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Eco-design as a sign of environmental maturity of manufacturing enterprises: the vivisection of the agricultural machinery industry

Abstract

Eco-design, a new stage in product development, has been gaining in importance for some years already. Against this backdrop, a series of studies was conducted aimed principally to assess environmental maturity of enterprises reflected in considering environmental aspects at early stages of product design when decisions are made, inter alia, as to materials that will be used, production technologies, and product durability. With regard to the above stated goal, the following actions have been recommended as necessary: at the theoretical level, identifying prerequisites against which we can assess the degree of environmental maturity using the reconstruction methodology and subject-matter literature review; at the project level, developing a research tool in the form of an evaluation sheet as a product of the exploration of writings and discussions held by a purposefully selected group of experts; and at the empirical level, identification of the eco-maturity degree of agricultural machinery manufacturers. In the context of the above stated goal, it seems justified to plan the studies based on literature review, expert knowledge, creative discussion, and direct interviews with selected representatives of the industry covered by the research. To managers, these studies having solid theoretical foundations should provide grounds for evaluation and inspire them to build their own eco-design strategies.

Keywords: eco-design, maturity of enterprises, environmental maturity, eco-maturity
JEL Classification Codes: M530, M510, L620, O340

Introduction

Nowadays, in the times of globalised economy and digital revolution, enterprises are faced with intensified competition increasingly more often. Comparative advantage depends on developing new products and putting in place new technologies. Growing competition and high dynamics of changes in the business environment, as well as consequences of the global economic crisis have stripped many traditional concepts of management of their validity. What we need is an unconventional approach to management, especially when market prices of raw materials and labour are skyrocketing. Concerning the premises behind creating such unconventional tools or using slightly modified instruments of business management already existing in such a volatile and unpredictable environment of industrial goods market, it seems reasonable to propose an idea that would take care of environmental aspects already at the early stages of product design when decisions are made about, inter alia, raw materials, production technologies, and product durability. The holistic approach to design, which considers environmental aspects side by side with traditional ones, helps in merging customer needs with corporate environmental responsibility [Luttropp, Lagerstedt, 2006]. Thus, eco-design consists in identifying environmental aspects connected with a particular product and including them into the design process at an early stage of product development. The environmental impact of a device or of a process can be reduced already at the design stage. To achieve this, one needs to examine the production process, product life cycle and its environmental impact, specify the consumption of raw materials and energy, calculate the pollution and waste generated by production, and potential energy savings over the exploitation period [Fargnoli, 2009].

As a result of heated discussions held recently by manufacturers in the agricultural machinery industry, the following question has re-emerged: *to what extent do manufacturers consider environmental aspects at early design stages when decisions are made as to raw materials, production technology, and product durability?*

In an attempt to fill this knowledge gap, a series of studies was conducted. In-depth research into the area, the author's observations of business practices, and empirical studies have led to the formulation of the following detailed research questions, answers to which condition the response to the main question.

- Are enterprises covered by the research practising design that considers environmental aspects reflecting their environmental maturity (eco-maturity) together with traditional design methods?
- What is the degree of implementation of selected micro-foundations that define the eco-maturity of businesses?

On the one hand, research questions combined with a strong belief that there is business demand for practical results were the source of inspiration for these studies and, on the other hand, they provided the starting point for the hypothesis below:

H_1: *The examined manufacturers consider environmental aspects already at an early design stage, which is why they can be regarded as eco-mature (micro-foundations that define environmental maturity have been implemented to a high degree).*

With regard to the above stated goal, the following actions have been recommended as necessary: at the theoretical level, identifying prerequisites that can help in assessing the degree of environmental maturity using the reconstruction methodology and subject-matter literature review; at the project level, developing a research tool in the form of an evaluation sheet as a product of the exploration of writings and discussions held by purposefully selected group of experts; and at the empirical level, identification of the eco-maturity degree of selected manufacturers of agricultural machinery.

To managers, these studies based on theoretical foundations should provide grounds for evaluation and become a source of inspiration for building their own eco-design strategies.

1. Starting point

When the public learns that an enterprise pollutes the environment or offers adverse working conditions, its revenues may drop, leading ultimately to serious financial problems. Manufacturing enterprises are aware of such mechanisms and are seeking to prevent or eliminate these problems at the earliest stages possible. Moreover, apparently having an environmental management system in place is not enough. The existing environmental management systems help in reducing the consumption of raw materials but also eliminate the already existing losses in production.

This is why manufacturing enterprises are looking for new ideas and business management methods whose overarching goal would be to eliminate losses before they occur in the production process. Response can be sought in modern management methods and concepts, such as eco-design.

Eco-design can be described in different ways as Design for Environment (DeF), ecological design, sustainable product design, green design or environmental design [Lewis, Gertsakis, Grant, Morelli, Sweatman, 2001; Kurczewski, Lewandowska, 2008; Lewandowska, Kłos, Kurczewski, Lewicki, 2009]. Eco-design aims to develop products having the least possible environmental impact throughout their entire life cycle [Mascle, Zhao, 2008]. The principal benefits of eco-design include:

- improving products and technological processes;
- reducing costs by reviewing and modifying products at early design stages;
- catching up with changing customer expectations;
- generating new customer needs and requirements;
- reducing the consumption of materials and energy of products at each stage of their life cycle;

- reducing the weight of products and their packaging;
- reducing production and exploitation costs.

Having put in order the applied approaches to the issue at hand, we can state that:

- eco-design reduces the negative environmental impact of emissions and consumption of natural resources;
- effects are presented from the perspective of the entire life cycle of a product or a process meaning that the negative environmental impact is considered not only within the framework of production process but also at pre- and post-production stages;
- eco-design should be seen in a wider context as an incentive and effect of changes taking place at social, technical, organisational, and institutional levels.

In summary, eco-design implies the development of new competitive products, processes, systems, and procedures to meet human needs and ensure better quality of life, while simultaneously minimising the consumption of natural resources per unit of production and pollution emission to the environment throughout the entire life cycle of a product compared to alternative solutions [Reid, Miedziński, 2008].

2. Material and methodology

By using the methodology of reconstruction and interpretation of the Polish subject-matter literature [Adamczyk, 2004; Woźniak, Ziółkowski, 2006; Legutko, 2007; Kurczewski, Lewandowska, 2008; Dostatni, Karwasz, 2009; Weiss, Dostatni, Diakun, 2009; Jabłoński, Wnuk, 2009; Łunarski, 2010; Baran, 2012; Kowal, Kucińska-Landwójtowicz, Misiołek, 2013; Matuszak-Flejszman, 2015; Matuszak-Flejszman, 2019] and foreign one [Ehrenfeld, Lenox, 1997; Hemel, Brezet, 1997; Lewis, Gertsakis, Grant, Morelli, Sweatman, 2001; Jones, Harrison, McLaren, 2001; Hemel, Cramer, 2002; Czaplicka, 2003; Midilli, Diner, Ay, 2006; Mascle, Zhao, 2008; Kurk, Eagan, 2008; Gehin, Zwolinski, Brissaud, 2008; K. Yeang, D.L. Yeang, 2008; Knight, Jenkins, 2009; Santolaria, Oliver-Solà, Gasol, Morales-Pinzón, Rieradevall, 2011; Matuszak-Flejszman, Szyszka, Jóhannsdóttir, 2019], questions were selected to elicit opinions about eco-maturity levels. Eco-maturity is the reflection of eco-design which combines traditional design with environmental components. At the project level, this enabled a discussion held by purposefully selected experts focused on the development of a research tool in the form of an evaluation sheet (B_P).[1] The study was carried out as free expert interviews unrolling in line with a pre-determined scenario.[2] Phenomenological (based on experience) quality

[1] Acquaintance with the author was an important criterion for the selection of experts. It allowed deciding whether an expert is independent in his/her views and has got sufficient knowledge and expertise in the field at hand.

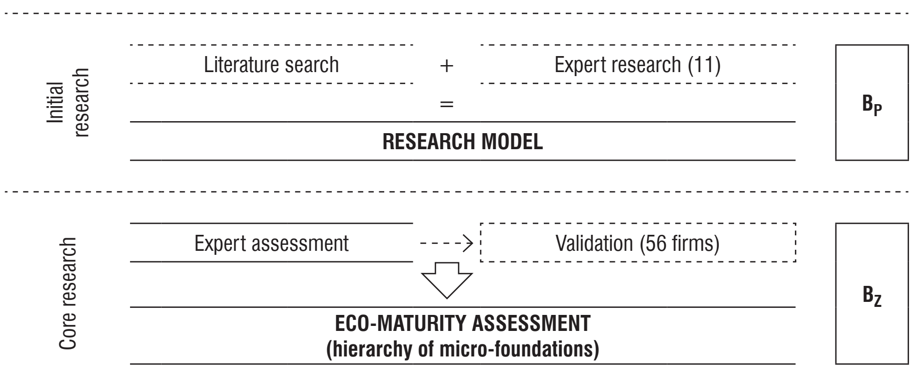
[2] The debate was attended by 11 representatives of the agricultural machinery industry, including: 8 owners of small (2 persons), medium-sized (5 persons), and large (1 person) manufacturing enterprises; a production technologist (organisation and coordination of manufacturing process); plenipotentiary for the Integrated Management System (ISO 9001, ISO 14001, PN-EN 18001); an expert for the EMAS system; an expert for IT tools supporting

studies enabled to explore opinions, feelings, and associations generated in this case by a series of factors relating to eco-design. Interviews helped to identify areas for further investigation, formulate problems, and specific issues. They have brought in interesting information about the language used by 'industry experts' to describe prerequisites of eco-maturity which lie at the heart of research interest.

Based on the suggestions of experts, a research questionnaire was developed. It contained twenty close-ended questions addressing selected micro-foundations that define eco-maturity. The restriction imposed on the number of questions to be answered in the study was dictated by the difficulties involved in, inter alia, asking too many questions within a time bound interview. In addition, in line with expert assessment, earmarked areas were considered sufficient to carry out a comprehensive assessment of eco-maturity.

Evaluation (B_Z) was carried out on a sample of 56 enterprises from the agricultural machinery industry selected purposefully, based on the availability criterion (collaboration with the Production Plant of Agricultural Spare Parts and Machines Fortschritt as a research partner). Assessment was made on a five-point scale describing the degree of implementation of selected micro-foundations that define eco-maturity, where '5' meant a very high degree of implementation, and '1' a very low degree. The research scheme is presented in Figure 1.

Figure 1. Research scheme



Source: own study.

The respondents represented micro (7.14%), small (30.36%), medium-sized (53.57%), and large (8.93%) manufacturing enterprises from the agricultural machinery industry. Most of them were between 31 and 40 years of age (36.21%); 8.62% of the respondents were under 30, the age of 27.59% of the respondents ranged between 41 and 50, 17.24% were from the age bracket 51–60, and 10.34% of the respondents were 60+. The group included a clear

product life cycle management (PLM) (integration of data and processes); 45.45% of the respondents were experts aged between 31 and 40, 27.27% were in the age bracket of 41–50, 9.09% were between 51 and 60, and 18.18% of experts were 60+; 72.73% of experts had higher, 18.18% secondary, and 9.09% vocational education.

majority of people with higher education (65.52%), 13 respondents (22.41%) had secondary education, while 7 people (12.07%) had a vocational background. Detailed characteristics are presented in Table 1.

Table 1. Respondent characteristics [n=58]

Expert	Age					Education			Company size			
	under 30	between 31 and 40	between 41 and 50	between 51 and 60	60+	Higher	Secondary	Vocational	Micro	Small	Medium-sized	Large
Respondents [n=58]	5	21	16	10	6	38	13	7	5	16	31	6
[%]	8.62	36.21	27.59	17.24	10.34	65.52	22.41	12.07	8.62	27.59	53.45	10.34
Total [%]	100					100			100			

Source: own study.

3. Results of the author's own research

Eco-maturity (environmental maturity) assessment is a difficult task, nevertheless, the paper makes an attempt at investigating it. Eco-design is one of key factors crucial for an organisation wishing to maintain its comparative advantage. Changes in the environment force out changes in production organisation, which, in turn, determines changes in materials, processes, or products. Against this backdrop, studies were undertaken to learn to what degree the manufacturers take account of environmental aspects already at early design stages.

The research problem is viewed as a collection of traits (micro-foundations). Some of them must be selected because they are important for eco-maturity. These traits have become assessment criteria.

Taking account of correlation criteria between the listed prerequisites of environmental maturity relating to eco-design, the traits were divided by the author into three groups of micro-foundations, representing high, medium, and low degree of implementation. The author adopted the following approach: the third quartile was the lower limit of the interval for the set of definitions representing high interdependence, while the first quartile was the upper limit of the interval for low interdependence definitions. As a result, the following intervals were obtained:

- 5.00–4.50 – (group 1) high degree of eco-maturity;
- 3.49–2.50 – (group 2) medium degree of eco-maturity;
- 2.49 and less – (group 3) low degree of eco-maturity.

An enterprise, the core component of business processes and the economy, is also a platform for natural circulation of the matter absorbed by the manufacturing process, transformed into products and waste, and returned to the social and natural environment. One needs to bear in mind that the environmental impact, including the consumption of technological resources, is to a large extent decided at the design stage. A number of studies dealing with the costs of a product life cycle have demonstrated that between 70% and 85% of costs of production depend on decisions taken in the design phase [Godlewska, Sidorczuk-Pietraszko, 2015].

Obviously, although rarely seen in practice, the key activities oriented at saving production resources are non-investment and organisational ones, such as eliminating losses and waste, mainly through developing adequate attitudes and behaviour of employees and proper work organisation. Activities aimed at saving resources undertaken by the examined enterprises usually consist in reducing the consumption of materials per unit of production (average score 4.73; 75.0% of '5' answers). Reduction of consumption of various principal and auxiliary materials necessary from a technological point of view (tools, production equipment, oils, coolant, water, etc.) is postulated. The next stage in the process includes changes which entail investment or major organisational and product changes (changes in technology). The enterprises covered by the study believe that optimisation of technological processes is a must (average score 4.64; 71.4% of '5' answers).[3] The growing number of construction options, reduced time to market, shorter product life cycle, as well as economic and environmental reasons force out the optimisation in technological production preparation and in the production process itself. Hence, entrepreneurs perceive the adverse environmental impact not only as a side effect of production but also in the context of pre- and post-production stages (average score 4.50; 62.5% of '5' answers).

The efficiency of manufacturing process is influenced by eco-innovations,[4] which generate solutions leading to the reduction of energy intensity of production processes and the consumption of materials per unit of production. Major barriers to eco-innovation include high costs of their implementation. Despite the lack of a comprehensive analysis of costs and benefits or cost calculation, the enterprises declare that they have sufficient financial resources for their implementation (average score 4.54; 64.3% of '5' answers). In the enterprises we can also observe a multi-directional flow of information in areas connected with eco-innovation (average score 4.23; 42.9% of '5' answers). The advancement of IT and technology bring forward design processes at each stage. Recently, software has been developed to assist eco-designers when making decisions about materials and applied technologies, which are wholeheartedly used by the enterprises selected for the study (average score 4.48; 60.7% of '5' answers). The introduction of environmental aspects at early design stages necessitates the implementation of concepts which meet expectations vis-à-vis given environmental parameters the best (average score 4.45; 58.9% of '5' answers).

Changes in the enterprises naturally lead to the evolution of views on the role of knowledge workers. Flows of knowledge taking place through workers' conduct that lead to knowledge

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[3] That is why there are so many implemented technological solutions (average score 4.41; 55.4% of '5'answers).

[4] They aim at developing new products and processes that would bring not only benefits to consumers and business but significantly reduce adverse environmental impacts. As a result, the implemented development strategy considers eco-innovation as part of goals of the investigated enterprises (average score 4.34; 48.2% '5' answers).

sharing face challenges, such as readiness to share a selected area of acquired knowledge with other workers (average score 4.41; 53.6% of '5' answers).[5]

When undertaking action within the framework of sustainable development, the examined enterprises give up production that causes more pollution (average score 4.41; 57.1% of '5' answers). They declare participation in voluntary schemes and programmes aimed to reduce their negative environmental impact.

To the enterprises covered by the study, the idea of materials and raw materials remaining in the economy for as long as it is possible and waste minimisation (average score 4.39; 51.8% of '5' answers) are especially important. It considers all stages of the product life cycle, starting from the design, through production, consumption, waste collection, and its disposal.[6]

Decisions taken in the design stage impact the costs of production and determine actions that will have to be launched in the last stage of the product life cycle, i.e. after it has been withdrawn from use [Dostatni, Karwasz, Diakun, 2013]. Experiences from the production practice demonstrate that the most meaningful effects of modern recycling technologies can be achieved already in early stages of product development, i.e., in the design stage. That explains why optimisation of the recycling system and withdrawal of products from production advocated by the enterprises included in the study are so important (average score 4.39; 51.8% of '5' answers).

The environmental trend strongly impacts broadly understood logistics increasingly more. Growing market requirements as to the shortening of delivery times and increasing the reliability of order execution linked with enterprises' efforts to achieve environmental optimisation confirm the rationale behind working towards multiple aspect optimisation of distribution networks (average score 4.39; 53.6% of '5' answers).

Successful policy promoting innovation, elimination of barriers to eco-innovation funding, systematic development of assistance schemes for eco-innovation, and actions aimed to improve environmental awareness are measures having a significant impact upon sustainable development of enterprises. That is reflected in seeing eco-innovation in a wider context, i.e., as a stimulus and effect of changes taking place at social, technical, organisational, and institutional levels (average score 4.38; 57.1% of '5' answers) and workers' involvement in designing new products and bringing them to the production stage (average score 4.38; 50.0% of '5' answers).

On the one hand, eco-design draws from a variety of technical achievements, while on the other hand, it may generate conditions favouring getting acquainted with technology and developing it through the shaping of technical culture. Technical culture is decisive for being able to benefit from positive aspects of technology and it prevents undesired and harmful effects that may result from incorrect exploitation of technical devices, their design and production stages. Maintaining adequate contact between man and technical products necessitates

[5] The growing importance of knowledge and sharing it should be treated as a specific type of environmental competences.

[6] It is assumed that environmental impacts exist at each stage of the product life cycle and should be identified and reduced at all these stages (average score 4.23; 57.1% of '5' answers).

economic management of technical resources, savings, and cost-effectiveness, which is why the enterprises perform preventive and surveillance maintenance (average score 4.36; 48.2% of '5' answers) and strive to minimise their environmental impact of the use of their products (average score 4.32; 46.4% of '5' answers).[7]

Supplying workers with adequate knowledge, developing their skills and the sense of responsibility for personal and social consequences of predictable technical actions, including effects that are undesired or even harmful to health and life are the pre-condition of all efforts. In accordance with this approach, technical culture concerns the activities of an organisation and its agency performance that brings new value. Ideation is the key concept, i.e., workers' ability to generate many solutions to open problems, to propose new, valuable ideas and concepts. Such attitudes can be favoured by a culture in which people can present new ideas without fearing of being disregarded (average score 4.30; 44.6% of '5' answers).

Environmental campaigns conducted more often at an increasingly wider scale encourage customers to purchase products that are 'friendly' to the environment. Unfortunately, products designed in line with eco-design principles are often more expensive than traditional ones. Their ultimate price includes costs of R&D work connected with new solutions being implemented in the construction or manufacturing of a new product.[8] Independently of the above, the enterprises pay attention to their minimising environmental impact also when a product is delivered to a consumer (average score 4.30; 53.6% of '5' answers). Against this context, analyses of the initial and target stage from the perspective of the entire product life cycle are carried out at environmental, economic, and social levels (average score 4.29; 48.2% of '5' answers). The so-called environmental marketing is put in place, which implies significant changes in the positioning of a product, its packaging, promotion, or price setting (average score 4.27; 50.0% of '5' answers).

Environmental competence, covering a range of comprehensive and highly diversified issues developed across a variety of areas, is important for building correct relationships with the environment (average score 4.25; 39.3% of '5' answers).[9] Environmental competence allows developing an environmental quality strategy. The latter is an anticipative strategy according to which effects should be eliminated before they actually occur to avoid environmental pollution (average score 4.23; 42.9% of '5' answers).

The number of companies which intend to allocate more funds and resources for their business development through R&D studies has increased compared to previous years. Cooperation with external actors helps in reducing costs, as well as enhances access to grants for this area of activity, which is why increasingly more enterprises covered by the research carry out projects in cooperation with external research centres or universities (average score 4.07; 33.9% of '5' answers).

[7] This implies choosing solutions of low environmental impact (average score 4.30; 48.2% of '5' answers).

[8] Hence moderate orientation at R&D work (average score 4.23; 42.9% of '5' answers).

[9] These are complex relationships based on the ability of collective learning and that is why they have been deployed to assess the degree of the eco-maturity of enterprises.

Summary

Operations performed by manufacturing enterprises undertaken to meet market needs triggers unlimited use of natural resources. Looking from this angle, it is important to launch activities that would 'seek to secure' the environment against the contamination of water, soil, and air by solid, liquid and gaseous substances that distort the 'homeostasis' of the environment and its constituent components. To meet these challenges, manufacturers have developed a system of environmental management whose principal objective is to eliminate harmful environmental impacts of an enterprise already at the stage of design.

Against this context, a series of studies was conducted whose primary goal consisted in making an attempt to assess eco-maturity of enterprises reflected in specific environmental aspects. Material collected in the research procedure enabled the validation of research hypothesis and led to the formulation of general and cognitive conclusions. The hypothesis adopted for this work has been fully confirmed in all its aspects by theoretical considerations and findings of the survey carried out on selected companies.

Results of studies unambiguously indicate that enterprises covered by the research take account of environmental aspects in the design stage which reflects their environmental maturity (eco-maturity). Selected micro-foundations of eco-maturity of enterprises were found to be implemented to a high degree.

Apparently, bioeconomy is the next foreseeable component of the next revolution in the global economy. On the one hand, it will tackle traditional industries which will increasingly more avail themselves of natural materials and resources, especially of biological (plant) origin; on the other hand, it means fast growth of biotechnology and its applications in new manufacturing areas. This is the area in research works where a considerable gap has been observed which, undoubtedly, needs to be bridged.

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