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Eco-efficiency as Part of Sustainable Farm Development[1]

Abstract: This paper shows the possible use of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) methodologies in analysing the eco-efficiency of agriculture. To use the descriptive and analytic method, the issue of product life-cycle costs identification and assessment was presented (assumptions for the methodology of costing in terms of impacts characterising the emissivity of production processes). A detailed analysis was performed of eco-costs which are not addressed in traditional enterprise accounts. Determining the eco-efficiency of agricultural production systems is consistent with the sustainable agricultural development concept and is a crucial aspect of CSR compliance in the agricultural sector. This is a conceptual paper and a starting point for further discussion and empirical studies.

Keywords: eco-efficiency, LCA, LCC, eco-costs

JEL: D2, M1, M3, L2

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1. Introduction

According to some authors (Siekierski, Rutkowska, 2008), the sustainable development (SD) concept is rooted in such early ideas as the works of Aristotle and Hippocrates, who believed that the whole is more than the sum of its parts (the world is composed of systems, and humans are not only a combination of organs and cells but also include a self-organising system which coordinates the phenomena operating in the external and internal environment). Thus, a system-based approach to the understanding of the world, which is so characteristic of the sustainable development concept, originates from a philosophy preaching the unity of everything.

The foundations for the future concept were co-developed by classical economists who investigated growth limits (the Malthusian Theory of Population), those who established the law of diminishing returns in agriculture, and the authors of the ground rent theory. Also, that topic was addressed by representatives of neoclassical economy, Marxism, institutional economics, and Keynesian economics (Landreth, Colander, 2005).

In the modern era, the term "sustainable development" emerged for the first time in the context of forestry, and meant managing the forest so as to prevent its disappearance and so that it may always be renewed (a forest management concept by H.C. von Carlowitz). In the early 1800s, that concept was promoted by all German forestry universities, and was translated into English as "Sustained Yield Forestry". Many years later, the term "sustainable" was appropriated by the environmental movement; soon (in the 1970s and 1980s), SD became a part of the political debate (Club of Rome, UN). The last four decades witnessed the emergence of many definitions of sustainable development[2]. Recently, SD has become an inherent part of the environmental policy, socio-economic policy and development strategies at all levels (from the local up to the global level).

The SD concept also has a noticeable impact on the operations and strategic objectives of today's enterprises which include: gaining a competitive edge, reducing the costs, improving the efficiency and implementing environmentally-friendly management methods (while addressing specific social expectations and maintaining relationships with various stakeholder[3] groups). This is especially important for enterprises which are not indifferent to their environmental impact. Changes in the micro- and macro-environment, escalating customer demands and the ever stronger environmental restrictions force enterprises to implement new meth-

2 Many papers have attempted to structure the terminology, including the authors' studies (cf. Bieńkowski, Jankowiak, 2006 or Jankowiak, Bieńkowski, 2010; Baum, 2011).

3 These enterprises implement the Corporate Social Responsibility (CSR) and sustainable production concepts. In recent years, the Circular Economy concept has also gained importance. It assumes that an environmental impact may be minimised by choosing reusability-oriented components and design methods.

ods for production and environmental management which may contribute to the above-mentioned objectives. One of such objectives is the eco-efficiency concept which takes account of economic and environmental aspects in the improvement of products and processes/technologies. The analysis of eco-efficiency is an instrument enabling the selection of best-quality, environmentally benign solutions (Burchart-Korol, Kruczek, Czaplicka-Kolarz, 2013a; Baum, 2018).

When assessing activities of enterprises (including in the agriculture[4], notably through the specifics of its relationships with the environment), all elements of production processes should be considered in terms of potential threats to the environment and cost generation throughout the product lifecycle. A fragmentary assessment of processes based on single environmental effects – or only on economic effects – is not enough as it fails to provide a comprehensive analysis which is assumed to be a prerequisite for sustainable development (Baum, Śleszyński, 2008). If the analysis is limited to only one period of a product's lifetime (e.g.: the production phase), it does not allow us to specify the costs of the product and its environmental impact in the longer term (i.e. later on, at the use and disposal stage).

The purpose of this paper is to present the issue of product life-cycle costs identification and assessment or – more precisely – assumptions of the methodology for determining costs in terms of impacts characterising the emissivity of production processes. The eco-efficiency of farming activities will be based on the product Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) methodologies. Eco-costs which are not addressed in traditional enterprise accounts will be detailed in the product lifecycle.

A descriptive and analytical method was used in this paper. It consists in thoroughly describing the selected topic and the use of the selected tool (LCA, LCC, eco-costs) in the context of specific socio-economic realities. Also, the method includes the presentation of the authors' own thoughts, assessments and conclusions regarding the topic discussed. The considerations were supported with graphics (figures and diagrams).

4 As regards farms, focus needs to be placed on the specific nature of land as a productive input. Agriculture is widely regarded as the "first industry" of mankind which used the productive capacity of land and resulted in the delivery of food products. Both the agriculture and the environment are important for human life. Agriculture continues to be the only way of providing food to humans; whereas the environment is indispensable for human life. The agriculture and environment interoperate with each other, impact each other and are related to vital, inseparable needs of humans, and therefore each alone and combined together require a special approach (cf. Bivona, 2007).

2. Eco-efficiency analysis

The definition of eco-efficiency is inseparably linked to the sustainable development concept. In 1991, the World Business Council for Sustainable Development (WBCSD) defined eco-efficiency as the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle[5]. The Organisation for Economic Cooperation and Development (OECD) defines eco-efficiency as combining economic and environmental efficiency to satisfy customer needs, and as the ratio of customer value to environmental indices. According to the European Environment Agency (EEA), eco-efficiency is a key concept of enterprise management in pursuit of sustainable development objectives (Czaplicka-Kolarz, Burchart-Korol, Krawczyk, 2010).

While allowing to reduce resource consumption and environmental impact, the analysis of eco-efficiency also enables increasing the value added of a product and improving the economic efficiency of production processes (Ekins, 2005; Huppes, Ishikawa, 2005). Depending on the relationship between total costs and the environmental impact, different variants of eco-efficiency may be identified (Figure 1). Eco-efficiency analyses of different product or technology variants may result in different eco-efficiency indices which may serve as the basis for ranking the technologies or products under consideration.

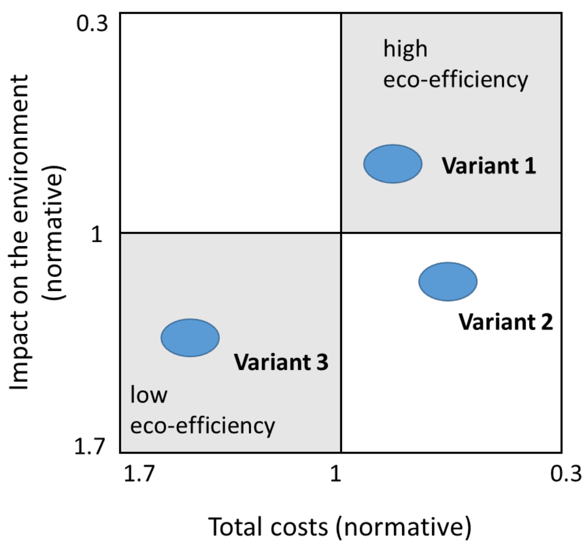

Figure 1. Different variants of eco-efficiency

Source: Czaplicka-Kolarz, Burchart-Korol, Krawczyk, 2010: 267–271

5 Cf. www.wbcsd.org [accessed: 29.04.2018].

Therefore, the basic eco-efficiency analysis is a function of two indices: the environmental index and the economic index. As mentioned earlier, according to WBSCD, eco-efficiency combines the economic index of value generated with environmental burden indices. While the eco-efficiency index may be defined in various ways, the following formula is the one most frequently used (Burchart-Korol, Kruczek, Czaplicka-Kolarz, 2013b):

$$\text{Eco-efficiency} = \\ = \text{Product (commodity or service) value/Environmental impact.} \qquad (1)$$

As shown by a literature study, eco-efficiency analyses may be performed for various sectors and products (extraction industry, petrochemical industry, timber and paper industry, waste management, electrical and electronic equipment)[6]. According to sources cited in the bibliography, the eco-efficiency analysis concepts takes account of different environmental indices. Also, the studies rely on various methods and techniques[7].

The assessment of product life cycle, and the related assessment of the product's life cycle costs, are of particular importance for eco-efficiency analyses.

3. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC)

The LCA concept stems from strategic management and marketing. The marketing approach is underpinned by the product's market life cycle whose assumptions, however, do not include the product's R&D stage. Consequently, the life cycle is limited to the following successive stages: introduction – growth – maturity – decline (Nowak, Piechota, Wierzbiński, 2004; Klinowski, 2008)[8].

6 Cf. Huisman, Stevels, Stobbe, 2004; Salmi, 2007; Van Caneghem et al., 2010; Charmondusit, Keartpakpraek, 2011; Wang et al., 2011; Zhao, Huppes, Voet, 2011.

7 Methods and techniques employed include: Life Cycle Assessment (LCA), Net Present Value (NPV), Life Cycle Costing (LCC), LCA expressed with the Normalised Global Warming (NGW) index, LCC expressed with the Normalised Cost (NC) index, Environmental Damage Costs (EDC), Cost-Benefit Analysis (CBA), Dynamic Generation Cost (DGC) or Economic Value Added (EVA). Eco-efficiency may be forecasted with multi-criteria analyses and various IT tools, such as neural networks (cf. Czaplicka-Kolarz, Burchart-Korol, Krawczyk, 2010; Burchart-Korol, Kruczek, Czaplicka-Kolarz, 2013b).

8 The following sequence may also be found in the relevant literature: development – growth – expansion – maturity – saturation – decline (cf. Biernacki, 2003).

This is not enough from the perspective of managerial accounting where the product's life cycle is considered to be a model which, on the one hand, reflects the product's ability to generate income and, on the other hand, forecasts the related costs. Note also that a "product" means a product class rather than a single unit; and that it may include both physical goods and services. Based on the literature study (Sobańska, Michalak, 1999; Nowak, 2000), it may be concluded that the approach presented above enables the identification of the following life cycle stages:

1) research and development,
2) introduction to the organisation's environment,
3) development,
4) maturity,
5) decline,
6) withdrawal (cancellation/renewal).

The duration of the entire cycle and its components depend on the product itself (its specificities) and on the general development level (the higher the development level, the shorter the life cycles).

Thus, the product life cycle curve is based on the premise that each product undergoes a typical development process split into characteristic stages which differ from each other in terms of sales volumes and proceeds, generated cash flows, costs, profits, etc.

The Polish Committee for Standardisation[9] defines the life cycle cost as total costs incurred throughout a product's life cycle, i.e. from the creation of a product's concept to its disposal. The relevant literature provides various definitions of the product's life cycle cost. The main reason for some contradictions is the number of life cycle stages to be taken into consideration when estimating the costs. This is due to the fact that the estimation may be performed for the entire cycle, for a single stage, or for a combination of various stages of a product's life cycle (Asiedu, Gu, 1998; Okano, 2001). For instance, Fabrycky and Blanchard (1991) claim that the total life cycle cost of a product or system includes research and development costs, construction and production costs, usage and operation costs, and decommissioning and storage costs. Initially, LCC was recommended by economists as a tool for assessing the economic viability of investment projects and for determining the significance of alternative solutions. Currently, the environmental life cycle costing has gained importance; this issue is related to the integration of environmental and cost aspects under an approach referred to as Life Cycle Sustainability Analysis (LSCA) (Guinee et al., 2011; Jørgensen, Herrmann, Bjørn, 2013; Grubert, 2017).

9 PN-EN 60300–3–3 Zarządzanie niezawodnością. Przewodnik zastosowań. Szacowanie kosztu cyklu życia (2006), Polski Komitet Normalizacyjny, Warszawa.

In the literature, there are various opinions about the general scheme for LCC models. Life cycle cost estimation models are categorised into several groups. Based on the stage of the product's life cycle, the following LCC models may be identified: pre-production LCC, production LCC and post-production LCC. Another classification criterion is the ability to assign LCC models to specific products (objects of calculation). Based on that criterion, general and detailed LCC models may be identified (Dziaduch, 2010).

Life Cycle Costing (LCC) is very useful for product cost management (especially when it comes to new products), meeting the expectations of customers and owners (including environmental protection, as mentioned earlier), resource optimisation (reduced resource consumption thanks to a holistic approach to all categories of resources used at various life cycle stages), and streamlining the value chain. The main purpose of life cycle costing is to analyse the costs of a product at each stage of its life cycle (from the concept to decommissioning). As mentioned earlier, because each product is unique, it is difficult to identify typical stages within its lifecycle. The analysis of relevant literature suggests that in a typical agricultural production process, the costs are unevenly distributed across life cycle stages (compared to the capability to influence the total costs)[10].

The authors assume that the subject matter of calculations in agricultural product life cycle costing (crops, animals and animal products) consists of three main cost groups:

1) reparation costs incurred at the pre-production stage (R&D, planning and launching, including costs involved in analysing the customer's requirements for the product),
2) implementation costs: production and sales costs and other cost components incurred at the product's marketing stage (this is where the consumption of enterprise resources is at its peak),
3) discontinuation costs incurred at the last stage of product life cycle.

In the classic product life cycle, as presented above, preparation is a relatively short preliminary stage for agricultural holdings (because of their specificities) after which the product's costs tend to increase. At the implementation stage, costs grow progressively to reach the maximum level. In turn, at the final stage (i.e. discontinuation), the cost level goes back to zero.

The cost classification shown above allows us to present the general mathematical formula for product life cycle costing (Nowak, Piechota, Wierzbiński, 2004: 104; Biernacki, 2005):

10 In the available bibliography, the discussion on LCC concepts is based on examples of products of the arms, chemical, construction, energy or transport industries where great importance is attached to the product designing stage which affects most costs incurred throughout the product life cycle (even 70–85% of product costs which cannot be easily reduced at the production stage), cf. for instance Dziaduch (2010).

$$Kc = Kp + Kr \cdot \left(1 + \frac{snKo}{100}\right) + Kz\,, \tag{2}$$

where: Kc – total life cycle costs of a product; Kp – product preparation costs; Kr – product implementation costs; $snKo$ – the rate of selling, general and administrative expenses; Kz – discontinuation costs[11].

Other, more detailed cost categories may be identified within the three cost groups specified above. Information needed for the calculations will be based on historical data obtained from farms (surveys, farmers' records, FADN reports). The analytical calculation procedure is assumed to include the following: determining the cost structure; determining the costs for particular categories of the cost structure; the LCC analysis conducted from the producer's perspective.

4. Eco-costs and the eco-costs to product value ratio

Each enterprise takes a series of measures to meet the defined objectives and assumptions. While these decisions and actions add value to products, they also affect the natural environment. Production processes involve a phenomenon referred to as eco-waste which means activities that entail an increased consumption of resources and adversely affect the natural environment while not contributing to customer value. This suggests a disintegration of the economy and ecology: the problem is to maximise end-user value while minimising the environmental burden (minimising the eco-costs).

In the Netherlands, the Delft University of Technology developed an LCA-based model to assess the eco-efficiency of products, services, buildings etc. (Hendriks, Vogtländer, Janssen, 2006; Vogtländer, Mestre, 2009). The model is also used to assess the environmental impact of different facilities as part of spatial planning of urban and rural areas. It is based on the Eco-costs/Value Ratio (EVR). The basic concept of EVR is the combination of Porter's[12] classic value chain with the "ecological product chain". In the value chain, at each stage of the life cycle, the product's market value grows (which affects its price) and additional related costs

11 The Japanese concept assumes that, rather than upon sale, product life ends when the final customer discontinues the use of the product. The following life cycle stages are identified in this approach: design stage, production stage and after-sales stage. Thus, total costs include costs incurred by the product manufacturer and costs incurred by the customer during the use of the product. On the customer side, LCC will include: purchasing costs (equal to the sales price), product operation costs, product maintenance costs (incurred to keep the product ready for operation) and decommissioning costs (cf. Sobańska, 2003).

12 Cf. Porter, 1985.

are incurred[13]. Similarly, the environmental impact (referred to as eco-costs and expressed in monetary terms) is visible at each stage of the value chain (cf. Figure 2).

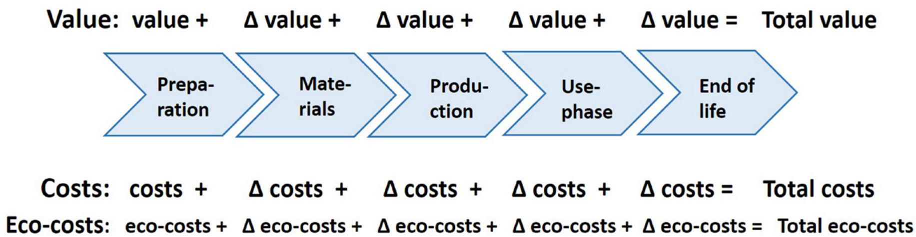

Figure 2. Eco-costs in the product value chain

Source: own elaboration based on Hendriks, Vogtländer, Janssen, 2006

Due to the fact that the current social awareness of sustainable production processes is relatively low, eco-costs are virtual, "what-if" costs (the costs of required preventive measures are not yet fully integrated with ongoing costs of the product chain, the life cycle costs). Eco-costs are related to measures that need to be taken to manufacture (and recycle) a product in accordance with the estimated "ecological carrying capacity of the Earth"[14]. Therefore, eco-costs are the "marginal prevention costs" of each pollution class (type) plus the costs of preventive measures against raw material depletion and energy exhaustion (in other words, costs that need to be incurred to reduce the existing pollution and resource depletion level to a sustainable level). Preventive measures reduce the costs of damages related to environmental pollution (e.g.: costs of medical treatment of humans). Savings resulting from preventive measures are comparable in value to prevention costs. Therefore, the society is provided with better living conditions with virtually no additional costs because the prevention costs are offset by savings.

13 In the agriculture, the food chain including all production stages is conventionally referred to as "field to table".

14 The problem is the growing ecological debt which means that by overexploiting the Earth, humans deprive the future generations of its resources. Humans use resources (soil, fossil fuels, forests, raw materials, water) on an increasingly intensive basis to manufacture goods and services beyond the Earth' capacity to renew them. The debt may be reduced in various ways, including afforestation, restocking, recycling and CO_2 absorption. This, however, requires financial resources (the source of which may be eco-costs to be included in production costs). In 2017, the Ecological Debt Day (i.e. the date on which humanity's resource consumption for the year exceeds the Earth's capacity to regenerate those resources that year) was as soon as August 2. From that day on, the human population lived at the ecological expense of future generations by "borrowing" resources from them – http://www.pap.pl/aktualnosci/news,1033194,dzien-dlugu-ekologicznego-od-stycznia-zuzylismy-zasoby-ziemi-na-caly-rok.html [accessed: 4.05.2018].

The eco-cost model is based on the total of marginal prevention costs incurred throughout the product life cycle (on an integrated basis, at the end of the process[15]).

Eco-costs fall into two major groups (Hendriks, Vogtländer, Janssen, 2006; Vogtländer, Mestre, 2009): The first includes direct costs defined as the total of (cf. Figure 3):
1) eco-costs of natural raw materials depletion,
2) eco-costs of energy and transport,
3) costs of virtual prevention against polluting emissions in the product's life cycle.

Indirect eco-costs are:
1) eco-costs of depreciation,
2) eco-costs of labour.

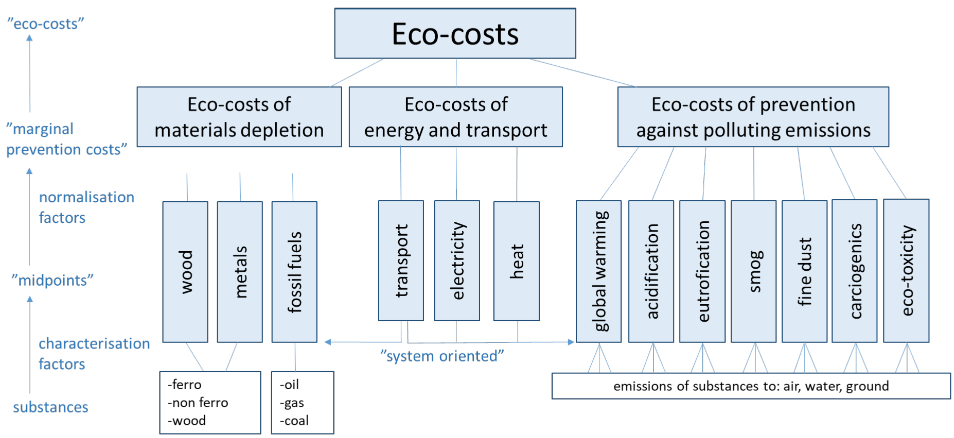

Figure 3. Structure and specification method of eco-costs

Source: own elaboration based on Vogtländer, Mestre, 2009

As regards eco-costs of raw materials depletion, the following assumptions were made by the authors of the EVR model:
1) eco-costs of raw materials depletion are assimilated to the market value of raw materials if the materials are non-recyclable;
2) if raw materials are partially recycled, a coefficient $(1 - \alpha)$ is used to calculate the market value of raw materials needed to create a new product; in that case:

$$\text{eco-costs of raw materials} = \text{costs of raw materials} \cdot (1 - \alpha), \tag{3}$$

where α – the recyclable fraction of raw materials used to manufacture a new product.

15 The "end of pipe" approach.

The fraction α should be specified for raw materials used to create a new product (rather than as the recycled part of an old product). That method is used primarily for metals; another procedure is applicable to plastics because their main source is usually oil. According to the model's logic, fossil fuels should be avoided as a raw material for the production of plastics; biomass should be used instead. This is why in the EVR model, the price of raw materials for plastics is based on biomass price, estimated to be 0.6 EUR/kg (Hendriks, Vogtländer, Janssen, 2006).

Eco-costs of energy (and of transport which is based on diesel fuel derived from oil) are calculated under the assumption that fossil fuels must be replaced with sustainable energies; eco-costs of energy are therefore equal to costs of energy derived from renewable sources which must replace the existing system (Vogtländer, Brezet, Hendriks, 2001).

The costs of virtual prevention against pollution in the form of toxic emissions are assessed for seven main categories of impact (costs of preventive measures based on technologies readily available in Western Europe). The Dutch scientists quoted above used the following costs (Vogtländer, Bijma, 2000):

1) 6.40 EUR/kg SO_x equivalent for acidification,
2) 3.05 EUR/kg PO_4 equivalent for eutrophication,
3) 3.00 EUR/kg VOC equivalent for summer smog,
4) 12.3 EUR/kg fine dust (PM10) for winter smog,
5) 680 EUR/kg Zn equivalent for heavy metals,
6) 12.3 EUR/kg PAH[16] equivalent for carciogenics,
7) 114 EUR/1000 kg CO_2 equivalent for global warming.

Eco-costs of labour are considered to be indirect eco-costs because labour as such hardly has any environmental impact. However, labour involves some environmental pressures related to commuting and using site equipment (buildings, heating, lighting, electricity used to power the computers, paper etc.). These eco-costs are calculated in a specific way and depend on the type of job. For the offices, eco-costs of labour are assumed to be ca. 10% of labour costs. The calculations for non-office workers (factory employees, salespeople, truck drivers etc.) show that eco-costs will range from 5% to 15% of costs. If eco-costs of commuting and electricity play an important role, a detailed costing procedure is recommended.

Eco-costs related to the use of fixed assets in the new product creation process ("eco-costs of depreciation") are also intermediate eco-costs[17]. The condition

16 Polycyclic aromatic hydrocarbon.

17 Fixed assets are involved in all stages of product life cycle, from the creation to the decline (or the renewal). The consumption of fixed assets is the result of usage, natural changes and technical progress. Fixed asset depreciation is governed by the regulations of the Balance Sheet and Tax Law and by IAS 16. It is impossible to provide reliable financial information on farms which are not required to keep accounting records. In this situation, it is important

to be met is that the machine or building must be clearly assigned to the product which is manufactured with the use of this equipment or inside these facilities. The principles for allocating depreciation costs to product life cycle costs are based on ISO 14041 (Vogtländer, Brezet, Hendriks, 2001; Vogtländer, Hendriks, Brezet, 2001). The authors of the EVR model relied on a simple calculation method: if EUR 3 of total costs for a product involves the depreciation of production equipment and EVR for the device is 0.4, the eco-costs of depreciation are $3 \cdot 0.4$, i.e. EUR 1.2. The calculations show the following characteristics of the eco-costs/value ratio (EVR):

1) sophisticated machinery: 0.3,
2) luxury (office) buildings: 0.3,
3) low-cost offices: 0.4,
4) refineries: 0.5,
5) steel structures: 0.6,
6) warehouses: 0.6.

The advantage of eco-costs presented above is that they are expressed in a normalised, commonly understood monetary form. The calculations are transparent and relatively easy compared to models based on damage (adverse effects) estimation which have the disadvantage of complicated calculations (with a subjective specification of weights of different aspects contributing to the total environmental impact).

Eco-costs have been presented in dedicated tables and databases (extending to 3,000 emissions and 5000+ different materials and processes) available online[18]. All of these components are calculated with LCA in accordance with ISO[19] definitions.

In the EVR model, "value" means the product's market value as perceived by customers[20]. The advantage of such a definition of eco-efficiency (instead of using "costs") is that customer behaviour and expectations are covered by the model; in other words, in an environmentally-friendly society, only "green" products and services (which provide consumers with value added) will survive. To understand

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to analyse the consumption of fixed assets in particular stages of product life cycle by using the life cycle accounting method as it will allow us to determine the economic benefits derived from fixed assets and the actual usage level of fixed assets (cf. Bąk, 2012).

18 Cf. http://www.ecocostsvalue.com/ [accessed: 5.05.2018].

19 PN-EN ISO 14041 (2002): *Environmental management – Life cycle assessment – Determining the objective and scope; file analysis.* Withdrawn and replaced by PN-EN ISO 14040 (2006) and PN-EN ISO 14044 (2006).

20 The value perceived by the customer (also referred to as "fair price") is the price the customer is willing to pay for a product. It results from the product's utility and after-purchase satisfaction expected by the customer (e.g.: after-sales support). It is abbreviated as "value" later in this paper.

the assumptions of the EVR model, it is necessary to understand the "value perceived by the customer" in today's management practices. Each product and service has three economic dimensions: costs, price and market value(all expressed as a monetary value). In a modern management approach, focus is placed on the value-to-costs ratio. Usually, the value is slightly higher than the price ("buyers' market") but may also be slightly lower than price ("sellers' market"). The EVR model assumes an intermediate situation where the value is the "fair price", i.e. the price an average buyer is willing to pay in a particular market situation.

The product's market value is determined by (Gale, 1994):
1) product quality and features,
2) service and operational quality,
3) product (brand) image[21].

The standard cost structure of a product includes:
1) materials purchase (raw materials, intermediates),
2) energy (fuel, electricity, etc.),
3) depreciation (of machinery, buildings etc.),
4) labour.

Therefore, considering the above-presented assumptions and the description of eco-costs provided earlier in this paper, in the production process of each company, it can be assumed as a simplification that taxes plus profit equals value less costs (as shown in Figure 4).

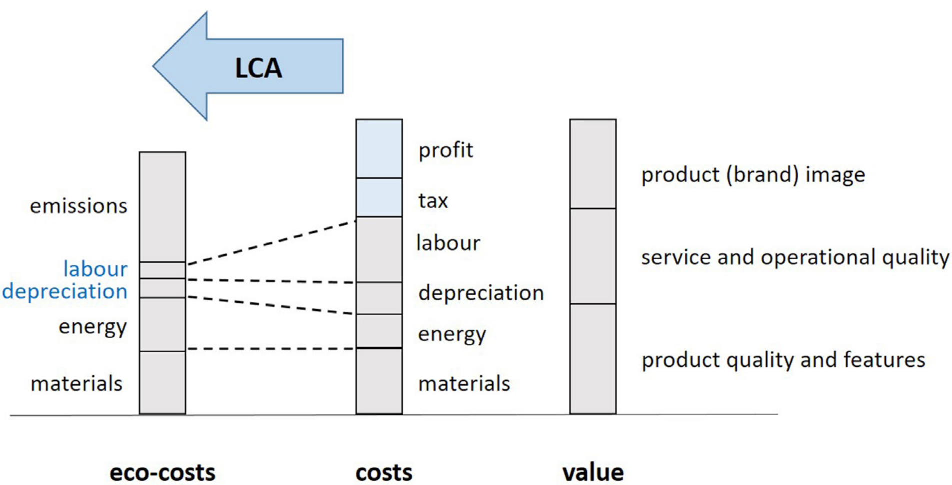

Figure 4. Structure of eco-costs, costs and product value

Source: own elaboration based on Vogtländer, Mestre, 2009

21 Note also that the above-presented elements are also drivers of value added for the product or service – cf. Encyklopedia Zarządzania, https://mfiles.pl/pl/index.php/Wartość_dodana_(Rachunkowość) [accessed: 6.05.2018].

Also, the value, costs and eco-costs may be summed in the entire production process, as shown below (Figure 5).

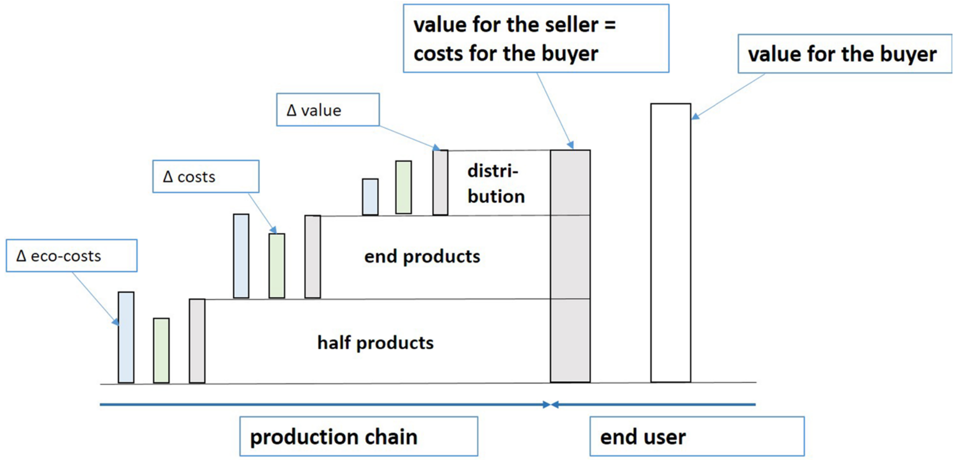

Figure 5. Cost and value distribution in the production process

Source: Hendriks, Vogtländer, Janssen, 2006: 136–148

A characteristic feature of each process, product or service is the ratio of value to eco-costs. According to EVR assumptions, the eco-costs/value index may be defined at each aggregation level of the production chain. A two-dimensional approach to that index seems to be of essential importance for both the calculation and the understanding of eco-efficiency components of a product/process.

The EVR reveals essential differences between environmental protection strategies at each stage of the production chain which are related to (Hendriks, Vogtländer, Janssen, 2006):

1) streamlining production processes (reducing eco-costs while keeping a constant level of production costs);
2) selecting raw materials and sources of energy (reducing eco-costs at production cost levels which tend to be higher);
3) "savings", e.g.: by limiting transport operations (a simultaneous reduction of production costs and eco-costs);
4) improving the value perceived by the consumer (increasing the value without a significant increase in eco-costs), e.g.: by enhancing the product with services.

A low level of EVR suggests that the product will be accepted in the sustainable society. In turn, a high EVR indicates that the value-to-product-costs ratio is likely to drop below 1 in the future (because today's virtual "external costs" will become a part of the "internal" cost structure). Therefore, either no market will be developed for that product or the product will not survive in the market in the future.

5. Further research plans

The general goal of the research is to conduct integrated environmental and economic evaluation of the impact of the main types of farm production with regard to their ecoefficiency by applying the methodology of life cycle (LCA) of product and life cycle costing (LCC).

Four specific research objectives supporting the implementation of the main project goal have been assumed:

1) carrying out an assessment of the environmental impact of processes and farming systems in different types of farms of varying production intensity and economic size;
2) life cycle costing analysis of products in the analysed farm types;
3) creating a primary inventory database of production processes in agriculture in order to apply the method of life cycle costing and environmental life cycle;
4) application of the LCA and LCC methods as supporting tools for the analysis of the sustainable development of agriculture from the perspective of low emission of production processes and their costs;
5) developing representative models of the major farming types on the basis of LCA and LCC analysis.

Analysis of production processes in agriculture should consider all elements of production processes with regard to a possibility of creating environmental threats and costs within the life cycle of products. A fragmentary evaluation based only on single environmental or economic effects is insufficient (McGregor et al., 2003; Jørgensen, Herrmann, Bjørn, 2013). It does not meet the complexity criteria of analysis, which are one of the main objectives of methodical analysis of sustainable development. Limiting the scope of analysis to only one of the life phase, for example, only to the production stage, does not allow us to determine the costs and the impact on the environment in the whole life of the product, e.g.: through the use phase and disposal. A comprehensive approach by extending environmental and economic analysis beyond the production stage of products offers new diagnostic capabilities for controlling production processes in a way that would contribute to reducing the costs and environmental burden throughout the product life cycle (Rudenauer et al., 2005; Grubert, 2017). To date, the known methods of impact assessment of agricultural production on the environment capture only fragmentary environmental effects. They are carried out in isolation from the recognition of economic conditions of production, and therefore they cannot be used to diagnose the possibility of functioning farms in a sustainable management system. Application of both the LCA and LCC methods will enable a thorough assessment of the costs, as well as the extent of emissions in many categories of external effects linked directly to the wide range of agricultural commodities. The results of these studies will also be used to develop future scenarios of enhanced sustainability of agricultural production in Poland.

6. Conclusions

A new concept in environmental management, eco-efficiency integrates environmental aspects with economic analyses to improve products and manufacturing technologies.

The methodology presented in this paper should contribute to determining the eco-efficiency of agricultural production systems. A comprehensive assessment of product life cycle costs will also enable a comparative analysis of products and production systems. The optimisation of existing systems in terms of eco-efficiency should result in achieving a high ratio of product value to costs, accompanied by a small environmental impact. Eco-efficiency is particularly important for farms because of their special relations with the natural environment (an impact on the agricultural ecosystem).

The use of eco-costs enables a more complete analysis of eco-efficiency (especially if the product value expected by the customer is also taken into consideration in the analysis). Because consumer behaviour is covered by the model, it will be possible to design and manufacture products more effectively. Also, the products will become greener and will be welcomed in the market. Eco-costs and the EVR model are part of a broader research problem which currently has not been identified on a more comprehensive basis. The eco-cost method presented in this paper may be used in LCA to determine the environmental burden based on related prevention costs. Eco-costs are costs that need to be borne to reduce environmental pollution and use natural resources in the economy at a rate consistent with the Earth's self-cleaning and resource renewal capacity. Therefore, as such, eco-costs are mainly virtual costs because they are not yet integrated with actual costs of today's production chains (eco-costs should be considered as liabilities concealed in product life cycle costs). However, eco-costs may be expected to become an integral part of product costs in the future (that process is already noticeable: "eco-taxes", tradable emission rights, other administrative measures) because in the longer term, the society will not accept the consequences of unstable situations harmful to the environment.

From the sustainable development perspective, all relevant research should be based on the exploration of the dynamic nature of development, on taking account of feedback loops and interrelations, and on monitoring the processes. Eco-efficiency is an important part of sustainable development, and the analysis of eco-efficiency provides a valuable tool for assessing the sustainability level of production processes. Thus, the diagnosis of eco-efficiency is not only consistent with global sustainable development trends but also meets the expectations of agricultural producers and their various external stakeholders. Even though the standard eco-efficiency analysis strictly integrates two out of three elements of sustainable development (the economic and environmental components), its relation to the natural environment makes it an important method for CSR enforcement among agricultural holdings (and therefore it indirectly covers the third, social, component of sustainable development).

References

Asiedu Y., Gu P. (1998), *Product life cycle cost analysis: state of the art review*, "International Journal of Production Research", vol. 36, no. 4, pp. 883–908.

Baum R. (2011), *Ocena zrównoważonego rozwoju w rolnictwie (studium metodyczne)*, „Rozprawy Naukowe", no. 434, Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu, Poznań.

Baum R. (2018), *Ekoefektywne tworzenie wartości produktu jako przejaw CSR*, "Marketing i Rynek", no. 11, pp. 15–28, https://www.pwe.com.pl/files/1276809751/file/CSR_MiR_11_2018_nowy.pdf [accessed: 6.05.2018].

Baum R., Śleszyński J. (2008), *Teoretyczne aspekty trwałego i zrównoważonego rozwoju gospodarstw rolnych*, "Ekonomia i Środowisko", no. 1(33), pp. 8–24.

Bąk M. (2012), *Środki trwałe i ich zużycie w cyklu życia produktu*, "Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu", no. 255, pp. 13–27.

Bieńkowski J., Jankowiak J. (2006), *Sustainable farming in the Wielkopolska Region – economic and environmental perspective*, [in:] Z.W. Kundzewicz, F.F. Hattermann (eds.), *Natural Systems and Global Change*, Research Centre for Agricultural and Forest Environment of the Polish Academy of Sciences, Potsdam Institute for Climate Impact Research, Poznań–Potsdam, pp. 130–141.

Biernacki M. (2003), *Foreign travel tour as a particular example of a product life cycle*, Turiba Biznesa Augstskola, Riga.

Biernacki M. (2005), *Rachunek kosztów cyklu* życia *produktu (LCC) w aspekcie zarządzania kosztami w małych i* średnich *przedsiębiorstwach*, "Проблемитеоріїтаметодологіїбухгалтерськогообліку, контролюіаналізу. Міжнароднийзбірникнауковихпраць", Випуск 3 (УДК 657), pp. 36–43.

Bivona G. (2007), *Rolnictwo i środowisko w politykach Unii Europejskiej*, "Przegląd Prawa Rolnego", no. 2, pp. 45–58.

Burchart-Korol D., Kruczek M., Czaplicka-Kolarz K. (2013a), *Koncepcja ekoefektywności w zrównoważonym zarządzaniu produkcją*, "Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie", vol. 63 (1888), pp. 59–71.

Burchart-Korol D., Kruczek M., Czaplicka-Kolarz K. (2013b), *Wykorzystanie ekoefektywności w ocenie poziomu ekoinnowacyjności*, [in:] R. Knosala (ed.), *Innowacje w zarządzaniu i inżynierii produkcji*, Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole, pp. 286–297.

Charmondusit K., Keartpakpraek K. (2011), *Eco-efficiency Evaluation of the Petroleum and Petrochemical Group in the Map Ta Phut Industrial Estate, Thailand*, "Journal of Cleaner Production", vol. 19, no. 2–3, pp. 241–252.

Czaplicka-Kolarz K., Burchart-Korol D., Krawczyk P. (2010), *Metodyka analizy ekoefektywności*, "Journal of Ecology and Health", vol. 14, no. 6(84), pp. 267–271.

Dziaduch I. (2010), *Modele szacowania kosztu cyklu życia: przegląd literatury*, "Logistyka" no. 2, https://docplayer.pl/35676269-Modele-szacowania-kosztu-cyklu-sycia-przeglad-literatury.html [accessed: 30.04.2018].

Ekins P. (2005), *Eco-efficiency: motives, drivers and economic implications*, "Journal of Industrial Economy", vol. 9, no. 4, pp. 12–14.

Encyklopedia Zarządzania, https://mfiles.pl/pl/index.php/Wartość_dodana_(Rachunkowość) [accessed: 6.05.2018].

Fabrycky W.J., Blanchard B.S. (1991), *Life Cycle Cost and Economic Analysis*, Prentice Hall Press, International Series in Industrial and Systems Engineering, Englewood Cliffs.

Gale B.T. (1994), *Managing Customer value*, Free Press, New York.

Grubert E. (2017), *The Need for a Preference-Based Multicriteria Prioritization Framework in Life Cycle Sustainability Assessment: Need for a Preference-Based Multicriteria Prioritization Framework in LCSA*, "Journal of Industrial Economy", vol. 21, no. 6, pp. 1522–1535.

Guinee J.B., Heijungs R., Huppes G., Zamagni A., Masoni P., Buonamici R., Ekvall T., Rydberg T. (2011), *Life Cycle Assessment: Past, Present and Future*, "Environmental Science & Technology", no. 45, pp. 90–96.

Hendriks Ch.F., Vogtländer J.G., Janssen G.M.T. (2006), *The Eco-costs/Value Ratio, a tool to determine the long-term strategy of de-linking economy and environmental ecology*, "International Journal of Ecodynamics", vol. 1, no. 2, pp. 136–148.

http://www.ecocostsvalue.com/ [accessed: 5.05.2018].

http://www.pap.pl/aktualnosci/news,1033194,dzien-dlugu-ekologicznego-od-stycznia-zuzylismy-zasoby-ziemi-na-caly-rok.html [accessed: 4.05.2018].

Huisman J., Stevels A.L.N., Stobbe I. (2004), *Eco-efficiency considerations on the end-of-life of consumer electronic products*, "IEEE Transactions On Electronics Packaging Manufacturing", vol. 27, no. 1, pp. 9–25.

Huppes G., Ishikawa M. (2005), *Eco-efficiency and Its Terminology*, "Journal of Industrial Ecology", no. 4, pp. 43–46.

Jankowiak J., Bieńkowski J. (2010), *Syntetyczna ocena stanu zrównoważenia produkcyjnego, środowiskowego i ekonomicznego rolnictwa w skali gospodarstwa i regionu*, [in:] J. Wilkin (ed.), *Wielofunkcyjność rolnictwa. Kierunki badań, podstawy metodologiczne i implikacje praktyczne*, Instytut Rozwoju Wsi i Rolnictwa, Warszawa, pp. 93–112.

Jørgensen A., Herrmann I.T., Bjørn A. (2013), *Analysis of the link between a definition of sustainability and the life cycle methodologies*, "The International Journal of Life Cycle Assessment", vol. 18, no. 8, pp. 1440–1449.

Landreth H., Colander D.C. (2005), *Historia myśli ekonomicznej*, Wydawnictwo Naukowe PWN, Warszawa, pp. 120–178, 246–247.

Klinowski M. (2008), *Analiza cyklu życia projektu w ocenie jego efektywności*, "Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu", no. 14, pp. 161–166.

McGregor M.J., Van Berkel R., Narayanaswamy V., Altham J. (2003), *A Role of Eco-Efficiency in Farm Management? Case Study of Life Cycle Assessment of Australian Grains*, "Farming at the Edge", 14th International Farm Management Congress, Perth, https://ageconsearch.umn.edu/record/24377/files/cp03mc03.pdf [accessed: 4.05.2018]

Nowak E., Piechota R., Wierzbiński M. (2004), *Rachunek kosztów w zarządzaniu przedsiębiorstwem*, PWE, Warszawa.

Nowak W.A. (2000), *Kalkulacje cyklu życia produktu*, "Zeszyty Teoretyczne Rady Naukowej SKwP", no. 37, pp. 156–166.

Okano K. (2001), *Life cycle costing – An approach to life cycle cost management: A consideration from historical development*, "Asia Pacific Management Review", no. 6(3), pp. 317–341.

PN-EN 60300–3–3 Zarządzanie niezawodnością. Przewodnik zastosowań. Szacowanie kosztu cyklu życia (2006), Polski Komitet Normalizacyjny, Warszawa.

Porter M.E. (1985), *Competitive advantage*, Free Press, New York.
Rudenauer I., Gensch C.O., Grieshammer R., Bunke D. (2005), *Integrated Environmental and Economic Assessment of Products and Processes. A Method for Eco-efficiency Analysis*, "Journal of Industrial Ecology", vol. 9, no. 4, pp. 105–116.
Salmi O. (2007), *Eco-efficiency and industrial symbiosis e a counterfactual analysis of a mining community*, "Journal of Cleaner Production", no. 15, pp. 1696–1705.
Siekierski J., Rutkowska M. (2008), *Zrównoważony rozwój jako koncepcja w naukach ekonomicznych*, "Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania" Uniwersytet Szczeciński, no. 8, pp. 359–368.
Sobańska I. (ed.) (2003), *Rachunek kosztów i rachunkowość zarządcza*, C.H. Beck, Warszawa.
Sobańska I., Michalak J. (1999), *Metoda cyklu życia produktu a strategiczna rachunkowość zarządcza*, "Zeszyty Teoretyczne Rady Naukowej SKwP", no. 52, pp. 47–56.
Van Caneghem J., Block C., Cramm P., Mortier R., Vandecasteele C. (2010), *Improving eco-efficiency in the steel industry: The Arcelor Mittal Gent case*, "Journal of Cleaner Production", no. 18, pp. 807–814.
Vogtländer J.G., Bijma A. (2000), *The "virtual pollution costs '99", a single LCA-based indicator for emissions*, "International Journal of Life Cycle Assessment", vol. 5, issue 2, pp. 113–124.
Vogtländer J.G., Brezet H.C., Hendriks Ch.F. (2001), *The Virtual Eco-costs '99, a single LCA-based indicator for sustainability and the Eco-costs/Value Ratio (EVR)model for economic allocation*, "International Journal of Life Cycle Assessment", vol. 6, issue 3, pp. 157–166.
Vogtländer J.G., Hendriks Ch.F., Brezet H.C. (2001), *Allocation in recycle systems: an integrated model for the analyses of environmental impact and economic value*, "International Journal of Life Cycle Assessment", vol. 6, issue 6, pp. 344–355.
Vogtländer J.G., Mestre A.C. (2009), *The Eco-Costs/Value Ratio for quantitative, LCA based, assessment of sustainability*, II International Conference on Sustainability Measurement and Modelling ICSMM 09, CIMNE, Barcelona, https://www.researchgate.net/publication/258238187 [accessed: 5.05.2018].
Wang Y., Liu J., Hansson L., Zhang K., Wang R. (2011), *Implementing stricter environmental regulation to enhance eco-efficiency and sustainability: a case study of Shandong Province's pulp and paper industry, China*, "Journal of Cleaner Production", no. 19, pp. 303–310.
www.wbcsd.org [accessed: 29.04.2018].
Zhao W., Huppes G., Voet E. (2011), *Eco-efficiency for greenhouse gas emissions mitigation of municipal solid waste management: A case study of Tianjin*, "China Waste Management", no. 31, pp. 1407–1415.

Ekoefektywność jako element zrównoważonego rozwoju gospodarstw rolnych

Streszczenie: W artykule wskazano na możliwości wykorzystania metodologii cyklu życia produktów (*Life Cycle Assessment* – LCA) i rachunku kosztów cyklu życia produktów (*Life Cycle Costing* – LCC) do analizy ekoefektywności w rolnictwie. Przy zastosowaniu metody opisowo-analitycznej przedstawiono zagadnienie identyfikacji i oceny kosztów cyklu życia produktów – założenia metodyki określania kosztów w kategoriach oddziaływań charakteryzujących emisyjność procesów produkcyjnych. Szczegółowo zanalizowano zagadnienie ekokosztów, które nie są ujęte w tradycyjnych rachunkach przedsiębiorstw. Określenie ekoefektywności systemów produkcji w rolnictwie wpisuje się w koncepcję zrównoważonego rozwoju rolnictwa i stanowi ważny element spełniania przez podmioty w rolnictwie zasad CSR. Artykuł ma charakter koncepcyjny i stanowi punkt wyjścia do dalszych rozważań oraz badań empirycznych.

Słowa kluczowe: ekoefektywność, LCA, LCC, ekokoszty

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