



REMANUFACTURING SUSTAINABILITY INDICATORS: A STUDY ON DIESEL PARTICULATE FILTER

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ABSTRACT. Background: Remanufacturing transforms end-of-life products into new products, which brings cost savings for the usage of energy and materials and environmental protection. Sustainability is a significant issue for remanufacturing SMEs trying to stay competitive in the marketplace, while remanufacturing seems to be a promising strategy to explore for increasing the environmental and economic burdens on society. Despite sustainability being a known concept, it very often becomes a purely strategic goal which is not defined at the operational level of business. The major objective of this paper is to determine a set of sustainability indicators for an evaluation of the remanufacturing process, integrating economic, social and environmental aspects of business.

Methods: The literature review method was used to verify current knowledge on remanufacturing sustainability indicators, while the observation method was used to determine the specifics of the remanufacturing process. The brainstorming method aimed to verify the usefulness of existing indicator frameworks and define a set of indicators developed for the assessment of remanufacturing sustainability.

Results: In the presented paper, a set of 11 remanufacturing sustainability indicators was prepared, which were tested on a company in Poland that was remanufacturing a diesel particulate filter.

Conclusions: Although the proposed set of remanufacturing sustainability indicators was defined for a specific company, it may be used as a guideline for comprehensive indicator framework development, regardless of the product type or the size of the company. The main challenge in introducing sustainability at the operational level of remanufacturing in business is enabling multilevel assessments while considering particular sustainability aspects and the company as a whole. This outlines directions for future research.

Key words: remanufacturing, sustainability; indicators, measurement, diesel particulate filter.

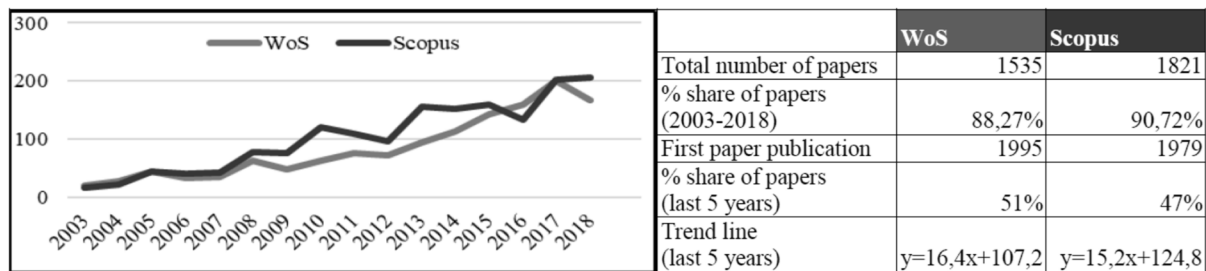
INTRODUCTION

This paper draws attention to remanufacturing as a considerable interest in remanufacturing as a research topic has been observed. The above may be confirmed, for example, by an analysis of documents collected in scientific databases including Web of Science or Scopus, where the term remanufacturing has been used as a keyword searched in the publication on many occasions (Fig. 1).

Although the first papers on remanufacturing appeared in the late '70s, the vast majority of works were prepared after 2003 and, as a consequence, Fig.1 contains data from 2003-2018. According to Fig. 1, the distribution of papers in both WoS and Scopus databases rose significantly over the period from 2003 to 2018, achieving the maximum value of 201 papers in WoS in 2017, and 205 papers in Scopus in 2018. This may be the result of a sustainable way of thinking, where remanufacturing becomes one of the preferred

things to do with used products. Despite an overall increase, the number of papers on remanufacturing peaked and troughed several times over the 15 years. Considering the percentage share of papers developed in the last 5 years (around 50%), a linear trend analysis was created for each database, which

confirms that the interest rate on the topic of remanufacturing has gone up. In the authors' opinion, this provides the necessary justification for research into remanufacturing, in particular because it has been a relevant issue for Business and Academia.



Source: own work

Fig. 1. Distribution of papers on remanufacturing in WoS and Scopus

Owing to the fact that remanufacturing includes a series of manufacturing steps applied to end-of-life products in order to return them to an as-new condition or at least one of better performance with a warranty [Golińska, Kuebler 2014], it is thought of as a key element of a circular economy [Butzer et al. 2016, Kurilova-Palisaitiene et al. 2018, Jensen et al. 2019], where resource input and output are minimized by closing material loops.

In the literature, there are many examples of remanufacturing benefits, which may be considered in a sustainability context, in particular, economic benefits from material and energy savings, which are related to environmental advantage from emissions and waste avoidance, and social benefits resulting from the creation of jobs and ensuring an accessibility of goods for low-income countries [Fatimah, Aman 2018]. Remanufacturing has often been considered better than manufacturing based on economic and environmental evaluations of these processes (e.g. alternators in [Kim et al., 2009], turbochargers [Li et al. 2017] and diesel engines [Dias et al. 2013]. In short, following Golińska-Dawson, it was assumed without any further investigation that remanufacturing is sustainable [Golinska-Dawson 2018]. Consequently, the focus of this paper lies in the sustainability of remanufacturing.

Sustainability has not been precisely defined in the literature, thus some problems with sustainability transfer at the operational level of business have been identified [Golinska-Dawson 2018]. Following Golińska and Kuebler, it was claimed that sustainability requirements at the company level may be characterized as a utilization of resources that is economically justified (profitable) and environmentally friendly, while also considering employees' social lives and the surrounding communities (to minimize the influence on them) [Golińska, Kuebler 2014]. Moreover, in order to operationalize the concept of sustainability, it should be measured. Based on the previous experience of researchers of sustainability measurement, it was recommended that several indicators be used. Firstly, these were identified in Agenda 21 as a guideline to measure progress towards achieving sustainability targets to inform decision-makers as well as the public about the current sustainability results. Moreover, indicators allow progress to be tracked over time for important phenomena, as this has been a significant issue for management. Additionally, indicators have been considered as practical tools usable by SMEs, particularly because many remanufacturing companies represent SMEs.

However, many global incentives for measuring sustainability performance with indicators have been identified (e.g. GRI, DJSI, OECD Sustainable Manufacturing Toolkit, etc.) [Golinska-Dawson 2018] that may be adopted by large industries, though some problems have also been acknowledged related to (i) adaptation at the SME level (ii) non-complex considerations of sustainability (e.g. a focus on the environment) and (iii) no adjustment to remanufacturing. Thus, the need to develop a sustainability indicator framework that is applicable, understood and relevant to SMEs has been identified. It must also be adjusted to the economic and political conditions of the country in which the remanufacturing business is being run. Consequently, the major objective of this paper is to determine remanufacturing sustainability indicators. Additionally, the proposed indicators were used to measure the remanufacturing sustainability of a diesel particulate filter remanufacturing company, representing SMEs in Poland. The measurement results have been included in the paper, which was based on the master's thesis of an author of the paper.

This paper is organized as follows. In Section 2, the results of a state-of-the-art analysis on remanufacturing sustainability indicators are included. Section 3 presents the company under study, the remanufactured product and the remanufacturing process of the diesel particulate filter. In the next section, the remanufacturing sustainability indicators used in the company's assessment are discussed. Finally, Section 5 summarizes the limitations of the study and gives an outlook for further research.

REMANUFACTURING SUSTAINABILITY INDICATORS – STATE OF ART

Considering the differences between manufacturing and remanufacturing, it has been stated that there is a need for remanufacturing sustainability indicators, so an in-depth literature review was carried out on remanufacturing sustainability indicators. The conducted search combined the following keywords: „remanufacturing” AND “measurement” OR “assessment” OR “indicators” within the publication title, in the Web of Science and Scopus scientific databases. Articles in English were reviewed, without a time limit, excluding papers on computer science, physics and chemical engineering research. Consequently, the process discovered 35 papers in the Scopus database and 38 papers in the WoS repository. In the second stage of the literature research, the duplicated results were eliminated, reducing the total number of articles to 58. In the final stage, those 58 papers were analyzed by authors of the paper in order to find indicators of remanufacturing sustainability. It is noteworthy that, despite an increasing interest in remanufacturing (Fig. 1), remanufacturing assessment in the context of sustainability is still an undiscovered research topic, as less than 2.5% of all papers on remanufacturing have addressed this particular issue. Moreover, only two papers about sustainability remanufacturing indicators were found and have been analyzed in detail, with the results presented in Table 1.

Table 1. Remanufacturing sustainability indicators available in the literature

Reference	Year	Research methodology	Complexity of sustainability	Indicators number	Requirements for indicators
[Fatimah, Aman, 2018]	2018	Literature review, case study, experts judgments brainstorming	YES	31	Understandability, applicability, relevance
[Golinska – Dawson et.al, 2018]	2018	Literature review, case study, experts interviews	YES	15	Availability of data, comparability, reliability, usefulness, simplicity

Source: own work

With reference to Table 1, only two papers were identified in which remanufacturing sustainability indicators were presented considering all three sustainability pillars without testing them in practice [Fatimah et al. 2018, Golinska-Dawson et al. 2018]. Graham

et al. [Graham et al. 2015] proposed a set of 25 indicators for remanufacturing, but they did not address sustainability directly, so this work was excluded from further analysis. The presented references (Table 1) were from 2018, so the topic of remanufacturing

sustainability indicators is a new issue for researchers. It was also assumed that in terms of the importance of sustainability in the context of increasing government pressure on the issue, in the coming years sustainability assessments may be obligatory, so an appropriate system of indicators should be determined. Considering the results of the literature review, the authors of the paper made the following conclusions:

- C1 – Indicators should be determined with the use of various research methods, considering existing solutions and expert knowledge from remanufacturing businesses and Academia;
- C2 – Indicators should meet the following requirements: understandability, applicability, relevance, data availability, simplicity, comparability, reliability;
- C3 – The number of indicators should be limited (according to the rule: “less is more”, no more than 20 indicators [Golinska-Dawson 2018]);
- C4 – Indicators should be suitable for particular remanufacturing businesses in the context of national requirements for sustainability reporting, taking into consideration specific socio-economic conditions.

Taking these conclusions into account, a set of 11 remanufacturing sustainability indicators was determined. These are presented in Section 4.

REMANUFACTURING PROCESS OF DIESEL PARTICULATE FILTER – POLISH CASE STUDY

In this paper, a Polish company remanufacturing diesel particulate filters representing SME, is described. In the subsections below, the following are presented: the company under study, the remanufactured product and the remanufacturing process.

The subject of the conducted research is a remanufacturing company representing the SME sector, with its headquarters in the Greater Poland province, in Poland. It has been on the Polish market since 2008. The main

field of the company's business is the maintenance and repair of vehicles, including the servicing and remanufacturing of diesel particulate filters (hereafter: DPF), which has become its core business activity. Its customers are individual vehicle owners from all over the country and abroad, but also business customers such as distributors of Pirelli Eco Technology particulate filters for trucks and buses.

In the company under study, DPFs are remanufactured. In the authors' opinion, this remanufacturing process is particularly relevant considering the environmental context of the product. The DPF is a device that captures and stores exhaust soot to reduce emissions from diesel cars. It should be noticed that DPFs have a finite capacity, so this trapped soot periodically has to be emptied or 'burned off' to bring the filter to an as-new condition. It is noteworthy that only proper remanufacturing in authorized facilities ensures that the correct filters work without polluting the environment. It has been claimed that on the market there have been many companies which do not respect any legal requirements, so they offer products at a low price but only partially remanufactured, not in a sustainable manner.

Remanufacturing is an industrial process in which returned products (cores) are restored to an as-new condition, or at least one of better performance, to be used for at least another lifecycle. This includes the following phases: inspection, cleaning, disassembling, reprocessing, reassembling and testing [Golińska, Kuebler 2014].

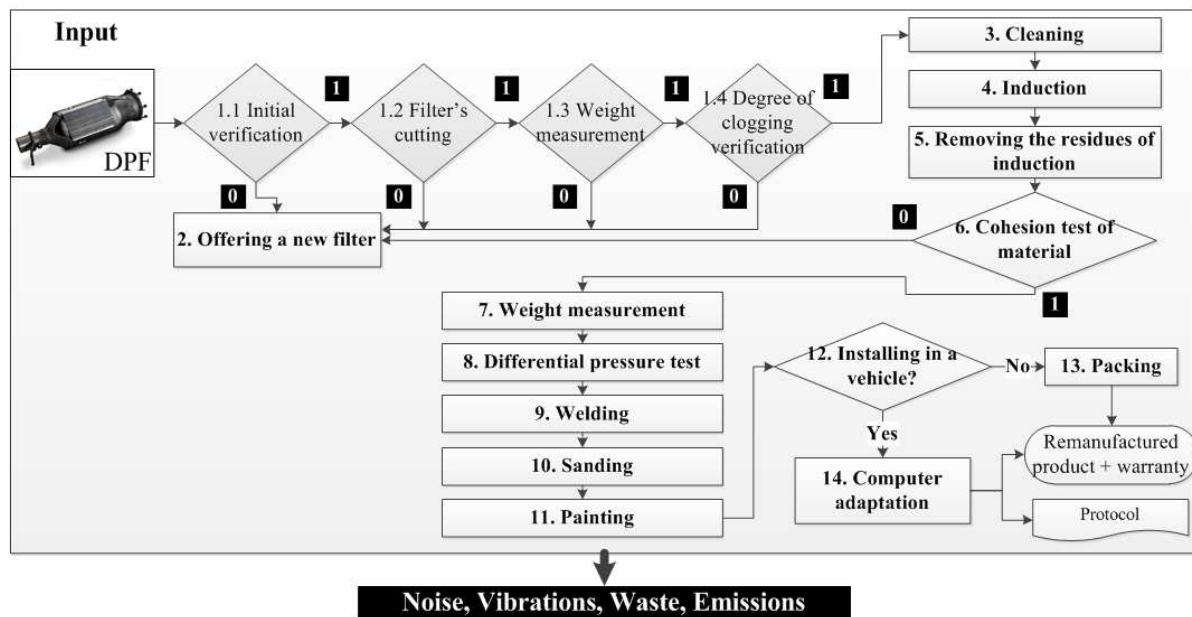
It is noteworthy that the steps of the remanufacturing process depend on the product and the company's knowledge and resources, which is related to the company's size. Considering the information from the previous subsections, the remanufacturing process realized by the company under study is mapped and presented in Fig. 2.

The remanufacturing process is started by DFP's delivery (input) as it is a made-to-order process. The customer may deliver a single part or a whole vehicle to have a complex

service including the disassembling of parts and the assembling and computer adaptation of remanufactured parts.

In the first stage of the remanufacturing process, the product is verified in a few steps (1.1.-1.4.). It is noteworthy that to save

resources at particular verification steps, a decision may be made to exclude the product from further stages of the remanufacturing process (where “0” means lack of compliance with requirements and “1”, meeting the requirements).



Source: own work

Fig. 2. Remanufacturing process of diesel particulate filter

During the initial verification, cracks and remelting are checked with the use of cameras and light. Secondly, the filter is cut to evaluate the internal product's structure. In the third step, a measurement of the weight of soot and ash is measured. Finally, the degree of clogging in the filter is verified with the use of light and cameras. If during any of the verification steps the requirements are not met, the remanufacturing process ends and the customer is offered a new product.

In the second stage of the remanufacturing process, the filter is cleaned and then an induction process is carried out so the filter is burned in the induction furnace. After that, the residues of induction are removed. In the next step, the final verification of the consistency of the material is done, where post-process cracks are identified. If there is no damage, the remanufacturing process is continued with the following operations: weight measurement, a differential pressure test, welding, sanding

and painting. When the customer is interested only in a remanufacturing service, the remanufactured part is packed and given to the customer with a warranty. In the case of a complex service, the DPF is installed in a vehicle with the required computer adaptation, which is done as long as all errors are deleted. A warranty is given on the product and reassembling service.

To sum up, the process output is a remanufactured DPF with a warranty which is as good as a new one. The whole process results in noise, vibration, waste and emissions, which affects people and the planet but also generates a profit for the company's owner and savings for vehicle owners (economic benefit), thus the sustainability context is significant in DPF remanufacturing.

Consequently, it is stated that the remanufacturing sustainability context is

essential for this process, thus it should be measured.

REMANUFACTURING SUSTAINABILITY INDICATORS

The objective of this paper was to determine a set of sustainability indicators in the remanufacturing process for SMEs dealing with a diesel particulate filter, to improve the company's competitiveness, as sustainability is perceived to be a critical success factor and a source of competitive advantage.

In order to achieve the major research objective, a brainstorming session was conducted with experts from the company under study and Academia experts (authors of the paper) to verify the usefulness of existing indicator frameworks (Table 1), considering guidelines C1-C4. Finally, a set of 11 remanufacturing sustainability indicators was determined, including all sustainability aspects: economic, social and environmental (Table 2).

Table 2. Remanufacturing sustainability indicators

Class	ID	Name	Description	Type	Range of values	Unit	Reference value	Score	Value
Economic	11	Remanufacturing quality	Percentage share of products damaged during the remanufacturing process in the total daily sale.	Quan.	0-100	%	100%	100%	5
	12	Complaints level	Percentage share of complained products in the total monthly sale.	Quan.	0-100	%	≤2,5%	1,4%	5
	13	Local market share	Percentage market share of remanufactured DPFs in province.	Quan.	0-100	%	≥ 8%	8%	5
	14	Equipment availability level	The utilization rate of all equipment calculated based on real working time/ available working time.	Quan.	0-100	%	≥ 85%	77%	3
Environment	15	Energy management	The qualitative indicator describing the approach to energy management in a company on basis of used practices in the assessed company.	Qual.	1-5	-	5	3	3
	16	Engagement in environmental activity	The qualitative indicator describing engagement in environmental activity on basis of used practices in the assessed company.	Qual.	1-5	-	5	5	4
	17	Filters recovery rate	Percentage share of filters intended for remanufacturing and remanufactured in the total number of filters delivered to company (per month). Indicator was calculated considering the complex service ¹ as well as only remanufacturing ² .	Quan.	0-100	%	≥85%	73,3 ¹ 78,8 ²	2 ¹ 3 ²
Social	18	Engagement in relation with customers	The qualitative indicator describing engagement in relation with customers on basis of used practices in the assessed company.	Qual.	1-10	-	10	10	5
	19	Employment	The change in employment within two considered periods (e.g. years) considering one of three situations: decrease {-1}, no changes {0} and increase the employment {1}.	Qual.	{-1,0,1}	-	1	1	5
	110	Engagement in relation with local community	The qualitative indicator describing engagement in relation with local community on basis of used practices in the assessed company.	Qual.	1-5	-	5	5	5
	111	Safe and healthy	Percentage share of employees' absence days in the total number of working days per month.	Quant.	0-100	%	≤2,5%	7,33%	2

Source: own work

With reference to Table 2, the following were included:

- Four indicators considering the economic aspects of remanufacturing (I1-I4), relating to all economic values associated with the use/utilization/management of resources,

energy, labor, technology, methods, waste, and market share of the conducted business;

- Three indicators considering the environmental context of the remanufacturing (I5-I7), which is associated with all environmental consequences caused by the

remanufacturing process, which may both positively and negatively affect people and environmental performance directly and indirectly in different ways. This context of assessment includes all activities undertaken to protect the environment, energy saving and material recovery;

- Four indicators in terms of the social sustainability context (I8-I11). The major social advantages of remanufacturing include jobs creation. However, possible social drawbacks of remanufacturing also need to be considered, including the health and safety of employees and relations with customers, as well as with the local community. Accordingly, the social impact assessment of the proposed indicators considers employees, customers and community.

In the authors' opinion, the indicators proposed in this paper (Table 2) enable a comprehensive assessment of

remanufacturing in the context of sustainability, in the company under study. Among the indicators used in the research, 55% were quantitative (hereafter: Quan.) which were calculated with the proper formulas, resulting in a score ranging from 0 to 100%. The reference value defines the aim of a particular phenomenon measured by the indicator. In the research, the reference values were defined by sector experts (e.g. more than 8% was the required value of I3). On the other hand, 45% of the indicators were qualitative (hereafter: Qual.), which were assessed with the use of proper qualitative scales prepared on the basis of brainstorming results, considering the results of the literature review (Table 1) and the experience of the experts. Most of the qualitative indicators were determined with the use of a 5-stage scale with values from 1 to 5, where each level was described with the use of practical solutions adequate for particular indicators. An example of an energy management indicator is presented in Table 3.

Table 3. Energy management indicator

Description of practice	Level of requirements fulfillment	Value
Monitoring the energy costs at the company level.	Very low	1
Taking ad hoc actions for energy consumption reduction (e.g. lighting replacement).	Low	2
Promoting Employees behaviors that are aimed at reducing energy consumption.	Moderate	3
Taking actions for reducing the energy at the equipment level, efforts on renewable energy.	High	4
Using renewable energy sources, implementation of an energy management system.	Very high	5

Source: own work

Considering the information presented in Table 3, it should be noticed that each description of the practice is presented from the perspective of the fulfilment of requirements for a particular indicator, with a value from 1 to 5 or 1 to 10 (for I8). However, most of the qualitative indicators were presented similarly to I5 (Table 3). The I9 indicator was an exception as employment is assessed from the perspective of the situation related to the change in employment rate. Consequently, without changes in employment, the value is "0". If the number of employees decreases, the indicator value is "-1", but if it increases, it is "1", which is the required situation considering the importance of job creation.

Taking into consideration the remanufacturing sustainability indicators, an assessment of the company under study was

carried out (Table 2, row: "Score"). Owing to the fact that in the assessment both qualitative and quantitative indicators were used, with various units and values, a relativization was done which resulted in an assessment value within the scale from 1 to 5. The relativized value had to present information about the fulfilment of requirements in the context of particular phenomena measured by the indicator to obtain information about the resulting measurement in the context of requirements for future improvements, according to Table 4.

With reference to Table 4, it was stated that the company under study obtained very positive results in economic and social contexts of sustainability, however, actions to improve the environmental context of company's activity should have been

undertaken. Considering all the results, for 55% of indicators it was recommended that their score be monitored as the company got satisfactory results from the assessment. For the following indicators: I4, I5, I6, I7, some actions should have been taken for improvement but only if organizationally and economically possible. The major problem of the company under study was safety and health

because the assessment result was unacceptable. Consequently, an immediate requirements were identified for corrective activities to improve indicator values and employees' working conditions. Unfortunately, though the company is able to change the working conditions, unplanned absences e.g. childcare, are out of the company's influence.

Table 4. Assessment of remanufacturing sustainability indicators

Level of requirements fulfilment		Assessment result	Direction for action
descriptive	numeric value		
Very high	5	Satisfactory	Monitoring
High	4	Good	Improvement actions, if possible
Moderate	3	Conditionally acceptable	
Low	2	Unsatisfactory	Corrective actions as soon as possible
Very low	1	Unacceptable	

Source: own work

To sum up, the presented remanufacturing sustainability indicators were considered as a useful tool for decision making in order to verify the sustainability state and to indicate the directions of future actions, and to be more competitive in the marketplace.

CONCLUSIVE REMARKS

In the presented paper, the authors have prepared a set of remanufacturing sustainability indicators which were tested in a company remanufacturing diesel particulate filters in Poland. Consequently, the major research objective was achieved.

As a result of the literature review and the experts' methods, indicators were determined and tested in the company under study, which allowed the indication of directions for future improvement. Two main conclusions were made based on the assessment results. Firstly, the level of complaints from warranty repairs, as very often customers do not follow the guidelines for remanufactured DPF use. Secondly, the low level of recovery rate (I7) is related to a core quality (DPF delivered to the company). It is noteworthy that the company's influence on core quality is limited because it depends on the customer's treatment of the DPF. On the other hand, the company should support customers by planning remanufacturing, starting with regular

customers e.g. by sending reminders for DPF remanufacturing, considering the number of miles driven. It was stated that the DPF's quality is essential considering the assessment of the remanufacturing company in the scope of sustainability.

In the presented research, a proposition of indicators was prepared for a specific business in a particular country. In the authors' opinion, it may be used as a guideline for comprehensive indicator framework development, regardless of the product's type or the size of the company. As a consequence, in future research, the authors are going to prepare a set of indicators which will be useful for the sustainability assessment of each remanufacturing process. Moreover, it is also planned to aggregate indicators in order to prepare a procedure enabling multilevel assessment of remanufacturing sustainability, considering a particular sustainability aspect and a company as a whole.

The major direction for the future research is to develop a model for material flow management in the remanufacturing business in order to support decisions at the operational level of business to ensure sustainable remanufacturing.

ACKNOWLEDGMENTS AND FUNDING SOURCE DECLARATION

This paper refers to the research conducted under Statutory activity, financed by MNiSW/Poznan University of Technology, Project ID: 11/140/SBAD/4169.

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WSKAŹNIKI DO OCENY REGENERACJI W KONTEKŚCIE ZRÓWNOWAŻONEGO ROZWOJU NA PRZYKŁADZIE REGENERACJI FILTRA CZĄSTEK STAŁYCH – STUDIUM PRZYPADKU

STRESZCZENIE. Wstęp: Regeneracja pozwala na przywrócenie produktów wycofanych z eksploatacji do ponownego wykorzystania, co bezpośrednio związane jest z oszczędzaniem używanej energii oraz materiałów a także co przyczynia się do ochrony środowiska. Zrównoważony rozwój stanowi kluczowe zagadnienie dla przedsiębiorstw zajmujących się regeneracją, należących do grupy MŚP, gdyż stanowi źródło budowania przewagi konkurencyjnej. Co więcej, regeneracja to scenariusz wtórnego zagospodarowania produktów, który zyskuje na znaczeniu ze względu na wzrost obciążeń środowiskowych oraz ekonomicznych dla ludzi. Pomimo tego, że zrównoważony rozwój to koncepcja powszechnie znana, zazwyczaj jej uwzględnienie ogranicza się do wskazania zrównoważonego rozwoju jako celu strategicznego, pomijając wymiar operacyjny prowadzenia działalności gospodarczej. Celem głównym artykułu było opracowanie zbioru systemu wskaźników służących do ewaluacji procesu regeneracji w kontekście zrównoważonego rozwoju, integrując aspekty: społeczny, ekonomiczny oraz środowiskowy w działalności gospodarczej.

Metody: W pracy wykorzystano metodę analizy literatury celem weryfikacji aktualnego stanu wiedzy w zakresie wskaźników służących do ewaluacji regeneracji w kontekście zrównoważonego rozwoju, podczas gdy metoda obserwacji wykorzystana została do określenia specyfiki procesu regeneracji. Celem weryfikacji użyteczności istniejących rozwiązań w zakresie oceny oraz zdefiniowania systemu wskaźników do oceny regeneracji w aspekcie zrównoważonego rozwoju, wykorzystano metodę burzy mózgów.

Wyniki: W pracy zaprezentowano system 11 wskaźników służących do oceny regeneracji w kontekście zrównoważonego rozwoju, które zostały zweryfikowane w przedsiębiorstwie zajmującym się regeneracją filtrów cząstek stałych w Polsce.

Wnioski: Pomimo tego, że zaproponowany system wskaźników został zdefiniowany dla konkretnego przedsiębiorstwa, to należy go potraktować jako zestaw wytycznych do opracowania kompleksowego systemu pomiaru, niezależnie od wielkości przedsiębiorstwa czy typu regenerowanego produktu. Głównym wyzwaniem w wdrażaniu zrównoważonego rozwoju na poziomie operacyjnym przedsiębiorstwa prowadzącego działalność w zakresie regeneracji, stanowi ocena wielopoziomowa, uwzględniająca poszczególne wymiary oceny zrównoważonego rozwoju oraz przedsiębiorstwo rozpatrywane jako całość, co stanowi kierunek przyszłych badań.

Słowa kluczowe: regeneracja, zrównoważony rozwój, wskaźniki, pomiar, filtr cząstek stałych

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