration of single fraction [%]
Paper	14	10	30	60
Cardboard	5	10	30	60
Glass	8	10	10	80
Non-iron metals	2	10	20	70
Iron metals	5	10	20	70
Plastics (film)	3	10	80	10
Hard plastics	5	20	70	10
PET	6	20	70	10
Textiles	4	0	90	10
Prganic substances	30	0	50	50
Other	18	0	50	50

At present in Poland, we have a municipal waste management system similar to scenario 0. The total quantity of municipal waste generated each year (2004) is 11 802 Mg (KPGO 2010). A reshaping of the waste management system from scenario 0 to one similar to scenario 1, 2 or 3 could provide significant savings in natural resource consumption. This is shown in table 7.

The results of all scenarios are affected by assumed allocation of the systems (Poland). The energy production is present in all scenarios. Therefore, some avoided emissions and natural resources consumption is also presented for Polish conditions.

TABLE 7. Values of Abiotic Depletion Indicator calculated for different scenarios

TABELA 7. Wartości wskaźnika wyczerpywania surowców mineralnych (ADI) wyliczone dla różnych scenariuszy

	ADI [kg Sbeq/Mg]	Change of ADI [kg Sbeq/Mg]	National scale ADI [kg Sbeq/year]	National scale Change of ADI (scenario 0 – baseline) [kg Sbeq/year]
Scenario 0	-6,86E-02	0	-8,10E+02	0,00E+00
Scenario 1	-5,92E+00	-5,85E+00	-6,99E+04	-6,91E+04
Scenario 2	-5,39E+00	-5,32E+00	-6,36E+04	-6,28E+04
Scenario 3	-1,99E+00	-1,92E+00	-2,35E+04	-2,27E+04

Sustainability

Sustainable development (SD) is a pattern of resource use which aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come. The term was used by the Brundtland Commission, which coined what has become the most often-quoted definition of sustainable development, development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN 1987, Smith, Rees 1998).

Environmental sustainability is the process of insuring that current processes of interaction with the environment are pursued with the intention of keeping the environment as pristine as naturally possible based on ideal-seeking behaviour.

Sustainability is a complex of social, economic and environmental issues. What is important and present in the contemporary approach is that we should not separate indices of economic, environmental, and social sustainability, but somehow combine them. We should emphasize the links between economic development, environmental degradation, and population pressure instead of viewing them as three independent subjects. In other words, we should be focused on viewing the economy and the environment as a single, interlinked system with a unified valuation methodology (Hamilton 1999; Pearce, Markandya, Barbier 1989).

One system is not separated form the other.

Each action, in order to gain environmental benefits, should be seen from the economic perspective. Each invested monetary unit could give different environmental results. Seeking solutions in energetic systems to achieve sustainability, we used to forget that the environment should be treated as a whole. Sometimes it would be more effective to invest in one sector rather than another in order to gain higher environmental benefits.

From this perspective, obligatory thresholds (for instance renewable energy ratio) seem to be a less than optimal solution. If the investment of 1 dollar in system 1 could gain a negative environmental impact in the abiotic depletion category of 1 kg of Sb_{eq}, why should we invest 10 dollars in system 2 in order to gain the same result? Maybe it would be wiser to invest 10 dollars in system 1 to gain 10 kg of Sb_{eq} benefit? After all, it doesn't matter whether natural resources are consumed by system 1 or 2. I does matter that they are consumed – and it is important to minimize this consumption as much as possible.

General objectives for environmental sustainability can be summarised as rational resource consumption. Allocation of expenses is a crucial issue. The decision makers should optimize their decision taking into consideration the environmental effect. If we would like to focus the analysis on mineral resources, the Abiotic Depletion Indicator would be helpful. In sustainability terms the best solution, as far as abiotic resources conservation is concerned, should be defined according to following equation:

$$\frac{dADI_i}{dIC_i} \rightarrow \max$$

where: dIC – investment cost of solution i,
$dADI_i$ – change of abiotic depletion indicator due to solution i.

What is important – not only the single systems should be analysed [meaning unclear]. As examples of waste management systems shown, some reserves much more efficient – in sustainability terms – could be gained in different sectors of the economy [meaning unclear].

Waste management and power systems are not separate. The reserve energy available from waste is quite high. The relationship can be shown using the Abiotic Depletion Replacement Indicator. This indicator makes it possible to compare and express abiotic depletion in one system in units of the other. The general concept is to seek equilibrium between the waste management functional unit and the power system functional unit. In other words, we would like to express Mg of waste in kWh of electric energy as the equivalent of abiotic depletion caused by each system. It could be done using following equation:

$$ADI_{system1} - ADRI_{system2}^{system1} \cdot ADI_{system2} = 0$$

where: $ADI_{system1}$ – Abiotic Depletion Indicator of system 1 [kg Sb eq/FU of system 1] ,
$ADI_{system2}$ – Abiotic Depletion Indicator of system 2 [kg Sb eq/FU of system 2],
$ADI_{system2}^{system1}$ – Abiotic Depletion Replacement Indicator of functional units of system 1 and 2.

Continuing the example of scenarios from the previous chapter, we could calculate the Abiotic Depletion Replacement Indicator of the waste management system (WMS) and power system (PS). Further, we can calculate this indicator on a national scale, taking into consideration the volume of MSW generated annually. The results are given in table 8.

The quantities in table 8 are quite large. They show the replacement potential of waste management system changes in the future. A national scale change of $ADRI_{WMS}^{PS}$ could be as high as – 8,32 E+06 kWh per year. We could treat this figure as a maximal quantity of electricity which cold be "purified" from abiotic depletion by changes in the waste management system.

TABLE 8. Abiotic Depletion Replacement Indicators for waste management system and power system calculated for Polish conditions in year 2004

TABELA 8. Wskaźniki zastąpienia wyczerpywania surowców mineralnych dla systemów gospodarki odpadami i energetycznego wyliczone dla warunków polskich w roku 2004

	$ADRI_{WMS}^{PS}$ [kWh/Mg of waste]	National scale $ADRI_{WMS}^{PS}$ [kWh/year]	National scale Change of $ADRI_{WMS}^{PS}$ (scenario 0 – baseline) [kWh/year]
Scanario 0	–8,27	-9,75E+04	0,00E+00
Scenario 1	–713,25	-8,42E+06	-8,32E+06
Scenario 2	–649,40	-7,66E+06	-7,57E+06
Scenario 3	–239,76	-2,83E+06	-2,73E+06

A proper evaluation is needed to determine whether, for instance, the transformation of a power system to reduce its resource consumption is less expensive (in economic terms) than the transformation of a waste management system to save the same amount of Sb_{eq} in the Abiotic Depletion impact category.

Conclusions

Power systems consume large amount of depletable natural resources. According to sustainable development policy, we should introduce actions to reduce the consumption of these resources as much as possible. This requires changes in power systems – for instance, the introduction of new technologies and generally the termination of hard coal utilization for energy production. This is not the only solution, not the optimal solution. According to the modern concept of sustainable development, we should treat the environment as a whole and make optimal decisions in environmental, economic and social terms. The aim is reducing abiotic depletion in any sector of the economy. The decision of where to invest in order to gain the best results should be made on the basis of proper LCA-based analysis focused on power systems, but also other areas such as waste management.

A national abiotic depletion inventory of all possible processes should be conducted. On this basis, we would make optimal decisions as to which process should be modified first in order to gain maximal environmental benefits with respect to abiotic depletion.

Acknowledgements

This work was financed by the Polish Ministry of Science and Higher Education as the research work from funds for science in year 2011.

References

BALDO G.L., 2000 – LCA Life Cycle Assessment. Uno strumento di analisi energetica e ambientale. Ipaservizi Editore, Milan, Italy.

BAUER C., BUCHGEISTER J., HISCHIER R., POGANIETZ W.R, SCHEBEK L., WARSEN L., 2008 – Towards a framework for life cycle thinking in the assessment of nanotechnology. Journal of Cleaner Production 16, 910–926.

BUTTOL et al. 2007 – BUTTOL P., MASONI P., BONOLI A., GOLDONI S., BELLADONNA V., CAVAZZUTI C., 2007 – LCA of integrated MSW management systems: case study of the Bologna district. Waste Management 27, 1059–1070.

Cycle Inventory, second ed. Blackwell Science Ltd., Oxford, United Kingdom.

Den BOER E. et al., 2005a – Deliverable Report on D3.1 and D3.2: Environmental Sustainability Criteria and Indicators for waste management (Work Package 3), Technische Universitaet Darmstadt.

Den BOER E., Den BOER J., JAGER J., 2005 – Waste Management Planning and Optimisation – Handbook for Municipal Waste Prognosis and Sustainability Assessment of Waste Management Systems. Ibidem Verlag, Stuttgart, Germany.

European Commission, 2006 – Directive 2006/12/EC of the Parliament and of the Council of 5 April 2006 on Waste, European Commission, Brussels.

European Wind Energy Association – EWEA – available http://www.wind-energy-the-facts.org – access July 2011.

GUINÉE et al., 2001 – Life Cycle assessment. An operational guide to the ISO standards. Final report.

HAMILTON K., CLEMENS M., 1999 – Genuine savings rates in developing countries. World Bank Econ Review, 13(2): 333–56.

KPGO – Krajowy Plan Gospodarki Odpadami (National Waste Mangement Plan) 2010.

McDOUGALL et al. 2001 – McDOUGALL F., WHITE P., FRANKE M., 2001 – Integrated Solid Waste Management: Life.

PEARCE D., MARKANDYA A., BARBIER E., 1989 – Blueprint for a green economy. Earthscan, London, Great Britain.

PIKOŃ K., 2003 – Environmental Impact of combustion – Applied Energy 75 (213-220), Elseiver.

PIKOŃ K., 2008 – Environmental aspects of municipal waste to energy systems, conference proceedings. Second International Syposium on Energy form Biomass and Waste, Venice 2008, International Waste Working Group, ISBN 978-88-6265-004-5.

PIKOŃ K., 2008 a – Environmental performance of Polish waste incineration plants. Polish Journal of Enviromnetal Studies, vol 17, no 3A.

PIKOŃ K., GASKA K., 2010 – Greenhouse gases emission mitigation relevant to changes in MSW management system. Journal of Air & Waste Management Association, 60 (7), pp. 782–788.

Road and Hydraulic Engineering Institute of the Dutch Ministry of Transport, Public Works and Water Management (V&W), Abiotic resource depletion; improving characterisation factors for abiotic resource depletion in LCA, 2002

SMITH C., REES G., 1998 – Economic Development, 2nd edition. Basingstoke: Macmillan. ISBN 0333722280.

UNEP, SETAC, 2007 – Life Cycle Management – A Business Guide to Sustainability. United Nations Environment Programme, Paris, France.

United Nations, 1987 – Report of the World Commission on Environment and Development. General Assembly Resolution 42/187, 11 December 1987. Retrieved: 2007-04-12.

Krzysztof PIKOŃ

Wyczerpywanie surowców mineralnych w systemach energetycznych i gospodarki odpadami

Streszczenie

Zasoby naturalne są zwykle utożsamiane ze źródłami energii oraz surowców, takich jak ruda żelaza czy ropa naftowa. Zubażanie surowców mineralnych jest jedną z kategorii wpływu w analizach LCA, która zawsze pojawia się we współczesnych analiz środowiskowych. Jest to również jedna z najczęściej dyskutowanych kategorii. Wytwarzanie energii jest zwykle związane z konsumpcją zasobów naturalnych na dużą skalę. Jej skala jest bardzo silenie uzależniona od technologii wytwarzania energii. Z drugiej strony znajduje się system gospodarki odpadami, który może stać się źródłem poważnych oszczędności jeśli chodzi o konsumpcję surowców naturalnych. Połączenie obu systemów w kategoriach konsumpcji zasobów naturalnych może przynieść ciekawe rezultaty.

W pracy zostały przedstawione analizy LCA ukierunkowane na kategorie wpływu „zubożenie zasobów mineralnych" w systemach energetycznych różnych krajów Unii Europejskiej. Przestawione zostały porównania i nakreślony związek pomiędzy systemem energetycznym i systemem gospodarki odpadami. Przestawiony został również potencjalny wpływ na gospodarkę surowcami mineralnymi oraz rola jaką może odegrać promocja poszczególnych metod zagospodarowania odpadów w skali ogólnopolskiej.

SŁOWA KLUCZOWE: wyczerpywanie surowców mineralnych, LCA, gospodarka odpadami, energia