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REGIONAL CASE STUDY

Green business process management in a Polish municipal waste treatment plant-regional case study

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Abstract

Despite COVID-19, the world economy still contributes to the growth of production and consumption worldwide. Waste disposal, recycling management and energy generation are challenges for many companies in developing economies, including Poland. This article aims to assess the operation of a municipal waste treatment plant (MWTP) from the perspective of green business process management (BMP) solutions. The processes implemented in the MWTP were discussed, with specific consideration of the mechanical waste processing (sorting) process, including the reuse and recycling of materials, composting, energy production (anaerobic process), landfill storage and efficiency parameters of the sorting line. A sustainable waste management system was identified; the cost as well as social and environmental perspectives were analyzed. Also, strategic goals and key performance indicators were considered. The performed analysis included costs, environmental criteria and key environmental indicators. This paper has shown the successful implementation of green BPM, with potential cost and material savings results. The findings of this case study are expected to inspire other waste management companies to adopt green BPM. The presented case study might help raise awareness and promote the implementation of green BPM in municipal plants in Eastern and Southern Europe.

Keywords Green business process management · Green BPM · Key performance indicators · Key environmental indicators · Municipal waste management · Case study

Introduction

Today's consumption-oriented society produces vast amounts of waste. The large volume of waste puts considerable pressure on the waste management sector. Moreover, waste management systems include many stakeholders and include socioeconomic, political, environmental and technological considerations [1]. It is assumed that waste should be treated as a resource and energy source [2]. The practical implementation and application of sustainable development principles in the waste management system require finding measures, criteria and indicators to evaluate the proposed solution and make measurements that will test its operation in a practical way.

According to Kaur et al. [3] 'the long-term success of companies can only be ensured if they adjust their strategic and structural orientation to the changing environmental and technological scenario.

Natural environmental changes and limited access to resources in many industries and sectors require a well-planned reorganization of business processes. For about a decade, companies have been interested in adapting business process management (BPM) to sustainable development [4].

Sustainable development is now defined as development that meets the needs of the present without compromising the ability of future generations to meet their needs. It is a

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stable development, taking into account such processes of change in which the exploitation of resources, the main areas of investment, the direction of technological development and institutional changes remain in a harmonious relationship, allowing meeting current needs as well as needs and aspirations in the future [4]. As suggested by Smith et al. [5], companies interpret sustainability as "meeting the local community's needs". Sustainable development has four dimensions: society, the environment, culture and the economy, while these four dimensions are not separate but interdependent [6].

Today companies, while improving their business processes, focus mainly on economic criteria: time, costs, efficiency and flexibility [7]. Many recognize the needs related to the climate and natural environment while they try to base their business model on the values of the social dimension of their activities, responsibility for the natural environment and the orientation of their activities towards sustainable development. Researchers are increasingly advocating for extending the scope of conventional business process management [8] and the dimension of environmental sustainability [9]. In the case of solid waste management, sustainability is practically established and based on the 3Rs principle: reduce, reuse and recycle [10]. Although prevention and recycling are identified as the best strategies, landfill disposal will not be eliminated; it still plays an essential role because a complete zero-waste scenario is impossible [11]. As suggested by Amato et al. [11] it is worth emphasizing that wrong decisions might negatively affect the environmental, economic, and social spheres.

Due to the energy crisis, research on municipal solid waste as an energy source is increasingly popular, and the approach might change the potential direction of environmental and energy management [12]. However, waste management in Eastern/Central European countries focuses on low-cost solutions, and the most important obstacle is the lack of cooperation between different lawyers of multi-governance in waste management [13].

It is observed trend in combining sustainable development with corporate strategy and implementing it in business activities. However, the main challenge to implementing sustainability in the organization is the technical and organizational integration; mainly, this intensive dialogue across management levels depends on management control practices [14].

Therefore, the concept of green BPM appeared. In addition to the classic criteria for evaluating the efficiency of processes, it also considers environmental issues and promotes the balance between individual criteria. Green BPM can therefore be seen as the evolution of classic BPM toward environmental and social issues. Consequently, the modeling and implementation of processes were enriched with an environmental dimension. Although the authors define the term green BPM differently [15], there is agreement that this concept relates to supporting the sustainable improvement of business processes and increasing the importance of a new approach. It has been assumed that each business process has a particular impact on the natural environment; therefore, business process management (BPM) should also be oriented toward the environmental perspective. Managers are required to use methods, techniques and indicators for assessing the implementation of business processes [15], which are aimed at environmental protection, recycling, reducing resource consumption, reducing CO_2 emissions and reducing greenhouse gas emissions. An important issue in this approach is the care for the well-being of employees, which is in line with Corporate Social Responsibility (CSR), involving various stakeholders in the company. In order to ensure a compromise between the economic and environmental objectives under green BPM, it is proposed to extend the classic Key Performance Indicators (KPIs) with environmental indicators (KEIs, Key Environmental Indicators). It becomes crucial to define them concerning the organization's strategic goals, identify and select methods for their measurement, obtain information about the impact of the processes being carried out on the environment and indicate the possibilities for improvement.

Couckuyt and van Looy [15] and Gohar and Indulska [16] indicated the need to use KEIs. Elkington [17] stated that organizations, to be successful in the long run, should focus on all three interdependent dimensions, i.e., economic, social and environmental. It is a relatively new approach to process management and an emerging research discipline [15]. There is little research on this subject, but efforts have been made to identify the key factors influencing the implementation of green BPM. The most frequently mentioned factors are the sector, organization size and market competition [15, 18–21].

Levina [22] showed that green BPM is used to achieve resource efficiency, which is expected to lead to more sustainable company operations. It becomes more and more important if the adoption of a "green" strategy is supported by top management. Loepp and Betz [23] came to the same conclusion when investigating German companies. According to Bossle et al. [24] companies operating in sectors such as health, finance and insurance are likely to face more difficulties with implementing green BPM compared to sectors where environmental policy and the reduction of harmful emissions are inherent. Bossle et al. [24] results are consistent with those obtained by Couckuyt and van Looy [15]. Other researchers stated that organizations that operate in a less competitive market would have less incentive to adopt green BPM [25, 26]. Additionally, smaller companies lacking organizational resources may be less interested in green BPM solutions [27]. According to Couckuyt and van Looy

[15], future research in this area should focus more on case studies to supplement existing results.

Therefore, in this article, practical experiences related to implementing green Business Process Management in the Polish municipal waste treatment plant (MWTP), named ZGO will be considered a case study because, nowadays, avoiding and reducing waste is crucial. However, improving plant processing is also a current topic, confirmed by the growing requirements regarding the levels of recovery and recycling. In recent years, the issue of waste management has become a global problem. Waste disposal, recycling management and energy generation are challenges for many companies in developing economies, including Poland.

According to the World Bank report "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050" [28], approximately 2 billion tons of solid waste is generated yearly. Experts predict that in 30 years, we can expect annual waste at 3.4 billion tons. Poland is one of the largest European Union countries in terms of population (4th place) and area (5th place) [29], which means that the waste problem is also regional. In Poland, the amount of collected municipal waste is increasing year by year [30]. Most came from households and amounted to 11.7 million tons, which is 85.5% of all waste generated [30]. The waste amount is inseparably linked to very high consumption.

Regarding waste generated per capita, Poland occupies a very high position in Europe. In 2021, out of 13.7 million tons of municipal waste, 5.4 million tons were collected selectively. Despite significant progress in the quality and quantity of selective collection, the result is far from satisfactory. According to the European Union law requirements, in 2025, 55% of municipal waste in Poland should be reused and recycled. However, in 2022, 26.9% of municipal waste was recycled, which is only 0.2 percentage points more than in 2021 [30].

The green BPM method is a relatively new approach to process management. It is more often described in the conceptual layer. There are relatively few examples of its use and there is still a lack of practical knowledge on this subject. It is also difficult to describe the use in waste treatment plants. The ZGO case study is the first example to be published when it comes to implementing the green BPM concept in a waste processing plant. The scarcity of the description of the use of this type of plant has been found. This research gap was why the authors referred to examples other than waste treatment plants. According to the authors, this is the value of this study, as well as its novelty and originality.

This article aims to evaluate the green BPM solutions in the functioning municipal waste treatment plant. The processes implemented in the MWTP were discussed, with the specific consideration of the process of mechanical waste processing (sorting), including the reuse and recycling of materials, energy consumption, landfilling and the efficiency parameters of the sorting line. Then a sustainable waste management system was identified, considering the cost as well as social and environmental perspectives. In this approach, strategic goals, KPIs and KEIs were considered.

The following research questions were formulated:

*RQ*1: To what extent does the presented company consider green BPM's aspects (social, economic and environmental) when implementing the processes?

*RQ*2: What is the relationship between the economic efficiency of the processes implemented and the environmental efficiency?

*RQ*3: What environmental performance indicators reflect the effects of improvement obtained?

*RQ*4: What should be the company's further improvement directions to minimize the negative environmental impact?

The rest of the article is divided into four sections: Sect. Background and definitions describes the relevant literature on green BMP. The methodology of research is described in Sect. Methodology. Section Results highlights the results and discussions. Finally, the article concludes in Sect. Discission, stating the present study's impacts, limitations and future research directions.

Background and definitions

Based on the systematic review of the literature, Couckuyt and van Looy [15] stated that there is no uniformity in defining green BPM, a relatively new approach to process management. Green BPM can be seen as a general approach to management [31] that extends the existing BPM [8] and in which not only technical but also management aspects play an essential role.

Regarding green BPM to the classic project management methodology (BPM Project Framework), the authors referred consideration formulated by Jenston and Nelis [32]. It presupposes identifying, modeling, controlling, measuring and optimizing business processes; it considers the implemented strategy. As a result, the entire organization's efficiency increases [32]. Organizations should take into account the demonstrated aspects in the implementation of process management in the following areas: social, economic and environmental, which include: leadership and appropriate process competencies, favorable organizational culture; appropriate law and order, which means governance, using a design approach and appropriate technological solutions.

One of the first articles on this subject was published in 2009 in the Australasian Journal of Information Systems [33]. Therefore, there are still attempts to define green BPM. It is combined with IT solutions to minimize the company's negative impact on the natural environment [16, 34].

However, it is not only about introducing technological changes but also about reconfiguring processes and considering the expectations of many stakeholders [15]. In this approach, green BPM is defined as the sum of all management activities supported by IT systems that help to monitor and reduce the negative impact of business processes on the natural environment; at the stage of design, improvement, implementation or operation, as well as leading to cultural changes of process contractors [34]. The concept focuses mainly on changes in the implementation of processes that go beyond IT and relate to reducing the negative impact on the environment, using fewer resources, reducing CO_2 and greenhouse gas emissions, as well as caring for the well-being of employees and other interested parties. Not only technical aspects but also management and those related to organizational culture play an essential role here. It requires an integrated approach and the introduction of significant changes of different natures.

The implementation of the company's business processes plays a vital role in contributing to the carbon footprint that the organization leaves in the environment [35]. Today, the challenge is the implementation of processes that reconcile the conflict between human activity as well as the natural and social environment. Therefore, BPM is environmentally sustainable and focuses on understanding and improving the company's business processes [36]. In green BPM, more attention is paid to the environmental effects of business processes [9] and their optimization considering the ecological dimension and striving to support environmental goals [8].

According to Seidel et al. [9], companies' sustainable development can be perceived as a goal of action and a tool for managing changes within the implemented business processes. It concerns understanding, documenting, modeling, analysis, simulation, implementing and introducing continuous changes in business processes, with particular emphasis on the environmental consequences of process implementation. Murugesan [37] proposes a comprehensive approach that follows four complementary pathways: use of green resources, green disposal, green design, and green production. In practice, it covers environmental sustainability projects and strategies, including data center design and location; energy-efficient processing, such as energy management and virtualization; responsible and regulatory-compliant disposal, recycling, and pollution prevention practices; and the use of green metrics, assessment tools, and methodologies like the ISO 14001 standard for efficient practice. However, Sohns et al. [41] indicated that while many organizations have put considerable effort into reducing the environmental impact of their business processes, the operational aspects of green BPM are poorly developed. The dominant barriers are limited availability of time, lack of resources, expertise, and knowledge, high implementation costs, and bureaucracy, and resource consumption and emissions are measured, monitored, and utilized by only a limited number of SMEs.

Bocken et al. [38] define green BPM as "a sustainable business model of innovations with a significant positive environmental impact." In turn, Maciel [39] describes green BPM as the result of combining the concept of sustainable development and BPM. Therefore, it defines them as BPM that generates business value with minimal impact on the environment and therefore does not violate the availability of environmental resources for future generations [40]. Hernández-González et al. [40] stated that implementing the green BPM concept is usually associated with achieving two goals: reducing the negative impact on the natural environment and introducing cultural changes that promote specific values and attitudes among members of the organization.

Couckuyt and Van Looy [15] extensively reviewed the definition of green BPM concerning information systems and sustainable BPM. The same authors also propose their definition of green BPM and stated that it "extends the optimization of cost, quality, time, and flexibility of business processes with an environmental sustainability dimension." Green BPM is concerned with modeling, implementing, optimizing and managing business processes with particular attention to their environmental implications while not overlooking organizational capabilities such as culture and structure.

Assuming that every business process has an environmental impact to some extent and can be considered in terms of energy consumption, water use of other resources, greenhouse gas emissions, carbon footprint and waste production, etc., a new approach to business process management has been proposed. As a result, while improving processes, such solutions are implemented, which, on the one hand, will contribute to economic success, but on the other hand, will take into account the ecological and social aspects, balancing the perspective of economic efficiency and environmental considerations. The environmental friendliness of a business process is the degree in which the process is carried out in terms of environmental impact, energy consumption, use of resources and/or recycled, the allocation of the required amount of resources and their use, greenhouse gas emissions and waste production and destination. Transitioning to green BPM and institutionalizing it in the long term requires a set of specific management mechanisms and the definition of new roles, duties, competence and responsibility. It can be introduced following the plan-do-check-act cycle in connection with management activities and cultural changes promoting specific values, thinking, and attitudes among process managers and contractors."

Wrong choices can negatively affect the environmental, economic, and social spheres [11]. Sohns et al. [41] identified barriers that hinder the implementation of green BPM in SMEs, the main ones being limited time availability, lack of

resources, knowledge and experience, high implementation costs and bureaucracy. In the case of ZGO, implementation was forced by external factors such as changes in law regulations, as well as knowledge and experience.

As pointed by Shibamoto [42], companies are focused on managing day-to-day cash flow and less long-term profits or solving social problems. ZGO is a not-for-profit organization that should serve the local community.

Taking into account the critical success factors of BPM, such as strategic management, applied methods, information technology, people and organizational culture [39], the critical capabilities required in green BPM can be identified. They can help design improvements in business processes from the perspective of reducing the negative impact on the natural environment.

In order to ensure a compromise between economic and environmental objectives, green BPM proposes to extend the classic KPIs with ecological indicators (KEI). It becomes crucial to define them concerning the strategic goals of the organization, identification and selection of methods of their measurement, obtain information about the impact of the processes being carried out on the environment and society as well as indicate the possibilities for improvement.

The key capabilities required in green BPM can be indicated. They can help design improvements in business processes from the perspective of reducing the negative impact on the natural environment. Various researchers point out the need to use KEI [8, 15, 16, 33]. The priority here is to define new strategic goals for the company, adjust new indicators and plan new measurement methods and aggregation of KPI and KEI.

Table 1 presents the perspective of BPM elements from the green BPM. They can help design improvements in business processes from the perspective of reducing the negative impact on the natural environment.

Methodology

This study employs a case-based research methodology [43–45]. One of the main advantages of case studies over other methods is collecting evidence from multiple sources (triangulation) [46]. Most remarkable characteristics of case studies is that they study phenomena in their natural environment in the real environment [43]. Due to case studies, both complex and rich, detailed social processes can be studied from a holistic perspective [47].

To understand the researched phenomenon as well as possible, which currently exhibits dynamics different from the conditions mentioned above and is very up-to-date, the article adopts the method of a single case study. The main research intention was to recognize the current phenomenon in real conditions at an early stage of knowledge in a given research area [48]. The pragmatic criterion of data availability dictated the purposeful selection of the case. The criterion related to ensuring data reliability, the possibility of conducting research in the enterprise with data triangulation and maintaining scientific independence were considered. Following the statement that a process implemented by an enterprise can be a research object [49], attention was paid to improving processes following the green BPI approach. The study was intended to describe a specific situation and the

Table 1 BPM elements from the Green BPM perspective

BPM Elements	Green BPM Perspective
Major Aspects in Lifecycle	-New Stakeholder: Ecological Officer -Ecologically aware process design -Ecologically aware resource selection -Sensoring and Monitoring of Ecologically Relevant Data Green Process Analysis and Evaluation -Certification
Major Aspects in Key Performance Indicators	-New performance indicators: Key Ecological Indicators -New strategic objectives -Trade-Off between conventional and new indicators -New Measurement and Aggregation of Indicators
Major Aspects in the Business Process Management Architecture	-New Sensors provide data related to Business Processes -New KEI services for determining ecological indicators -Appropriate Monitoring Facilities supporting KEIs -Ecological Management Dashboard -Methods and Tools for Ecological Process Analysis -Methods and Tools for Ecological Process Adaptation
Major Aspects in Business and Strategy	-New or adjusted strategic objectives define the extensiveness of environmental awareness -Environmental awareness affects both primary and support activities of organizations

Source [62]**:**

mode of action and to identify key, distinctive problems that a given case highlights [48]. The study was descriptive. The "gaps and holes" approach was adopted, in which theory is the starting point for research design [50]. According to Yin [48] the adopted framework determined by theory defines the research question, the direction of the data search and the analysis method. It is worth emphasizing that variables and the research question "how and why" can be modified during the work. According to Ridder [50], gaps and holes were revealed and after identification within the existing theory, are "filled" with empirical data. This approach can be used both to develop the theory and test it. Theory development refers to phenomena that are already partially described and understood.

The source of information was semi-structured interviews with senior executives and other board members from the company's management, based on open-ended leading questions and documents about the company. Interviews with respondents lasted about 60 min and included detailed notes. The interviews took place from December 2021 to May 2022 and concerned all areas of activity of the analyzed company. The interview began with collecting data about each of the respondents, i.e., their position, length of service in a given organization, how many years they have been working in a given position and their responsibilities.

Respondents were asked to present the audited entity's characteristics to obtain basic information such as the subject of activity, the scope of activity, legal and organizational form, time of operation on the market, source of capital, number of employees and applied management concepts and methods. Respondents shared their organization's experience in business process improvement (scope of business process improvement, implementation/ participation in process improvement projects). They were also asked about the implementation of business process improvement. In this case, the emphasis was placed on the premises for improving business processes (environmental, economic and social); methods used to improve business processes (what technological changes); planning activities to improve business processes (such as projects, investments, optimization, modernization); selection of processes for improvement (RDF, composting, digestion and which processes are most important and why). Questions were asked about the implementation of business process improvement (decision on the project initiation and realization; source of the finance for the projects, feasibility study, a study on conditionality) and then about the assessment of the benefits obtained from the point of view of the three pillars: environmental, economic and social. The study considered the perspective of one selected company. Finally, the respondents were asked to identify problems that hinder the improvement of processes (e.g., still large amounts of waste sent to the landfill, the exhausting capacity of the environment, energy purchase costs, RDF fees, increase in environmental fees, low effectiveness of educational activities, low social awareness in sorting). Respondents were also asked to list the factors that favor and hinder the improvement of business processes. Ten people from different levels of company management (top, middle and lower) were interviewed. The top management was represented by the Plant Director, who provided general information on the projects underway and the company's ownership structure. The Mechanical Waste Processing Department manager and his deputy represented the middle management level, who provided data on the sorting plant and the RDF line. The landfill manager was also part of this group. Information on the electricity balance and historical data, i.e., before 2015, was obtained from him. The Head of the Biological Waste Processing Department provided information on the functioning of the fermentation department and composting plant, including electricity production since 2015. The Sales Manager was also interviewed, which provided data on the sale of raw materials. The lower level was represented by the Sorting Foremen (2 persons) (information on the Sorting Cabinet and the RDF line); records and reporting specialists (2 persons) (amounts of accepted and processed waste).

In addition, data from the company's internal reports, electricity invoices, project implementation reports, data on waste data records, as well as sales statements were analyzed.

The questions asked provided information on:

- the amount of waste generated in the region where the company is found,
- projects (activities) aimed at expanding the company's existing infrastructure and introducing new innovative technologies to better manage the current waste in the period from 2000 to 2022,
- implementation of new technology in the company enabling the management of new waste (expansion of the enterprise's activity),
- defining the company's strategic goals on the environment, economic and social aspects,
- defining indicators related to the environment, economic and social aspects that help achieve the strategic goals of the company related to functioning as a green BMP,
- establishing KPIs and methods of measuring them to verify the achievement of the planned goals,
- comparison of the values of indicators (environmental, economic, social) before the introduction of improvements in the described enterprise, also after the implementation of the first, second and third projects,
- The purpose and legitimacy of conducting the information and educational campaign as part of the project.

Consequently, retroactive data were collected in real-time to ensure the validity of external and internal data [51]. However, the information about the number of sorting personnel, the layouts of the processing lines, the composition of MSW and recyclable materials, the specifications of the equipment, the process mass balance and financial details, e.g. maintenance costs, income, revenue, etc. were classified as internal/confidential data, thus it could not be presented in the study.

The respondents explained uncompleted questions via email and telephone. Case studies are rich empirical descriptions of specific phenomena based on various data sources [52]. To gain additional insights and improve the accuracy of the conclusions, the authors analyzed the company website and reports on the completed projects.

Results

The presented municipal waste treatment plant, ZGO, is in Lower Silesia (NUTS2), Poland.

The owner of the MWPT is the local government (NUT5 region), co-owners are three partners: 1. Ecological Association of Municipal Waste Management "EKOGOK"; 2) Ślęza-Oława Inter-Commune Association, 3) Jelcz-Laskowice [53]. It serves approximately 260,000 inhabitants from 17 communes (NUTS5): cities: Oława, Brzeg; communes: Oława, Lubsza, Skarbimierz, Żórawina, Domaniów, Czernica, Cieplowody, Przeworno, Borów; urban–rural communes (Jelcz-Laskowice, Siechnice; Bierutów, Strzelin, Wiązów, Ziębice) [54].

It is not a commercial entity, a not-for-profit organization, meaning it does not earn profit for its owners. The owners care about keeping the price as low as possible for residents, and all money earned through pursuing business activities or donations goes back into running the organization and only covers operating costs.

ZGO has all the necessary decisions and permits to operate [55]. The level of decision-making in communes was delegated from the central to the local government. That means that decisions in the entity are made on local levels by local government.

The main responsibilities of ZGO is the management of waste other than hazardous and inert, production of electricity and heat from biodegradable waste, waste sorting (selective collection and municipal waste), recovery of bulky waste, transfer of separated waste for recovery and recycling, neutralization of waste by depositing it in a landfill, sale of secondary raw materials: paper (newspaper mix); cardboard; plastic packaging (PET) by color: colorless, blue, green, mix; household chemicals; mixed foil; mixed glass packaging; aluminum can; steel can; combustible waste (RDF alternative fuel); batteries [53].

Regulations for the provision of waste acceptance and management services are clearly defined [55]: the service price lists [56], general conditions of sale of raw materials [57].

In 2020, Lower Silesia region has the highest indicator of the amount of municipal waste generated per capita in Poland (400 kg/capita with the national average being 342 kg/capita) [30]. MWTP has been operating since 1999. It serves a region inhabited by more than 250 thousand people, although it should be emphasized, that there is currently no regionalization of waste management in Poland.

The enterprise operates following the applicable provisions of Polish law, including the Act of Waste (14.12.2012), on waste and the relevant ordinances of the Minister of Climate and Environment (formerly the Minister of Environment), European Union directives, assumptions of the National Waste Management Plan, and Provincial Management Plan Waste. However, the latter is planning, not decision-making, for implementation process changes. They specify the necessary infrastructure for municipal waste and the processing capacity to prevent and manage this waste, ensuring the achievement of the objectives set out in the regulations.

From the beginning, the company has been consistently developing the waste treatment process and systematically introducing improvements to the processes.

During 2000–2002, the plant was expanded, a waste sorting line was launched and a composting facility was made available. Behind that decision were law regulations changes [Environmental Protection Law; (OJ L, 62, item 627, 20.06.2001); Act on Waste (OJ L, 62, Item 628, 27.04.2001]..

In 2008 Directive 2008/98/EC on waste and repealing certain Directives (OJ L 312, 22.11.2008, pp. 3–30) and the company needed to adjust to this regulation. In December 2008, the Ślęza-Oława Inter-Commune Association (owner then) commissioned the development of full documentation for extension and modernization. In June 2009, the General Meeting of Shareholders of the Company decided to accept the extension and modernization for implementation. Waste management system Ślęza – Oława", co-financed from the Cohesion Fund under the Operational Program Infrastructure and Environment and by the National Fund for Environmental Protection and Water Management, project value was PLN 129,598,908 (gross). The value of the co-financing was PLN 61,707,457 [58].

The planned investment included: an installation for processing biological waste in fermentation and oxygen stabilization, a modern sorting line and an alternative fuel production line (refuse-derived fuel, RDF). In 2009 ZGO was the first plant in Poland that used two optopneumatic separators to sort plastic and paper waste. In the second half of 2011, the General Meeting of Shareholders of the

Company decided to carry out construction and installation works for individual installations as part of the expansion of the mechanical and biological parts of the plant.

In June 2012, the Lower Silesian Voivodeship authorities adopted a resolution on the implementation of the Voivodeship Waste Management Plan [58], in which the ZGO installation was recognized as the Regional Municipal Waste Processing Installation for the eastern region of the Voivodeship Waste Management Plan for the Lower Silesian Voivodship, inhabited by over 250,000 residents.

Later on, still changes in law requirements appeared. For example, the Waste Act has been amended and the Ordinance of the Minister for the Environment of 29th December 2016 on the detailed method of selective collection of selected waste fractions has been implemented. This regulation was the reason for further expansion of the entity.

As a consequence, in 2017–2019, the company implemented a project co-financed by the EU funds called "Optimizing processes and adjusting the plant to operate in a circular economy." under Priority Axis No. 4 "Environment and resources" Measure No. 4.1 "Waste management" of the Regional Operational Program for the Lower Silesian Voivodeship 2014–2020 Project value was PLN 25,667,214.09 (gross). Co-financing value amounted to PLN 16,978,839.38 [59].

The National Fund for Environmental Protection and Water Management [60], was responsible for both projects implementation and monitoring (the national level of governance).

As part of the project, modern equipment was purchased for the sorting process and a refuse-derived fuel – RDF production line with fuel-drying equipment was equipped with new machines. The construction of a bulk waste warehouse with a recovery segment and a warehouse for waste recovery and selectively collected waste was also started. A line was launched for the thorough cleaning of selectively collected biowaste. An information and educational campaign were also carried out, addressed to residents of the municipalities from which the waste processed by the MWTP originates. The MWTP's expansion aimed to adjust the waste treatment process to changes in the waste morphology and introduce a large-scale separate collection system.

Considering Commission Implementing Decision (EU) 2018/1147 (10.08.2018) establishing best available techniques (BAT) conclusions for waste treatment, under Directive 2010/75/EU of the European Parliament and of the Council (OJ L, 208/38); in 2020, an EU project called "Implementation of new waste treatment and recovery processes to increase the levels of recycling" meets the environment's needs, such as the need to combat climate change and adapt to the best available techniques (BAT) conclusions. Plant development project POIS.02.02.00–00-0036/18–00 under Measure 2.2 Municipal waste management priority axis II Environmental protection, including adaptation to climate change of the Operational Program Infrastructure and Environment 2014–2020. The total cost of the Project PLN 85,070,928.13 gross, co-financing value of PLN 47,243,141.42 [61].

The project involved the modernization and expansion of the installations and facilities on the enterprise's premises. It is expected that as a result of the project, the amount of landfilled municipal waste should be reduced, and the amount of waste processed and recycled is to increase.

As a result, a complex mechanical and biological waste treatment plant was established, for which a schematic diagram of the management of unsorted (mixed) municipal solid waste (MSW) is presented in Fig. 1.

It was also assumed that project implementation would improve the natural environment condition in the region and beyond, mainly through:

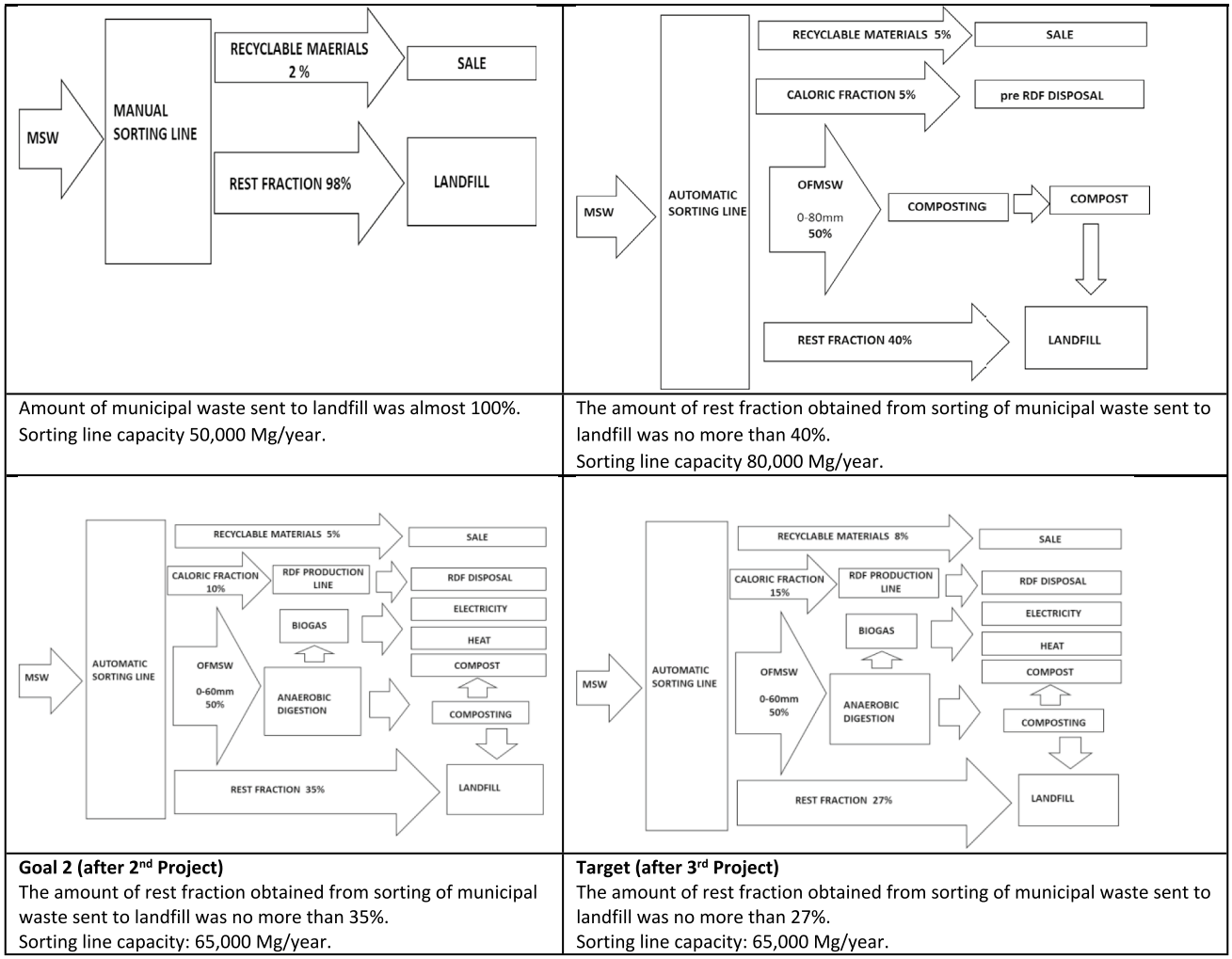
- Increasing the recovery and recycling of waste,
- Production of compost from biodegradable waste, which should reduce the use of artificial fertilizers,
- Reducing the use of natural energy resources through the production of electricity and heat from biogas,
- Increasing awareness of the local society through educational campaigns and activities to prevent waste generation.

An essential element of this project was to conduct educational and information workshops in educational institutions and prepare a waste management guide. The implementation of the project goals defined in this way relates to all installations used in the enterprise for waste processing. In connection with all of the above, it was planned, among other things, the expansion of the sorting plant with a second reception hall and a sorting line for collected source waste.

Before process investment (Fig. 1) in 1999, when the whole amount of municipal solid waste collected by ZGO after manually sorting valuable raw materials was sent to a landfill.

In the next stage of Green BPM improvement (Goal 1, Fig. 1), a sorting facility with two optopneumatic separators was introduced into the process, which allowed for higher recovery of valuable materials (from 2 to 5%) and a caloric fraction (5%). However, most of the waste was still sent to the landfill. Compost and the rest fraction were more than 75% of the treated waste.

The MWTP was expanded to process more efficiently with the introduction of waste collection at the source (Goal 2). This process improvement caused the reduction of the landfilled waste amount. The process development included (1) increasing the number of optopneumatic separators to five; (2) building an RDF production hall and (3) an anaerobic digestion facility (dry, continuous digestion in



Amount of municipal waste sent to landfill was almost 100%. Sorting line capacity 50,000 Mg/year.	The amount of rest fraction obtained from sorting of municipal waste sent to landfill was no more than 40%. Sorting line capacity 80,000 Mg/year.
Goal 2 (after 2nd Project) The amount of rest fraction obtained from sorting of municipal waste sent to landfill was no more than 35%. Sorting line capacity: 65,000 Mg/year.	**Target (after 3rd Project)** The amount of rest fraction obtained from sorting of municipal waste sent to landfill was no more than 27%. Sorting line capacity: 65,000 Mg/year.

Fig. 1 Schematic diagram of mixed municipal waste management in the analyzed plant

thermophilic conditions with yearly capacity 32,000 Mg). This improvement aimed to obtain the level of landfilled rest fraction after waste sorting to be no more than 35% (Goal 2). As a result, OFMSW and rest fraction amount decreased and caloric fraction increased to 10%. However, the process still needed to be improved because of the amount of landfilled waste.

Produced RDF was characterized by its low quality because of its very high water content. The low quality of RDF fuel caused problems with selling it; the selling price was too low compared to the production costs. This poor quality was the reason behind the business operator's decision to purchase the drying RDF. Introducing the drying process of RDF also reduced the waste volume sent to the landfill (e.g., sorting ballast or bulky waste) by using them as components for RDF.

During the most recent expansion of the plant (Target, Fig. 1), a sixth optopneumatic separator for separating PET bottles into colors was installed and a ballast sorting line was constructed and introduced into the process to reduce the amount of landfilled rest fraction to less than 27% together with caloric fraction increase to 15%.

It can be seen that the sorting effect of the sorting line is not easily improved. However, it was observed that the total and processing capacity had been improved (Fig. 1). Also, when we assume that the efficiency of the sorting line is the amount of the recovered secondary raw materials which was sold,and it is increasing (Table 2). What is more, comparing data on the volume of sold raw materials before (2011) and after (2020) process improvement, it was more than 220%.

Changing the sorting method by residents (at source) was forced by law regulations (Regulation of the Minister of the Environment, 29.12.2016 on the precise method of selective collection of selected waste fractions (OJL of 2016, item 19), in which it was indicated. that municipal waste is subject to separate collection and that it is collected separately: glass. paper. metals. plastics and biodegradable waste. with particular emphasis on bio-waste. Its last update took place

Table 2 Changes in electricity consumption and production and recovered secondary raw materials during process development in ZGO

Electricity consumption and production							
Year	Phase	Electricity consumed [MWh]	Electricity purchased [MWh]	Electricity generated [MWh]	Electricity sold [MWh]	Maximum absorbed power/ power demand [MW]	Sold the mass of recovered secondary raw materials [tonnes]
> 2011	Base Value	411.00[a]	411.00[a]	-	-	n/a	2000.00[a]
2011	Goal 1 (after 1st Project)	1051.45	1051.45	-	-	331	4227.41[b]
2012		1074.16	1074.16	-	-	312	4227.41
2013		1176.76	1176.76	-	-	348	4474.16
2014		1771.02	1771.02	-	-	606	6346.20
2011 vs. 2014		+68.44%+	+68.44%	nd	nd	+83.08%	+50.12%
2015	Goal 2 (after 2nd Project)	3024.19	1745.82	1759.21	480.85	716	8385.29
2016		3406.57	477.14	4244.05	1314.63	806	8515.99
2017		3957.67	442.97	5065.97	1551.27	872	8914.93
2018		4037.28	235.27	5983.80	2181.79	856	9380.06
2019		4442.88	703.36	5101.31	1361.79	905	11,380.66
2015 vs. 2019		+46.91%	− 59.71%	+189.98%	+183.2%	+26.4%	+35.72%
2020	Target (after 3rd Project)	4771.72	677.69	5558.21	1464.18	945	12,324.14
2021		4880.89	715.97	5544.88	1379.96	963	13,539.03
2020 vs. 2021		+9.86%	+1.79%	+8.70%	+1.33%	+6.41%	+18.97%
Effect of process improvement							
2011 vs. 2021		+364.21%	-31.91%	nd	nd	+190.94%	+220.27%
2015 vs 2021		+61.39%	-58.99%	+215.19%	+186.98%	+34.50%	+61.46%

[a]data not available; the assumption based on company's permissions

[b]data not available; the assumption was that the amount was the same as in 2012

in May 2021: Regulation of the Minister of Climate and Environment (10.05.2021) on the method of selective collection of selected waste fractions (OJ L 2021, item 906), which provides for the selective collection of fractions: paper, glass, metals, plastics, multi-material packaging (these three can be collected together) and biowaste.

The regulations mentioned above caused the introduceda separate waste collection system. For example, "door-to-door" in the case of rural and single-family housing and assuming disposal in various standard bins regarding multi-family housing is bringing the expected results. It should also be noted that ZGO organized informative campaigns about separate waste collection, with each development addressed mainly to children and adolescents.

Process improvement of effected on electricity consumption and production and recovered secondary raw materials during process development in ZGO is presented in Table 2. In terms of energy, it has been observed that process improvement needs more energy (an increase of 364.21% when comparing 2011 versus 2020). The increased demand for energy was related to new equipment and facilities in the whole treatment process, e.g., the number of conveyors increased from about 10 to about 100 in this time; furthermore, the RDF production line and RDF drying line which require much energy were installed. On the other side, introducing anaerobic digestion into the process and better separating the waste biodegraded generated more energy and less was purchased. Additionally, there was a decrease in the maximum adsorbed power during the analyzed period.

Furthermore, the introduction of the RDF drying process allowed for improved fuel quality and enhanced cooperation conditions with the cement plant. The parameters of wet and dried RDF were presented in Table 3.

Considering changes in electricity consumption it can be assumed that the company development was mainly possible thanks to the AD facility and its own electricity and heat generation. In addition, the last analyzed development was also aimed at increasing the biogas yield by introducing

Table 3 The RDF characteristic

Parameter	Before drying	After drying
Ash content [%]	12.8	14.2
Moisture [%]	25.03	16.5
Caloric Value [kJ/kilo]	16,049	19,424
S content [%]	0.26	0.26
Cl content [%]	0.62	0.61

biowaste (from approx. 105m^3 to 111 m^3 per ton) and its losses reduction (e.g., additional biogas storage tank).

In order to present the activities undertaken by the analyzed company, it should be looked at from the economic, environmental and social perspectives (Table 4). We rely on the model proposed by Zaman [62].

The MWTP focus on environmental aspects and implementing the described projects caused specific effects. Their interpretation is based on the adopted strategic goals, KPIs and measurement methods presented in Table 4. The goals achieved are compared to the base value before the investment process. It can be seen that the strategic goal, which was to improve the technological process by increasing investments in waste processing technologies, was achieved to the highest degree. There is a significant improvement in the recycled materials used and a visible increase in revenues related to the dimensions of sustainable development.

Furthermore, a 50% reduction in CO_2 produced was reached compared to the baseline value, which entailed an improvement in the use of renewable sources. However, the low return on investment is due to the local government ownership of the waste management plant, which is not-profit-oriented and only covers operating costs. Social goals, such as establishing relationships with stakeholders, increasing employee satisfaction and introducing social marketing policy, are also partially or not entirely achieved. Obtained values of social indicators mean that the social area should be focused on managing in MWTP. Social indicators might also be an interesting area for future research in other case studies.

Discussion

The article assessed the operation of a municipal waste treatment plant (MWTP) from the perspective of green business process management (Green BMP) solutions. It discusses the processes implemented at the MWTP, with particular emphasis on the process of mechanical processing (sorting) of waste, including the reuse and recycling of materials, composting, and energy production via anaerobic digestion, landfill storage, and efficiency parameters of the sorting line.

As for research question RQ1, it was observed that in the analyzed municipal waste treatment plant, the share of renewable energy grew with each completed investment project. Before the anaerobic digestion facility construction, all electricity was purchased, which in Poland is practically from burning coal. The biogas recovery in CHP units allowed MWTP to produce a significant part of electricity demand through renewable sources (Tab. 2). The waste management improvement and resource recovery have fostered technological developments.

The introduced changes resulted mainly from the changing external conditions of MWTP's operation, such as changes in legal regulations, development of technology, and increased public awareness of climate change. The literature recognizes the relationship between many external factors and waste management development [63]. These factors include waste legislation and infrastructure (e.g., landfill taxes, local duty rates, waste management efficiency, and strict waste policies). However, it should be noted that the efficient operation of waste management systems requires enormous investment and labor. Therefore, when designing waste disposal technology, economic benefits are most often put in the first place [62], which can be considered an obstacle to Green BPM.

Sohns et al. [41] identified barriers that hinder the implementation of Green BPM in SMEs, i.e., limited time availability, lack of resources, knowledge and experience, high implementation costs, and bureaucracy. In the case of ZGO, implementation was forced by external factors such as changes in law regulations, as well as knowledge and experience.

As pointed out by Shibamoto [42], companies are focused on managing day-to-day cash flow and less long-term profits or solving social problems. ZGO is a not-for-profit organization that should serve the local community.

As for the research question RQ2, the processes implemented at the MWTP were analyzed, with particular emphasis on the process of mechanical processing (sorting) of waste, including the reuse and recycling of materials, composting, incineration and energy production, landfill storage and efficiency parameters of the sorting line. An attempt was made to assess the waste management system's sustainable dimension, considering the costs incurred, the results obtained, and the social and environmental perspectives. It corresponds to the statement that a comprehensive view of business is impossible without omitting social and environmental aspects, and emphasizing only the economic aspect does not reflect the diversity of processes in the company.

The results show the relationship between the economic efficiency of the implemented processes and environmental efficiency. Before the construction of the biogas plant, all electricity, which in Poland comes from burning coal, was purchased. The structure of the biogas facility allowed to cover the demand for electricity from renewable sources. Generating own electricity and heat resulted in savings. At the same time, sorting line development affected an increment in the volume of raw materials and the company's revenue.

Regarding research question RQ3, the analysis included costs, environmental criteria, and key environmental indicators. It has been noticed that despite progressing development and investment in MWTP, some indicators are not monitored, especially social factors. It is worth mentioning

Table 4 Environmental, economic and social indicators toward Green BMP

Environmental indicators							
Strategic goals	Key Performance Indicator	Formula	Measurement	Base value (before investment process)	Goal 1 (after 1st Project)	Goal 2 (after 2nd Project)	Target (after 3rd Project)
To improve the use of the renewable sources	renewable sources rate	Yearly consumed green energy/ yearly total consumed energy	renewable sources/other sources	0%	42%	80%	90%
To reduce superfluous resources consumption	efficiency resources use rate	Electricity consumed in the sorting line/treated waste amount	energy used per thousand kilos treated waste (kWh/1000 kilo treated waste), total consumption of water and other resources per thousand kilos treated waste)	35	40	40	35
To reduce greenhouse gasses emissions	total direct or indirect emissions of greenhouse gases by weight	Carbon dioxide emission/ treated waste amount	% reduction of CO_2 produced compared to the baseline value (kilo CO_2/1000 kilo treated waste)	0%	25%	50%	50%
Environment's safeguard	waste reduction rate	Landfilled waste amount/ treated waste amount	percentage of waste generated per treated waste	98%	40%	35%	27%
To improve the effort to greenness	percentage of reusable/recycled material	Amount of recycled materials used in waste treatment process/ amount of all materials used in waste treatment process	recycled material used/total material used	10%	18%	40%	55%
Economic indicators							
Strategic goals	Key performance indicator	Formula	Measurement	Base value (before investment process)	Goal 1 (after 1st Project)	Goal 2 (after 2nd Project)	Target (after 3rd Project)
Increase the return on investment	ROI related to environmental protection	Financial data of the company	cost analysis	2%	2%	2%	2%
Increase the revenues associated to sustainability dimensions	% additional revenue (additional price premium brand differentiation, income from recycling/close-loop programs, sustainable innovations	Financial data of the company	financial reporting	9.63%	14.32%	8.31%	19.30%
To improve the technology process	% of investments in environmental technology	Financial data of the company	investments in environmental technology/total investments	0%	99.14%	99.07%	99.67%

Table 4 (continued)

Economic indicators							
Strategic goals	Key performance indicator	Formula	Measurement	Base value (before investment process)	Goal 1 (after 1st Project)	Goal 2 (after 2nd Project)	Target (after 3rd Project)
To guarantee the quality of the process	Production sites with environmental certification, environmental information accuracy rate, environmental information availability rate	Data obtained from the company	survey	0	0	0	2
Social indicators							
Strategic goals	Key performance indicator	Formula	Measurement	Base value (before investment process)	Goal 1 (after 1st Project)	Goal 2 (after 2nd Project)	Target (after 3rd Project)
Inclusion of all society members in developing sustainable goals	integration rate (founding budget)	Financial data of the company	questionnaire	205 k. PLN	232 k. PLN	249 k. PLN	249 k. PLN
Stakeholders' relationships	stakeholder' satisfaction rate	Data obtained from the company	questionnaire	0	0	0	0
Participate in all social initiatives	social initiatives at a national and local level	Data obtained from the company	total social initiatives at a national and local level	13	13	9	10
To increase employees' satisfaction	employees' satisfaction rate	Data obtained from the company	questionnaire	0	0	0	0
Social marketing policies	stakeholder's satisfaction rate	Data obtained from the company	questionnaire	0	0	1	1

that factors such as population, amount of waste generated, human behavior, local waste management practices and urbanization are crucial to designing waste management systems [62]. It can be said that the higher the ecological awareness of the society, the more pro-ecological activities can be expected from people and institutions generating waste. Undoubtedly, regulations enforcing specific waste segregation methods and implementing business processes by waste disposal plants may play a primary role in this regard. The need to consider environmental indicators in the decision-making system of companies dealing with waste management and implementing green processes seems indisputable. Elements of environmental management should be included in all stages of business process management, such as planning, measurement and improvement. These are indicators relating to process inputs (e.g., rational use of raw materials, materials, energy) and those relating to outputs (reduction of waste and emissions) while maximizing the reuse of waste [64]. At the same time, it can be noted that there is still very little analytical data available on the interdependence of social, economic and environmental requirements for waste management systems [62]. In the analyzed MWTP, indicators verifying progress in this area could be used to a greater extent: the degree of energy recovery, recycling and reuse of materials, implementation of policies similar to reducing the emission of harmful substances or landscape design, including tree planting. These indicators should help measure progress toward sustainable development and show environmental, social and economic impacts.

Introducing indicators other than financial ones is not easy to implement. Rajnoha et al. [65] conducted a sample analysis of all relevant sectors (164 companies). They showed that only traditional financial indicators influence the overall results. While the use of the balanced scorecard method was envisaged, the system initially focused solely on economic indicators based on accounting data from previous years. While enterprises do not operate in a closed system of relationships but in a dynamically changing environment, it is necessary to look at the functioning of business differently and consider its nature. Attention was paid to non-financial indicators and more complex systems supporting business results, emphasizing the strategy and business goals (concerning technological innovation, environment, social aspects, and IT). However, some limitations remain, especially in combining economic, environmental and social outcomes.

Regarding research question RQ4, it should be emphasized that waste disposal, recycling management and energy generation are challenges for many companies in developing economies, including Poland. Despite the perceived depletion of natural resources, the decline in biodiversity and observed climate change, the global economy continues to contribute to increased production and consumption worldwide. In this situation, economic, social and environmental factors significantly impact the development of waste management [62]. Waste management is a complex system with different impact aspects, and its functions are also dynamic and interdependent. Recovery of resources from waste is one of the primary goals of waste management systems in developed countries. The development of the presented MWTP should also go in this direction. Many companies today focus on waste-to-energy technology, but for Eastern/Central European countries, the priority is low-cost options. However, advanced waste management systems are associated with various environmental and socio-economic problems. Due to the development of awareness about environmental pollution and the various consequences of climate change, a sustainable waste management system is required, which is relatively difficult to achieve.

To further enhance its environmental impact, the MWTP could consider expanding the waste-to-energy technology to increase the efficiency of energy generation from waste, thereby reducing reliance on fossil fuels and lowering greenhouse gas emissions. Implementing advanced composting methods can improve the quality and efficiency of compost production, enhancing soil health and reducing the need for chemical fertilizers. Increasing the recovery of valuable materials from waste, such as metals and plastics, through improved sorting and recycling technologies can reduce the extraction of raw materials and promote a circular economy. Adopting and rigorously applying ISO 14001 standards for environmental management can systematically mitigate environmental impacts, ensure regulatory compliance, and improve overall sustainability practices. Enhancing community outreach programs to educate the public on waste reduction, recycling, and the benefits of composting can lead to better waste segregation at the source and higher-quality recyclable materials. Establishing a robust system for monitoring and reporting environmental performance, including regular assessments of energy use, emissions, and resource recovery rates, can inform continuous improvement efforts.

By focusing on these areas, the MWTP can further its commitment to green BPM, resulting in positive environmental changes such as reduced emissions, improved resource efficiency, and increased community engagement in sustainable waste management practices. These targeted improvements will help the MWTP meet regulatory requirements and contribute significantly to the broader goals of environmental sustainability and climate change mitigation.

Future improvement directions should include educating households about the importance of reducing waste, increasing recycling rates, and composting. Public education that raises ecological awareness directly impacts the minimization of MWTP's negative environmental effects. Research conducted by SEC [66] indicates that in 2022, Poland saw a significant increase in public awareness related to the value

of sustainable development (ESG), but it still remains significantly below the global average. A well-planned advertising campaign can also play a significant role, as its message can influence the attitudes and behaviors of the local community regarding waste generation and segregation methods. The potential of social marketing to shape desired social behaviors is very large. Research shows [67] that the high awareness of the importance of separating waste could further be strengthened through the tools of social marketing as a factor for social change. Changing people's attitudes, mindset, and behaviors is the way to positively impact the environment, Changing people's attitudes, mindset, and behaviors is crucial to positively impact the environment [68]. This applies not only to promoting individual environmentally-friendly lifestyles, but also in the context of building support for systemic changes so that each entity (e.g., at the individual and business level) behaves in accordance with ecological values [69].

The development of green BPM can take place in stages. Such transformation should be planned and structured, considering the needs of various stakeholders, including the local community. The change towards green BPM requires that all process improvement initiatives align with the organization's strategic goals, considering the process architecture and the operational plane (implementation of changes). There is a close relationship between process architecture, process management across the organization, redesigning business processes in a "green" direction and adapting technological changes. Sustainable development issues usually involve a combination of three pillars: economic, social and environmental [70]; the decision-making approach should consider and integrate all three. These aspects may lack relevant data, have multiple (sometimes controversial) goals, or have different stakeholders responsible and interested in achieving those goals. It is also difficult to talk about the advantage of one group over the other.

The approach to gain empirical insights into how Green BPM is implemented at different maturity levels in manufacturing SMEs was applied. The business sustainability practices of waste management in Eastern/Central European countries focus on low-cost options. There are vast discrepancies in waste management performance across different regions.

Different factors influence whether companies integrate economic, social and environmental indicators into their performance management system. Larger companies and companies in environmentally low-impact industries generally integrated more sustainability indicators into their performance management systems, especially if sustainability managers considered them important to performance. Large companies and companies from environmentally high-impact industries integrated social, but generally not environmental indicators into their performance management systems. Conspicuously, whether or not an indicator was included in corporate sustainability reports did not influence its integration into a company's performance management system. The results thus highlight the lack of synergy between external corporate sustainability reports and internal sustainability performance management, which organizations need to address to become more sustainable.

Furthermore, it is imperative to acknowledge the limitations within the research, which can impact the extent to which these findings can be generalized. The study primarily shows the perspective of a single selected company, which naturally restricts the broader implications of the introduced changes across the entire network of connections. An intriguing avenue for future research lies in exploring the comprehensive effects of these alterations, including a thorough assessment of the CO_2 emissions associated with utilizing the produced RDF throughout various sectors. Regrettably, due to the case study design, it was confined to the examination of a solitary company. As a result, the authors could not provide information regarding the specific CO_2 emissions resulting from using RDF as a fuel in cement plants.

Moreover, the study encountered constraints stemming from the unavailability of specific data. The company deemed some data confidential and proprietary, precluding their inclusion in this research. These classified data were, therefore, omitted from the study, limiting our ability to present a complete and comprehensive analysis.

Conclusions

The MWTP's performance has been monitored for 12 years while the financial and environmental impact of the implementation of green BPM has been studied. This paper has shown a successful implementation of BPM, with promising results when it comes to costs and material savings. The study also shows how implementing green BPM makes the municipal waste treatment company environmentally aware and economically feasible. These results must be interpreted cautiously because this case study deals only with the Polish municipal waste treatment plant. The authors are aware that their case study is limited and may not represent Polish waste treatment plants and that the conclusions may not be transferable to other settings due to the difficulty of replicating the results. The case study's findings are expected to inspire other waste treatment plants to adopt green BPM. Perhaps the following case study will help raise awareness and promote the implementation of green BPM in municipal plants in Eastern and Southern Europe. Future research is needed to confirm statements among other companies to get more representative results. It is extremely important

to verify the implementation of green BPM because of a lack of practical knowledge on this subject. Our research fulfills the gap in practical studies in implementing green BPM. Various factors drive the trends in the development of waste treatment technology. Their identification is essential to understanding and planning the design of a new system in the waste management sector. However, the development of waste technology also involves other issues, such as changing personal and social viewpoints. Therefore, the MWTP still needs to develop the green BPM approach; it still does not implement such strategic goals as increasing social awareness, the impact of human behavior, local management practices and the introduction of social marketing. To further minimize its negative environmental impact, the MWTP should consider several specific directions for improvement. First, expanding waste-to-energy technology can increase the efficiency of energy generation from waste. Second, implementing advanced composting techniques can enhance the quality and efficiency of compost production. Third, increasing the recovery of valuable materials from waste through improved sorting and recycling technologies can foster a circular economy. Adopting ISO 14001 standards can reduce environmental impacts, ensure regulatory compliance, and enhance sustainability practices. Enhancing community outreach programs can lead to better waste segregation and higher-quality recyclable materials. Finally, establishing a robust monitoring and reporting system for environmental performance can support continuous improvement efforts.

These targeted improvements will help the MWTP meet regulatory requirements and significantly contribute to broader environmental sustainability and climate change mitigation goals. The positive outcomes of these efforts include reduced emissions, improved resource efficiency, and increased community engagement in sustainable waste management practices.

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References:

1. Zaman AU, Lehmann S (2013) The zero waste index: a performance measurement tool for waste management systems in a 'zero waste city.' J Clean Prod 50:123–132. https://doi.org/10.1016/j.jclepro.2012.11.041
2. Ham GY, Matsuto T (2021) Comparison of energy recovery system from municipal solid waste in terms of energy balance and life cycle CO2 emission. J Mater Cycles Waste Manag 23:1751–1764. https://doi.org/10.1007/S10163-021-01212-9/FIGURES/6
3. Kaur S, Gupta S, Singh SK, Perano M (2019) Organizational ambidexterity through global strategic partnerships: a cognitive computing perspective. Technol Forecast Soc Change 145:43–54. https://doi.org/10.1016/j.techfore.2019.04.027
4. UN General Assembly (2015) Transforming Our World: The 2030 agenda for sustainable development. 21 October 2015, A/RES/70/1
5. Smith H, Discetti R, Bellucci M, Acuti D (2022) SMEs engagement with the sustainable development goals: a power perspective. J Bus Res 149:112–122. https://doi.org/10.1016/J.JBUSRES.2022.05.021
6. Tare M (2020) Education for sustainable development. Technol Innov 21:1–3
7. Reijers HA, Liman Mansar S (2005) Best practices in business process redesign: an overview and qualitative evaluation of successful redesign heuristics. Omega (Westport) 33:283–306. https://doi.org/10.1016/j.omega.2004.04.012
8. Nowak A, Leymann F, Schumm D (2011) The differences and commonalities between green and conventional business process management. 2011 IEEE ninth International conference on dependable, autonomic and secure computing. IEEE, pp 569–576
9. Seidel S, Recker J (2011) Green business process management and a call the role of business process management in green initiatives. Bus Inf Syst Eng 3:245–252
10. Das S, Lee SH, Kumar P et al (2019) Solid waste management: Scope and the challenge of sustainability. J Clean Prod 228:658–678. https://doi.org/10.1016/J.JCLEPRO.2019.04.323
11. Amato A, Magi Galluzzi L, Beolchini F (2022) Effect of MBT on landfill behavior: an Italian case study. J Mater Cycles Waste Manag 24:2569–2581. https://doi.org/10.1007/S10163-022-01501-X/TABLES/1
12. Kumar A, Singh E, Mishra R et al (2023) Global trends in municipal solid waste treatment technologies through the lens of sustainable energy development opportunity. Energy 275:127471. https://doi.org/10.1016/J.ENERGY.2023.127471
13. Malinauskaite J, Jouhara H, Czajczyńska D et al (2017) Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy 141:2013–2044. https://doi.org/10.1016/J.ENERGY.2017.11.128
14. Beusch P, Frisk JE, Rosén M, Dilla W (2022) Management control for sustainability: towards integrated systems. Manag Account Res 54:100777. https://doi.org/10.1016/J.MAR.2021.100777

15. Couckuyt D, van Looy A (2020) A systematic review of Green Business Process Management. Bus Process Manag J 26:421–446
16. Gohar SR, Indulska M (2020) Environmental Sustainability through Green Business Process Management. Australas J Inf Syst 24:1–30. https://doi.org/10.3127/AJIS.V24I0.2057
17. Elkington J (1999) Cannibals with forks: the triple bottom line of 21st century business. Choice Rev Online. https://doi.org/10.5860/choice.36-3997
18. Dustdar S, Fiadeiro JL, Sheth A (2008) Business process management. Data Knowl Eng 64:1–2. https://doi.org/10.1016/j.datak.2007.06.004
19. Ortbach K, Plattfaut R, Poppelbuß J, Niehaves B (2012) A dynamic capability-based framework for business process management: theorizing and empirical application. 45th Hawaii International conference on system sciences. IEEE, pp 4287–4296
20. Niehaves B, Poeppelbuss J, Plattfaut R, Becker J (2014) BPM capability development—a matter of contingencies. Bus Process Manag J 20:90–106. https://doi.org/10.1108/BPMJ-07-2012-0068
21. Weitlaner D, Kohlbacher M (2015) Process management practices: organizational (dis-)similarities. Serv Ind J 35:44–61. https://doi.org/10.1080/02642069.2014.979402
22. Levina O (2015) Exploring the Role of Business Process Management in Sustainability Initiatives. In: MCIS 2015 Proceedings. p 35
23. Loepp F, Betz S (2015) Sustainability practices in companies : strategies business process management ICT. In: SIG Green Workshop. pp 1–10
24. Bossle MB, Dutra de Barcellos M, Vieira LM, Sauvée L (2016) The drivers for adoption of eco-innovation. J Clean Prod 113:861–872. https://doi.org/10.1016/j.jclepro.2015.11.033
25. Eiadat Y, Kelly A, Roche F, Eyadat H (2008) Green and competitive? An empirical test of the mediating role of environmental innovation strategy. J World Bus 43:131–145. https://doi.org/10.1016/j.jwb.2007.11.012
26. Masoumik SM, Abdul-Rashid SH, Olugu EU (2015) Importance-performance analysis of green strategy adoption within the Malaysian manufacturing industry. Procedia CIRP. Elsevier, pp 646–652
27. Kumar Piaralal S, Nair SR, Yahya N, Karim JA (2015) An integrated model of the likelihood and extent of adoption of green practices in small and medium sized logistics firms. Am J Econ 5:251–258
28. Kaza S, Yao LC, Bhada-Tata P, Van Woerden F (2018) What a waste 2.0. What a waste 20: a global snapshot of solid waste management to 2050. World Bank Publications
29. Eurostat (2023) Eurostat Report
30. Statistics Poland (2022) Environment. Warsaw
31. Kuppusamy M, Gharleghi B (2015) "Green business process management" in manufacturing firms: examining the role of upstream and downstream suppliers. Int J Appl Bus Econ Res 13:259–271
32. Jeston J (2014) Business process management : practical Guidelines to successful implementations. Routledge
33. Zeise N, Link M, Ortner E (2012) Measurement systems for sustainability evaluation and extension of common measurement systems with regard to sustainability. In: vom Brocke J, Seidel S, Recker J (eds) Green business process management. Towards the sustainable enterprise, 127th edn. Springer, Dordrecht, pp 131–146
34. Opitz N, Krüp H, Kolbe LM (2014) Green business process management–A definition and research framework. Proceedings of the Annual Hawaii International conference on system sciences. IEEE, pp 3808–3817
35. Lan Y-C (2011) Reengineering a green business. Int J Green Computing 2:1–11. https://doi.org/10.4018/jgc.2011010101
36. Hoesch-Klohe K, Ghose A, Lê LS (2010) Towards green business process management. Proceedings–2010 IEEE 7th International Conference on services computing. IEEE, pp 386–393
37. Murugesan S (2008) Harnessing green IT: principles and practices. IT Prof 10:24–33. https://doi.org/10.1109/MITP.2008.10
38. Bocken NMP, Short SW, Rana P, Evans S (2014) A literature and practice review to develop sustainable business model archetypes. J Clean Prod 65:42–56
39. Maciel JC (2017) The Core Capabilities of Green Business Process Management – A Literature Review. In: International Conference on Wirtschatsinformatik. pp 1526–1537
40. Hernández González A, Calero C, Pérez Parra D, Mancebo J (2019) Approaching green BPM characterisation. J Softw: Evol Process 31:e2145
41. Sohns TM, Aysolmaz B, Figge L, Joshi A (2023) Green business process management for business sustainability: a case study of manufacturing small and medium-sized enterprises (SMEs) from Germany. J Clean Prod 401:136667. https://doi.org/10.1016/J.JCLEPRO.2023.136667
42. Shibamoto M (2022) Environmental Awareness and Green Business Practices in the Small Business Sector: Empirical Evidence Using a Small and Medium-sized Enterprises Survey in Japan. Discussion Paper Series
43. Martinsuo M, Huemann M (2021) Designing case study research. Int J Project Manage 39:417–421. https://doi.org/10.1016/j.ijproman.2021.06.007
44. Martinsuo M, Huemann M (2021) Reporting case studies for making an impact. Int J Project Manage 39:827–833. https://doi.org/10.1016/j.ijproman.2021.11.005
45. Lindgreen A, di Benedetto CA, Beverland MB (2021) How to write up case-study methodology sections. Ind Mark Manage 96:A7–A10. https://doi.org/10.1016/j.indmarman.2020.04.012
46. Rowley J (2002) Using case studies in research. Manag Res News 25:16–27. https://doi.org/10.1108/01409170210782990
47. Vrontis D, Siachou E, Sakka G et al (2022) Societal effects of social media in organizations: Reflective points deriving from a systematic literature review and a bibliometric meta-analysis. Eur Manag J 40:151–162. https://doi.org/10.1016/j.emj.2022.01.007
48. Yin RK (2014) Case study research design and methods. Sage, Thousand Oaks, CA
49. Dyer JH, Nobeoka K (2000) Creating and managing a high-performance knowledge-sharing network: the Toyota case. Strateg Manag J 21:345–367
50. Ridder HG (2017) The theory contribution of case study research designs. Bus Res 10:281–305. https://doi.org/10.1007/S40685-017-0045-Z/TABLES/2
51. Eisenhardt KM, Graebner ME (2007) Theory building from cases: opportunities and challenges. Acad Manag J 50:25–32. https://doi.org/10.5465/AMJ.2007.24160888
52. Ebneyamini S, Sadeghi Moghadam MR (2018) Toward developing a framework for conducting case study research. Int J Qual Methods 17:160940691881795. https://doi.org/10.1177/1609406918817954
53. Profil działalności ZGO Gać | Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/o-firmie/profil-dzialalnosci.html. Accessed 28 Apr 2023
54. Mapa Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/kontakt/mapa-dojazdu.html. Accessed 28 Apr 2023
55. Podstawy działalności - Decyzje, pozwolenia | Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/podstawy-dzialalnosci/decyzje-pozwolenia.html. Accessed 28 Apr 2023
56. Podstawy działalności - Cennik | Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/podstawy-dzialalnosci/cennik-uslug.html. Accessed 28 Apr 2023
57. Podstawy działalności - Ogólne warunki sprzedaży surowców | Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/podstawy-dzialalnosci/ogolne-warunki-sprzedazy-surowcow.html. Accessed 28 Apr 2023

58. Projekty UE - "System gospodarki odpadami Ślęza-Oława" | Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/projekty-unijne-/system-gospodarki-odpadami-sleza-olawa.html. Accessed 28 Apr 2023
59. Projekty UE - "Optymalizacja procesów..." | Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/projekty-unijne-/optymalizacja-procesow.html. Accessed 28 Apr 2023
60. (2023) Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej. https://www.gov.pl/web/nfosigw/narodowy-fundusz-ochrony-srodowiska-i-gospodarki-wodnej. Accessed 28 Apr 2023
61. Aktualny projekt | Zakład Gospodarowania Odpadami Gać Sp.z o.o. https://zgo.org.pl/aktualny-projekt.html. Accessed 28 Apr 2023
62. Zaman AU (2013) Identification of waste management development drivers and potential emerging waste treatment technologies. Int J Environ Sci Technol 10:455–464. https://doi.org/10.1007/s13762-013-0187-2
63. Cainelli G, D'Amato A, Mazzanti M (2015) Adoption of waste-reducing technology in manufacturing: regional factors and policy issues. Resour Energy Econ 39:53–67. https://doi.org/10.1016/j.reseneeco.2014.11.004
64. Kralj D (2010) Environmental waste management in constructions. In: Sarkar SK (ed) Environmental management. Sciyo, pp 35–68
65. Rajnoha R, Lesníková P, Krajčík V (2017) Influence of business performance measurement systems and corporate sustainability concept to overal business performance: "save the planet and keep your performance." Ekonomie a Management 20:111–128. https://doi.org/10.15240/tul/001/2017-1-008
66. Poland Report 2023-Reports-ESG Monitor|SEC Newgate. https://secnewgate.com/esg-monitor/reports/poland-report-2023/. Accessed 12 Jun 2024
67. Faganel A, Streicher A (2022) Social marketing as a tool for a sustainable municipal waste management. Econ Cult 19:87–97. https://doi.org/10.2478/JEC-2022-0008
68. Esmaeilian B, Wang B, Lewis K et al (2018) The future of waste management in smart and sustainable cities: a review and concept paper. Waste Manage 81:177–195. https://doi.org/10.1016/J.WASMAN.2018.09.047
69. Chomsky N, Pollin R, Polychroniou CJ (2020) Climate crisis and the global green new deal: the political economy of saving the planet. Verso Books
70. Gholami R, Watson RT, Molla A et al (2016) Information systems solutions for environmental sustainability: how can we do more? J Assoc Inf Syst 17:521–536. https://doi.org/10.17705/1jais.00435