Article

Importance of Machine Modernization in Energy Efficiency Management of Manufacturing Companies

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Abstract: Saving energy and looking for alternative energy sources are both elements of energy efficiency management, which is still a significant challenge for many companies around the world. Unfortunately, energy efficiency in companies is often equated only with thermo-modernization or the replacement of lighting. However, one of the most important methods of improving energy use in manufacturing companies may be the modernization of the machine park. Therefore, the main purpose of the paper was to investigate the activities of enterprises in the field of the modernization of machines and the impact of this on the actual improvement of energy efficiency. The modernization of machines in production plants is understood as adapting new parts to the old device or rebuilding the machine in such a way that it can cooperate with its new subassemblies. Companies usually decide to modernize the machinery fleet, bearing in mind the benefits of production efficiency, and they do not always combine this modernization with energy efficiency improvement measures. This is confirmed by the presented results of a survey conducted with a group of 111 manufacturing companies. Several important statistical relationships in the studied area were indicated by conducting an analysis based on the chi-square test and, in some cases, by clarifying the results of the z-test with the Bonferroni correction.

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1. Introduction

As a result of climate change and ever increasing costs, energy as a raw material is becoming more and more important for companies in highly industrialized countries, but also in developing countries [1]. Additionally, the Directive 2012/27/UE [2] on energy efficiency aims to clarify and promote energy-saving and environmentally friendly solutions to optimize the energy consumed. Thus, the standards of modern companies in the field of energy efficiency and energy awareness are being raised more and more often, which enables companies to gain a competitive advantage through the skillful use of resources. As noted by Franz et al. [3] energy efficiency is a business-related key performance indicator (KPI) that is aimed both at achieving customer satisfaction and focusing on green production and optimizing internal costs. A competitive market, as well as the efficient use of available resources are the driving forces of energy management. Some researchers believe that the sustainable use of energy in industry should be ensured through energy audits and energy management systems. [4]. The issue of energy efficiency management (also known as energy management) is still an important issue that arouses the interest of many researchers, despite the fact that the very concept of energy management was first used in the middle of the last century [5]. The reasons for the great interest in energy management are the fact that developed economies are aware of the depletion of non-renewable energy sources, while the so-called green technologies for obtaining energy are not yet sufficiently developed. Their efficiency does not allow global energy needs to be met, but they are only of auxiliary importance and used in the case of supplementing the

energy consumption balance. In practice, if a company invests on a larger scale in one or more projects of the same type, which aim at improving energy efficiency, and if, as a result of their implementation, energy savings are not the equivalent of less than 10 tons of oil on average per year, the company may apply for a white certificates [6]. White certificates are energy efficiency certificates; in other words, they are mechanisms that stimulate and enforce energy saving behavior.

According to the data of the Central Statistical Office, industry is responsible for 83% of the total electricity consumption in Poland [7]. In turn, the report entitled "Energy costs. Challenges and Opportunities for Enterprises", which was created on the basis of research commissioned by the international advisory group Ayming [8], shows that Poland still has to catch up with the distance that separates it from the most energy-efficient European countries, and for 93% of energy-intensive companies, electricity expenditure plays a significant role in production costs. As a result, companies are placing more and more emphasis on reducing their energy consumption. This is influenced, not only by rising electricity prices, but also by the pressure on enterprises from the environment itself to make them operate in a more ecological and sustainable manner. The solutions that are most often implemented by companies for the purpose of energy management include [1,9–12]: long term strategic plans, planning and implementing of energy projects, identifying the key point indicators, energy audits, involving employees, employing an energy manager, supporting by top management, developing policies, allocating responsibilities in the area of energy activities, and controlling energy consumption.

An important element in a company's strategy that is aimed at increasing energy efficiency, and, thus, sustainable development, is the preparation and implementation of ISO 50001 standards for the energy management system. The application of this is aimed at helping organizations to reduce energy consumption through its effective use, understood as the rational and sustainable use of both energy itself and the energy resources used to generate it. Improving energy efficiency is sometimes referred to as the "sixth fuel" because it limits the increase in fuel and energy demand [13]. Currently, reducing energy consumption in enterprises due to ever higher energy costs is an economic necessity. Over the last dozen or so years, it can be concluded that the situation on the electricity price market has been quite stable (after a significant jump in 2008/2009 caused by the economic crisis, energy prices have stabilized). However, it is expected that the adjustment to energy regulations [14] will result in a significant increase in energy prices in the near future. Therefore, in order to avoid an increase in costs and maintain a competitive position on the market, production companies face the need to reduce energy consumption and use it more efficiently. In order to achieve low energy consumption, which is desirable due to the rising costs and increased requirements, it is not enough to only carry out the thermal modernization of buildings in Poland for many years, but also numerous other technical improvements in various fields (e.g., in the field of electricity supply systems and water), much wider use of energy from renewable and unconventional sources, and the introduction of the principles of energy-efficient use of buildings and energy monitoring and control systems should be implemented. Changes in the sphere of operation are also necessary, and above all, changes in the behavior of users regarding energy use. In this area, the awareness of staff is important both at the stage of the operation of machines and devices, as well as their modernization and further improvement [15]. Focusing on continuous improvement of energy efficiency in these areas can bring the desired results. For this purpose, first of all, it is necessary to gain knowledge about which areas of the company's operation should be improved in order to use energy. Here, the use of Toyota management principle 14 [16] may be extremely helpful, according to which the content should: become a learning organization, thanks to tireless reflection (hansei) and continuous improvement (kaizen). This principle illustrates how important it is to focus on continuous improvement and constant improvement in line with the kaizen philosophy. Liker and Meier [16] also emphasize the importance of the human factor here, especially in its awareness of the importance of energy rationalization. It is this

approach that can be key in identifying areas that require the optimization of energy use, which is often forgotten by modern managers. Employees directly involved in production processes are an important link in identifying malfunctions in the production system components and an executive link in the process of improving energy use. One of the methods of improving the use of energy in production companies is the modernization of the machine park, which is part of the recently popular concepts, such as Lean Green [17] or machine learning [18]. The research carried out among Polish enterprises shows that many devices require modernization and the most frequently indicated barrier for Polish enterprises is low investment opportunities, which confirms the importance of capital for the implementation of efficiency investments [19]. Maintaining the required efficiency of machines and devices is one of the basic conditions for the proper functioning of enterprises' production systems. It is natural that machines and devices are subject to wear. Therefore, it is necessary to carry out periodic reviews, as a result of which actions are often taken to maintain the required efficiency or decisions related to the scope of the necessary modernization are made. These activities are in line with the EN 13306: 2017 Maintenance—Maintenance terminology standard. Maintenance is defined as the combination of all technical and organizational activities required to maintain equipment, installations and other physical assets in the desired operational condition or to restore them to that condition [20–22]. On the other hand, this article covers not only maintenance (i.e., adapting new parts to an old device or rebuilding the machine in such a way that it is able to work with new devices), but also the replacement of devices with new ones and the use of modern technologies, such as: control system software, virtualization, servers, database, And client computers, etc. Thus, the modernization considered in the article is a broader concept than just maintenance. Thanks to the modernization of the machine park, it is possible to gain a chance for further, efficient operation and minimize the possibility of stopping production due to recurring failures, and thus is the starting point for improvement in the field of energy use.

It is noted that the level of energy use is not one of the main objectives of modernization or maintenance activities. For example, Visser and Pretorius [23] indicate that the objectives of modernization carried out by enterprises focus mainly on achieving the production goal with the required quality and within the state and safety of the system. Additionally, according to the British Standards Institution [24], the objectives of maintenance management can be summarized as follows: ensuring the functioning of the system, ensuring the viability of the system, ensuring safety and ensuring human well-being. This is confirmed by the data on publications in this field (Table 1).

Table 1. Number of publications in the studied area.

ScienceDirect Databasis		Title, Abstract or Author-Specified Keywords			
		Safety	Production	Quality	Energy Efficiency
articles with the terms:	machines	29,440	77,154	85,606	19,919
	maintenance	47,787	114,295	86,743	24,358
	machine maintenance	9453	19,296	15,517	5418 * (4211) **

* Total number of publications ** number of research publications.

As can be seen from the data in Table 1, publications on machine modernization, taking into account the issue of energy efficiency, have the smallest share. In the period 2011–2020, 3619 articles were written containing the term machine maintenance and energy efficiency, of which 2855 were research articles. Section 2 of this article presents examples of works in this field (Table 2), mostly using heuristic methods, modeling and developing procedures using case studies. However, in this study we present a different approach to this subject. A questionnaire study was developed in which we check the awareness

of enterprises regarding the correlation of actions taken related to the modernization of machines and increasing the efficiency of energy use.

It is true that a significant number of entrepreneurs consider the management of energy use and the related costs to be an important element of their activity, but they do not have the knowledge, organization and funds needed to take the necessary actions to improve energy efficiency. As shown by Smelkova [25], support for entrepreneurship from government institutions is low. Specialist knowledge and the experience of advisors are necessary to indicate methods and means of improvement and to obtain the expected results of the actions taken. Not without significance is also the increasing availability of support programs aimed at increasing energy efficiency through modernization (e.g., grants from the National Fund for Environmental Protection and Water Management and the Polish Agency for Enterprise Development, EU funds or the system of white certificates), which allows for compensating some of the costs incurred for the modernization of existing production processes. According to the information from the President of the Energy Regulatory Office, the final energy savings achieved in this way in 2017 amounted to 364,991 toe [26].

The scientific literature also includes studies showing research on the use of energy-saving machines [27] or Lean tools [28] in relation to energy consumption savings. It is noteworthy that currently the most commonly used energy efficiency management solutions in the industry are those related to the reduction of the base loading. Therefore, all resources in the enterprise, interconnected by processes or energy flows, must be managed in an efficient manner, taking the problem of production control, infrastructure and the technical systems of buildings into account, while taking the specificity of a given industry into account [3]. Enterprises improving their energy efficiency can feel a real improvement in the reduction of production and general costs, which in turn has a positive effect on the economy of the entire business. However, it is very often associated with considerable expenditure that must be incurred to achieve the desired level of energy efficiency (modernization of buildings, machinery and equipment, and insulation of installations, etc. [29]. In practice, the greater the efficiency of a given device, installation, and medium, the greater the savings for the enterprise and, consequently, the greater the possibilities of being competitive. According to the International Energy Agency [30], energy efficiency is the process of managing and limiting the growth of energy consumption. Energy efficient activities consist in delivering a higher level of service with the same amount of energy or the same level of service with less energy [31]. It is noted that there is a whole range of opportunities to improve energy efficiency in companies. Businesses that require investment in technology or production processes tend to cost more and payback times are longer [32]. However, they can also include soft activities that depend only on the organization and require small financial expenditures, but bring profits quickly; for example, using energy saving office equipment is one way of doing this. Much also depends on the employees themselves. The lack of staff consciousness can be the most significant barrier in energy management [33]. Changing employees' habits to become more energy-efficient can reduce energy consumption in the company. The benefits can be more than simply financial, because pro-efficiency activities also build a positive image of the company on the market and the satisfaction of employees who appreciate the fact that their company cares about sustainable development.

As the above examples show, energy management or energy efficiency in enterprises is a vivid and still-relevant topic. However, current studies refer to specific cases of companies in which certain improvements have been introduced or present new models and methodologies that can be used in production plants, reducing energy consumption [34,35], but they do not present broader research concerning all production companies that verify the activities of these entities related to modernization in the context of energy management. In this paper, it was decided to investigate how enterprises relate to the modernization of their machine park and whether they treat modernization activities as part of the energy management process. An attempt was also made to examine the relationship between the

given areas of modernization and energy efficiency of enterprises. Therefore, the main purpose of the paper was to investigate the activities of enterprises in the field of broadly understood modernization and its impact on the actual improvement of energy efficiency. The following research hypotheses were adopted:

Hypothesis 1 (H1). *The period of prospering of enterprises on the market influences the actions taken by these entities to increase energy efficiency.*

Hypothesis 2 (H2). *The modernization of the machinery park improves the efficiency of energy use in the surveyed enterprises and it is possible to indicate the areas of this modernization that show greater significance of this dependence.*

Hypothesis 3 (H3). *Enterprises consider the activities related to the modernization of machines as part of the activities increasing the efficiency of energy use. For this purpose, a questionnaire survey was carried out, which covered 111 enterprises of various industries related to the industry. The available statistical methods were used, as a result of which it became possible to verify the hypotheses.*

2. Problems of Energy Efficiency Management in the Context of Machine Modernization—Literature Review

From the point of view of this paper, it is important to first identify the difference between energy management and energy efficiency. Energy management is defined as a procedure or work relating to energy matters in industry and is considered as one of the key internal activities to improve cost and energy efficiency [9]. Energy management, as Andersson et al. point out, is the most important way to improve energy efficiency, and improving energy efficiency is, in turn, the cornerstone of decarbonization [36]. Sustainable development and concern for the environment, as well as more and more stringent regulations in this field and rising energy costs, all contribute to the need to increase energy efficiency in every industrial sector. The research of D. K. Zuzek and B. Mickiewicz [37] on the motives that determine the implementation of actions from the point of view of sustainable development may prove to be the confirmation. They show that the most common motive for undertaking actions by enterprises in this area were savings related to the reduction of energy and raw materials, in which 45% of respondents indicated a given factor as the most important. It was followed by "concern for the natural environment" (37%) and "compliance with legal requirements" (35%).

In recent years, there has also been a lot of interest from enterprises in using renewable energy sources (RES) as a means of obtaining energy. This subject is dealt with by a wide group of researchers, as evidenced by the number of publications in this field. In the ScienceDirect database alone, you can find almost 250,000 papers since 1995. On the other hand, the real upward trend in this subject begins in the last decade, when over 210,000 papers were published. In practice, it is noted that the interest in RES is not only purely theoretical. According to EU estimates, the share of RES in gross final energy consumption for 27 EU countries increased by several percentage points each year, with the highest increase (10%) compared to the previous year recorded in 2007, 2009 and 2012 [38]. At the same time, the consumption of energy produced from RES by all sectors of the EU-28 countries economy increased from 5.1% in 2004 to 10.2% in 2019 [39]. Despite the undoubted advantages of using RES, attention should be paid to the risks associated with investments in RES. There are political, legal, technical, economic and social risks [40,41]. Moreover, the energy solutions related to the use of RES are not always sufficient. Therefore, enterprises also use other practices to increase energy efficiency, including those aimed at rationalizing energy management. There are many studies in the scientific literature showing the different methods used by companies to increase their energy efficiency. They concern technical, organizational and system changes (Table 2).

Table 2. Examples of publications in the studied area.

Paper	Method Characteristics	Changes' Type	Machine Maintenance and Energy Efficiency
Gong 2021 [34]	Heuristic, experimental, mathematical model; reduced energy consumption by reducing the total number of machine restarts	technical	yes
Beck M. et al. 2016 [42]	Heuristic, methodology; use of the existing potential of energy efficiency in the metal industry; validation performed on a specific machine	system	yes
Chojnacka 2021 [35]	Experimental and hybrid methods; economic and ecological changes in a production process	technical	no
Paczkowski 2021 [43]	Experimental, research on changes in the machine, demonstration of energy savings	technical	yes
Unver 2019 [44]	Experimental, methodology; energy saving of 65% or 6.57 TOE was achieved by using the Lowest Energy Consuming Production Process	organizational/system	no
Thiede 2020 [45]	Experimental, methodology identifying improvement potentials using machine learning and process factors	technical	yes
Petruschke et al. 2020 [46]	Heuristic, model, methodology, case study; method for identifying energy efficiency potentials at the machine tool level as well as the central cooling system level (based on Beck 2016)	technical	yes
Wen, X. 2021 [47]	Methodology, case study; lean method to integrate energy efficiency into production management	system	no
May et al. 2015 [48]	Case studies, methodology, it supports the identification of weaknesses and areas for energy efficiency improvements related to the management of production and operations	system	no
Meo 2017 [49]	Heuristic, methodology, case study, structured method to perform fast and simplified energy assessments	system	no
Zhu 2021 [50]	Heuristic, methodology; energy efficiency evaluation and prediction method	system	no
Sihn 2018 [51]	Heuristic, methodology, case study; integrated hybrid discrete/continuous simulation method enabling to accurately capture dynamic interactions between material and energy flows	system	yes
Gong 2017 [52]	Heuristic, methodology; new energy efficiency evaluation method for ethylene production	system	no
Menghi 2020 [53]	Heuristic, methodology, a case study in an automotive sector company; a methodology for energy efficiency re-design of production systems	technical/organizational	yes
Adenuga 2019 [54]	Heuristic, methodology, case study; proposed an Energy Efficiency Analysis Modelling System as a tool to estimate energy costs in a manufacturing plant	system	yes
Cui 2021 [55]	Heuristic, methodology, case study; an optimal energy saving control method based on N-policy, validated by case studies	organizational	yes
Šarauskis 2020 [56]	experimental, case studies, innovations in process production	organizational	no
Xia 2021 [57]	Heuristic, methodology, case study, an energy-oriented joint optimization of machine maintenance and tool replacement policy by integrating energy consumption mechanisms and joint maintenance opportunities in a machine-tool system	system/technical	yes

Table 2. Cont.

Paper	Method Characteristics	Changes' Type	Machine Maintenance and Energy Efficiency
Palasciano 2016 [58]	Heuristic, procedure, case study; the solution allows for the identification of abnormal energy consumption during the machine operation cycle, caused by incorrect sizing of parts or incorrect cutting conditions programmed by the technologist	system/technical	yes
Hoang 2016 [59]	Heuristic, model, case study; the new model-CBM 9 (Condition-based maintenance), based on energy efficiency using the energy efficiency indicator	system	yes
Mausavi 2014 [60]	Heuristic, methodology, case study; the model takes into account energy directly in the optimization of maintenance	technical/system	yes
De Carvalho 2015 [61]	Heuristic, methodology, case study; a method of increasing the energy efficiency of machine tools and devices with computer numerical control (CNC) or programmable logic controller (PLC); validated in case studies.	technical	yes

It should be added that all energy management practices are considered to be some of the leading instruments for improving energy efficiency in manufacturing companies. However, due to the degree of development of national economies and industries, there can be no precise and unanimous method concerning energy management practices [62]. This perspective is also shared by Christoffersen et al. [10], who argues that the use of universal solutions is not appropriate when it comes to encouraging companies to practice improved energy management. Certainly, there are industrial energy management systems that include program solutions, ongoing monitoring and management, and enable industrial companies to actively manage energy consumption and energy purchases. However, these systems are usually adapted to the specific needs of the company or the specifics of the industry, and as a result, their functionality is limited, mainly as a result of various identified gaps, such as: simplification of processes, incorrect measurement points, and lack of motivation, etc. [63]. Additionally, it is worth noting that even in energy-intensive companies, such as the processing industry, energy management is rarely treated strategically [64]. Moreover, although energy management systems reduce energy consumption, they overlook the energy that is consumed until commissioning (including raw material procurement, production and transportation) and during the use phase (including operation and maintenance), which often becomes a problem [65]. Energy saving is the amount of energy, which is the difference between the energy potentially consumed by a facility, technical device or installation in a given period before the implementation of one or more projects aimed at improving energy efficiency, and energy consumed by this facility, technical device or installation in a similar period, after carrying out these projects and taking into account the standardized conditions affecting energy consumption [66]. On the other hand, a project aimed at improving energy efficiency is an activity consisting in introducing changes or improvements in a facility, technical device or installation, as a result of which energy savings are achieved [66].

Identifying the places that generate the greatest losses of electricity is a real challenge for enterprises. Finding ways to reduce consumption is just as difficult. According to research by Deloitte, as much as 65% of electricity consumed in industry is used by electric drives, therefore looking for savings in electric motors seems more and more justified [67]. Nevertheless, the changes taking place in the technological and environmental sphere make it possible, or even require, improvements that increase the energy efficiency of industrial enterprises. Despite the research on energy saving methods, such as improved feedback control, supervisory and optimization controls, as well as control coordination [68], published in the last century in the scientific literature, the issue related to energy management is often neglected in production plants. As noted by Fahad et al. [28], this is due to mis-

perceptions, including high initial investment, production rate, and the long payback period (break-even point), etc. Other studies show some barriers to energy management practices, the most important of which are the perceived lack of cost-effective technical measures, high perceived risks due to uncertain future energy costs, and poor information quality. At the same time, these studies indicate that reducing energy costs through improved energy efficiency is the most important factor in energy efficiency [1]. However, the available research [15] also shows that a large group of entrepreneurs do not understand and do not know how to properly manage energy, and most of them lack a specific set of solutions enabling the effective implementation of, for example, EU directives, and moreover, enterprises are not sufficiently involved in the implementation of the concept of efficiency according to EU guidelines and they rate the transparency of the regulations low in this regard. In the case of micro and small enterprises that have implemented basic management systems, such as ISO 9001 or ISO 14001, there is often a lack of tools or simply financial resources to introduce solutions that ensure the establishment of an energy policy and its implementation (i.e., investments in solutions reducing energy consumption, and monitoring) [1].

Nevertheless, as noted by Fahad et al. [28], the increasing number of companies that understand that energy management is a step towards green production and sustainable development, and the benefits in this area are not only limited to economic savings, but also include a significant reduction in emissions.

3. Methodology of the Research

The basic premise for undertaking the research was the indicated gap in publications on companies' awareness of modernization of the machine's influence on energy efficiency in industrial enterprises. The importance of the problem of improving energy efficiency during manufacturing processes has been the subject of many empirical studies and theoretical considerations in recent years. In the literature, individual types of investments in energy efficiency are widely discussed separately. Therefore, it seemed interesting and important, taking the achievements of world and national literature into account, to undertake research that is aimed at assessing the impact of modernization on the machine park as an element of energy efficiency management in Polish enterprises.

In order to verify the adopted research goal, a CAWI (Computer-Assisted Web Interview) survey was carried out, consisting of filling in an electronic questionnaire by the respondents. No sensitive data was collected during the study and the respondents were guaranteed anonymity. The link to the survey was sent via e-mail and available messengers, including social media. The study was conducted from March to August 2021. Ultimately, 111 full questionnaires were obtained in the study from enterprises differing in the type of industry, employment, and other parameters (Table 3).

Large enterprises (43.2%) were the most numerous in the study, followed by small and micro enterprises (19.8% each) and medium enterprises (17.1%). The surveyed companies differed from each other in terms of the length of their operation on the market, as well as the range and type of the industry. The largest share in the study was constituted by entities operating for 16 or more years on the market (56.8%). When determining the scope of their activities, the surveyed companies most often indicated the international market (58.6%). The selection of the research sample was focused on manufacturing companies, therefore the research involved entities operating in industries characterized by various manufacturing processes with increased energy demand. The study included, inter alia, enterprises concentrated in industries, such as: metal, with a share of 22%; electronics, with a share of 15%; automotive, with a share of 14%; and food, with a share of 9%.

Table 3. Characteristics of the research sample.

Enterprise Size	Incidence	Percentage
Large (more than 250 employees)	48	43
Medium (50–249 employees)	19	17
Small (employment of 10–49 employees)	22	20
Micro (below 10 employees)	22	20
Overall	111	100
The length of the company's prosperity in the market	Incidence	Percentage
16 years and more	63	57
11–15 years	15	14
6–10 years	16	14
Up to 5 years	17	15
Overall	111	100
Industry	Incidence	Percentage
Automotive	15	14
Clothing/footwear	10	9
Electronic	17	15
Energetic	7	6
Food	10	9
Metal	24	22
Pharmaceutical	2	2
Other ¹	26	23
The range of the company's operation (multiple choice question)	Incidence	Percentage
Local	18	16
National	40	36
International	65	58

¹ furniture, chemical, pharmaceutical industries, production of wooden products, mining and others.

The developed research was based on a questionnaire containing closed questions, questions with the possibility of supplementing the answers (semi-open), including single and multiple choice questions. The survey was divided into several parts. The first part concerned information on enterprises (size of entities, scope and duration of activities, etc.). The second part was about modernization. Respondents were asked if and when the last modernization took place (and if enterprises had not modernized so far, they were redirected to the third part of the questionnaire), which areas were concerned and whether the impact of modernization on reducing energy consumption was noticed. In the questions about the moment of the noted modernization, several ranges were distinguished for the ten-year period, because this time range allows for verification regarding the assessment of energy efficiency and, for control purposes, the time period over 10 years. The third part contained questions on the efficiency of energy use. Among others, whether the company had an improvement in the efficiency of energy use (if not, it was redirected to part three B—here the respondents answered the supplementary question—which indicated the factors that could influence the company's decision to implement measures to improve the efficiency of energy use), whether there were any activities related to increasing energy efficiency, what these activities were, what the reasons were and what funds were financed, etc., including energy management.

The selection of the research sample was focused on production companies with their headquarters throughout Poland. The addressees of the survey were people with knowledge about the subject of the study, who, usually in medium and large enterprises they, were employed as process managers (large 30, medium 11) and managers of technological processes (large 18, medium 8), while answers regarding small and micro enterprises were mainly provided by the owners themselves (small 14, micro 20) and the persons holding direct production positions, such as machine operators (small 8, micro 2). The IBM SPSS

package was used to process the collected data in order to test the adopted theoretical assumptions. In most cases, the chi square test was used to check whether there was a relationship between the data. In situations where there are many possibilities (answers), we only received information about a certain dependency. To clarify this, the z-test with the Bonferroni correction can then be used to clarify which variables there is a relationship between, which has also been done. Certainly, in the case where the answers to the question are fewer (or if, for example, there were multiple choice and each answer is considered separately), the chi-square test and the z-test can be used interchangeably.

4. Results

In the study, it was decided to check whether the currently operating enterprises modernized, how long these entities have prospered on the market for and whether the modernization (modernization area) improved energy efficiency.

First, the obtained results were analyzed by making a cross-table for the variables: length of prosperity in the market and date of the last modernization (Table 4). In order to check whether the duration of the prosperity of enterprises is important here, a cross table was prepared for the variables: duration of prosperity on the market and the date of the last modernization (Table 4).

It can be seen (Table 4) that 26% of the surveyed enterprises have not modernized any area so far, including those related to machines and devices. Moreover, most enterprises modernized over the last year (31.5%). It should also be noted that, in the case of modernization in the period of 2–5 years, the highest percentage was recorded for enterprises operating for 16 years and more (36.5%), which is justified by the time followed by the wear of the machines. However, in the same period (2–5 years), there is a noticeably high share of enterprises carrying out modernization in the group of enterprises operating for 6–10 years (31.1%), which is quite surprising. This may result, for example, from the need to update the software of machines, which may be newer than those used in enterprises that are more prospering on the market, but, having more electronic modules, also require more frequent maintenance activities.

Table 4. Dependencies between the length of the company's prospering on the market and the time of its last modernization.

			When Was the Last Modernization Carried Out					Overall
			During the Last Year	In the Period of 2–5 Years	In the Period of 6–10 Years	Over 10 Years	The Company has Not Carried out Modernization so Far	
The Length of the Company's Prosperity in the Market:	Up to 5 Years	N	5	1	0	0	11	17
		% row	29.4%	5.9%	0.0%	0.0%	64.7%	100.0%
	6–10 Years	N	4	5	3	0	4	16
		% row	25.0%	31.3%	18.8%	0.0%	25.0%	100.0%
	11–15 Years	N	4	3	3	0	5	15
		% row	26.7%	20.0%	20.0%	0.0%	33.3%	100.0%
	16 Years and More	N	22	23	2	7	9	63
		% row	34.9%	36.5%	3.2%	11.1%	14.3%	100.0%
Overall		N	35	32	8	7	29	111
		% row	31.5%	28.8%	7.2%	6.3%	26.1%	100.0%

In order to check whether and how the length of prospering on the market affects the modernization of the surveyed companies, the null and alternative hypotheses were formulated:

Hypothesis 0 (H0). *There is no relationship between the length of the prosperity of enterprises on the market and the occurrence of modernization.*

Hypothesis 1 (H1). *There is a relationship between the length of prospering of enterprises on the market and the occurrence of modernization.*

The result of the chi-square test ($\chi^2 = 33, 130, p < 0.001$) means that there is no reason to reject the alternative hypothesis, according to which there is a relationship between the duration of the proposition of enterprises on the market and the occurrence of modernization. Thus, this relationship is statistically significant. As these are qualitative variables that can be presented on an ordinal scale, the C-Pearson contingency coefficient (C_p) was used as a measure of the strength of the correlation. We can use the C_p contingency coefficient when at least one question has more than two answers. The value of this coefficient depends on the number of possible answers to both questions; therefore, the more answers, the higher the values of the coefficients in general. The following ranges of the value of the contingency coefficient were adopted for the assessment of the dependence [69]:

<0.0; 0.2>—very weak relationship;
 (0.2; 0.4>—weak relationship;
 (0.4; 0.6>—moderate dependence;
 (0.6; 0.8>—strong dependence;
 (0.8; 1.0>—very strong dependence.

Thus, the result of $C_p = 0.479$, with the significance level $p < 0.001$, proves the moderate impact of the variable length of prospering on the market and the occurrence of modernization.

In the next step, the relationship between the length of prospering on the market and activities related to increasing energy efficiency was checked (Table 5). The following hypotheses were made:

Table 5. Dependencies between the length of prospering on the market and activities related to increasing energy efficiency.

			Does the Company Undertake Activities Related to Increasing Energy Efficiency:		Overall
			Yes	No	
The Length of the Company's Prosperity in the Market	Up to 5 Years	N	9 _a	8 _a	17
		% row	52.9%	47.1%	100.0%
	6–10 Years	N	13 _a	3 _a	16
		% row	81.3%	18,8%	100.0%
	11–15 Years	N	8 _a	7 _a	15
		% row	53.3%	46,7%	100.0%
	16 Years and More	N	50 _b	13 _a	63
		% row	79.4%	20,6%	100.0%
	Overall	N	80	31	111
		% row	72.1%	27.9%	100.0%

The subscript “a” represents a subset of the category “Does the company undertake activities related to increasing energy efficiency”: where the proportions of the columns do not differ significantly at the level, 05.

Hypothesis 0 (H0). *There is no relationship between taking actions related to increasing energy efficiency and the length of the company's prosperity on the market.*

Hypothesis 1 (H1). *There is a relationship between taking actions related to increasing energy efficiency and the length of the company's prosperity on the market.*

The chi square dependency test was used. As a result of the analysis, there are no grounds to reject H1. It was found that there was a significant relationship between the duration of prosperity on the market and activities related to increasing energy efficiency ($\chi^2 = 8.042, p = 0.045$). Companies that operated on the market for many years significantly more often undertake activities related to increasing energy efficiency than younger companies. It was also decided to check the strength of the correlation of variables, the

duration of prospering on the market and to undertake activities related to increasing energy efficiency. On this basis, with the level of the contingency index C_p , amounting to 0.26 at the significance level $p = 0.045$, it was concluded that the relationship between the duration of prospering on the market and activities related to increasing energy efficiency was characterized by a weak strength, although it was statistically significant. It was then checked whether there was a link between the modernization of machines and the improvement of energy efficiency.

For this, the null hypothesis was adopted:

Hypothesis 0 (H0). *There is no relationship between the modernization of the machine park and the improvement in energy efficiency.*

With the alternative hypothesis:

Hypothesis 1 (H1). *There is a relationship between the modernization of the machine park and the improvement in energy efficiency.*

In this case, the chi-square dependency test was used to test the relationship. Based on the analysis of the results, there are no grounds to reject the alternative hypothesis "H1: modernization of the machine park improves energy efficiency". Thus, it was found that there is a significant relationship between the modernization of the machine park and the improvement of energy efficiency (chi-square dependence test: $\chi^2 = 30.380$, $p = 0.000$). In order to check the differences in more detail, z-tests (with Bonferroni correction) were performed for all responses. Detailed results are presented in Table 6.

Table 6. Dependencies between the modernization of the machine park and the improvement of energy efficiency.

			Does the Company Observe an Improvement in Energy Efficiency?			Overall
			No	Maybe	Yes	
When the last modernization of the machine park in the company took place:	During the last year	N	3 _a ^d	5 _a ^c	27 _b ^d	35
		% row	8.6%	14.3%	77.1%	100.0%
	In the period of 2–5 years	N	4 _a ^d	10 _a ^c	18 _a ^{c,d}	32
		% row	12.5%	31.3%	56.3%	100.0%
	In the period of 6–10 years	N	2 _a ^{c,d}	1 _a ^c	5 _a ^{c,d}	8
		% row	25.0%	12.5%	62.5%	100.0%
	over 10 years	N	5 _b ^c	2 _{a,b} ^c	0 _a ^c	7
		% row	71.4%	28.6%	0.0%	100.0%
	The company has not carried out modernization so far	N	9 _a ^{c,d}	12 _a ^c	8 _b ^c	29
		% row	31.0%	41.4%	27.6%	100.0%
Overall	N	23	30	58	111	
	% row	20.7%	27.0%	52.3%	100.0%	

Each letter in the subscript ("a", "b") stands for a subset of the category "Does the Company Observe an Improvement in Energy Efficiency?", whose column proportions do not differ significantly on the level 05. Each letter in the superscript ("c", "d") stands for a subset of the category "When the last modernization of the machine park in the company took place", whose column proportions do not differ significantly on the level 05.

As a result of the analysis, several important conclusions can be drawn. Firstly, in most enterprises which modernized more than 10 years ago, no improvement in energy efficiency was observed ($p < 0.05$). Secondly, among enterprises which modernized between 2–5 years and 6–10 years ago, no significant differences were observed between the number of enterprises which improved and which did not improve their efficiency. Thirdly, in the majority of enterprises which modernized within the last year, an improvement in

energy efficiency was observed ($p < 0.05$). Fourth, in the majority of enterprises that were not modernized, no improvement in energy efficiency was observed or the respondents were not sure about it ($p < 0.05$). Fifthly, the respondents significantly more often indicated improvement in energy efficiency in enterprises that were modernized within the last year than in enterprises that were modernized more than 10 years ago or were not modernized at all ($p < 0.05$). The strength of the relationship was also tested using the C_p contingency index (Table 7).

Table 7. C_p contingency index for improving the efficiency of energy use and modernization.

	C_p Contingency Index	C_p Contingency Index Max:	C_p Contingency Index Adjusted	Significance
Improving the efficiency of energy use/modernization	0.464	0.816	0.568	$p < 0.001$

Interpreting the result ($C_p = 0.464$ at the significance level $p < 0.001$), it can be concluded that the relationship between the variables, noting an improvement in energy efficiency and the occurrence of modernization, is a relationship of moderate strength. In order to deepen this area of research, it was decided to check which of the modernization areas improves energy efficiency.

The null hypothesis was put forward:

Hypothesis 0 (H0). *There is no relationship between given area of modernization and improvement in energy efficiency.*

and an alternative hypothesis:

Hypothesis 1 (H1). *There is a relationship between given area of modernization and improvement in energy efficiency.*

As a result, it is concluded that there is a significant relationship between some areas of modernization and the improvement of energy use efficiency (chi-square dependence test—Table 8). In order to check the differences in more detail, z-tests (with Bonferroni correction) were performed for all responses. Detailed results are presented in the table.

When analyzing the results, some dependencies can be observed. First, there has been a significant improvement in energy efficiency following the modernization of existing equipment, replacement of components and the use of modern technologies. Second, there has been no significant improvement after the purchase of new equipment and other areas of modernization.

In order to determine the strength of the observed relationships between the specified areas of modernization and the improvement of energy efficiency, the C-Pearson contingency indices (Table 9) were calculated. Due to the fact that the question about the areas of modernization was multiple choice, in order to compare the values for all correlations, an adjusted contingency coefficient was given (it is the contingency coefficient divided by the number of columns and rows).

Based on the results of the adjusted coefficient of contingency (adjusted C_p), it can be concluded that only one of the analyzed dependencies (improvement of energy efficiency versus the use of modern technologies) shows moderate strength, while two of them (improvement of energy efficiency/replacement of components and improvement of energy efficiency/purchase of new devices) are characterized by weak, although still statistically significant, strength.

Table 8. Dependencies between the modernization of the machine park areas and the improvement of energy efficiency.

			Does the Company Observe an Improvement in Energy Efficiency?			Chi-square Test
			No	Maybe	Yes	
What areas did the modernization cover?	Modernization of existing equipment	N % row	3 _a 6,0%	10 _a 20,0%	37 _b 74,0%	$\chi^2 = 19.413$ $p = 0.000$
	The purchase of new equipment	N % row	14 _a 20,9%	12 _a 17,9%	41 _a 61,2%	$\chi^2 = 5.582$ $p = 0.061$
	Replacement of components	N % row	5 _{a,b} 20,8%	1 _b 4,2%	18 _a 75,0%	$\chi^2 = 7.517$ $p = 0.023$
	The use of modern technologies	N % row	5 _{a,b} 17,9%	0 _b 0,0%	23 _a 82,1%	$\chi^2 = 15.327$ $p = 0.000$
	Other areas of modernization	N % row	0 _a 0.0%	1 _a 33.3%	2 _a 66.7%	$\chi^2 = 1.193$ $p = 0.551$

Each letter in the lowerscript (“a”, “b”) stands for a subset of the category “Does the Company Observe an improvement in energy efficiency?”, whose column proportions do not differ significantly on the level 05.

Table 9. C_p contingency indexes for areas of modernization and improvement the efficiency of energy use.

	C _p Contingency Index	C _p Contingency Index Max:	C _p Contingency Index Adjusted	Significance
Improvement the efficiency of energy use/modernization of existing devices	0.103	0.707	0.146	$p = 0.551$
Improvement the efficiency of energy use/Purchase of new devices	0.219	0.707	0.310	$p = 0.061$
Improvement of energy efficiency/replacement of components	0.252	0.707	0.356	$p = 0.023$
Improvement the efficiency of energy use/application of modern technologies	0.348	0.707	0.492	$p < 0.001$
Improvement the efficiency of energy use/other areas	0.103	0.707	0.146	$p = 0.551$

Moreover, the study also examined the occurrence of dependencies between the variables “Taking action with increasing energy efficiency” and “Modernization occurrence”.

In this case, the null hypothesis (H₀) was made: there is no relationship between taking actions related to increasing energy efficiency and the occurrence of modernization, with the alternative hypothesis (H₁): there is a relationship between taking actions related to increasing energy efficiency and the occurrence of modernization.

Detailed dependencies are presented in Table 10.

With the significance level $p = 0.000$ and degrees of freedom = 1, the chi-square test result of 12.702 indicates the existence of a significant relationship between the studied variables. What is more, the share of enterprises that claim that they do not take action was related to an increase in energy efficiency, while the occurrence of modernization was noted in them. This may indicate that these companies are not aware that modernization is an activity aimed at increasing energy efficiency and affects it. In this case, the phi coefficient was calculated to estimate the strength of the relationship. There are two questions here, each with two possible answers, and therefore the contingency coefficient C_p cannot be used. The phi factor is a special determinant for a 2 × 2 situation. The calculated value

of the co-factor ϕ is 0.361 with the significance level $p < 0.001$ and the same intervals determining the strength, as in the case of C_p , means a relationship of moderate strength.

Table 10. Dependencies between taking actions related to an increase in energy efficiency and the occurrence of modernization in the enterprises.

The Occurrence of Modernization in the Enterprise					
			Yes	No	Overall
Actions related to an increase in energy efficiency	yes	N	67	13	80
		% row	60.4%	11.7%	72.1%
	no	N	15	16	31
		% row	13.5%	14.4%	27.9%
	Overall	N	82	29	111
		% row	73.9%	26.1%	100.0%

5. Discussion and Conclusions

Considering the fact that the processing industry is one of the main sources of greenhouse gas emissions and its energy demand is enormous, manufacturing companies for which sustainable development is important cannot fail to take measures to improve energy efficiency. We therefore agree with the statement that energy management is an integral part of industrial production, including the logistics and environmental management system [70]. It is noteworthy that large companies employing more than 250 employees have a statutory obligation to carry out an energy audit every four years (meaning a detailed review of, among others, energy consumption in buildings and industrial installations) and submit a report on it to the ERO (Energy Regulatory Office) [26]. Nevertheless, Polish companies are still more energy-intensive than companies in Western countries. The potential for efficiency is enormous, but an economic impulse is needed.

In terms of improving energy efficiency and reducing utility media consumption, depending on many factors, including, for example, the specificity of production - as shown, for example, [44,51,56], financial possibilities [32] or the degree of modernity of the plant [42], various approaches. They include activities at various levels of the organization of the enterprise and on a different scale. Increasingly, at the government level, projects are developed to finance activities that are aimed at reducing the energy footprint of companies and thus improving their energy efficiency. For example, Shang [31], in accordance with the theories of transaction costs and dependence on resources, constructs the mode of financing energy efficiency improvement projects based on the total volume of control and quota transactions. On the other hand, [32] points to the influence of the government, industrial structure and foreign capital as key drivers of innovation in low-carbon technologies. Saving energy, looking for alternative production sources, and improving energy efficiency remain a significant challenge for many companies in Poland. Importantly, experts see a real breakthrough in this market, caused primarily by the surge in energy prices in 2020 [67]. With ever higher energy prices, investments in energy efficiency pay off very quickly; a trend which has also started to be observed by Polish companies [71].

Nevertheless, in smaller Polish enterprises there is still the perception that energy efficiency is primarily about thermo-modernization or the replacement of lighting (not taking the benefits associated with savings into account). Therefore, in this paper, it was decided to investigate awareness of enterprises regarding the correlation of actions taken related to the modernization of machines and increasing the efficiency of energy use. For this purpose, a questionnaire survey was carried out covering 111 units of the industry sector based in Poland. The collected results were used to carry out statistical analyses, which, however, we treat with a certain degree of caution, as the research sample was not very large. This is undoubtedly a limitation of the presented research; however, the results of the analysis may shed light on certain trends in the area under study.

When analyzing the results of the study, several important conclusions can be drawn. Firstly, the vast majority of the surveyed companies (74%) modernized machines, with the largest share (49%) of companies operating on the market for 16 years or more (Table 4). Secondly, among the surveyed companies that have modernized machines in the last five years, the largest number were those with long-term experience—as much as 41% (Table 4), while only 7% have been prospering for 11–15 years. Moreover, as shown by the available scientific research, tasks in the field of improving energy efficiency can be carried out from those that are more detailed to those that are more general, i.e., starting at the lowest level, for example by replacing individual energy-intensive devices with newer, energy-efficient models or by optimizing their operation [34,35,42,55]. Activities can then be expanded on a larger, but still relatively small scale, that is, improving energy efficiency and reducing utility consumption locally, within individual machines or stations, by focusing on individual pieces of equipment. In turn, entire processes, installations and production lines, as well as plant-wide application systems, can be modernized on a larger scale and more comprehensively. One of the actions that can be taken at the lowest level and on a small scale is to replace engines with energy-saving models. These are also an example of devices for which increasing energy efficiency is imposed from above and regulated by law [67]. In light of the results of this research, the following areas of modernization can be indicated: over 60% of the surveyed companies decided to replace the devices with new ones, 45% of the respondents modernized the existing devices, and 25% used modern technologies, such as control system software, virtualization, servers, database, and client computers, etc., 21% used component replacement, while less than 3% indicated other areas (replacement of lighting, elimination of compressed air losses, replacement of means of transport with new ones). Thirdly, the vast majority—72%—of the surveyed enterprises undertake activities aimed at increasing energy efficiency and the existence of a significant relationship ($\chi^2 = 8.042$, $p = 0.045$) has been proven between the length of prospering on the market and these activities (Table 5). It was demonstrated that companies that have been operating on the market for 16 years or more significantly more often undertake activities related to increasing energy efficiency than other companies. Fourthly, as the presented studies showed (Table 10), as many as 13.5% of the surveyed companies do not, however, identify the modernization of machines with taking actions related to increasing the company's energy efficiency. However, it was found that there is a significant relationship between the modernization of the machine park and the improvement of energy efficiency (chi-square dependence test: $\chi^2 = 30.380$, $p = 0.000$). This conclusion is consistent with the findings indicated by other researchers. As Grondys et al. [15] shows, the lack of knowledge and awareness of the organization makes it difficult to optimally use energy in economic activity. These are the causes of improper energy management in entities, which confirm that the unclear and simplified provisions of the directive reduce the involvement of entrepreneurs in activities contributing to increasing energy efficiency in their activities. Finally, it has been proven that there is a significant relationship between the improvement of energy efficiency and two areas: modernization of owned machines and the use of modern technologies.

Based on the presented analysis of the collected data, it can be concluded that the modernization of the machine park may be one of the important elements of energy efficiency management. Therefore, the main purpose of the paper, which was to investigate the activities of enterprises in the field of modernization of machines and the effect of this modernization on the actual improvement of energy efficiency, has been achieved. The adopted research hypotheses, H1, H2 and H3, were proven by conducting chi square tests and z-tests (with Bonferroni's correction) in order to detail the existing dependencies and compare the percentage results, and test their strength with the C_p and phi coefficients.

It is obvious that, as with all studies, this too has some limitations and barriers. In addition to the aforementioned limitations related to the size of the research sample, the scope of the study, which only included companies operating in Poland, can be mentioned. In the future, it may be tempting to expand the research. Another limitation is the type of

collected data—most of them are qualitative data, requiring non-parametric statistical tests in order to present selected relationships. Collecting data on, for example, the number of modernization measures or the amount of funds allocated to these measures and costs incurred before introducing modernization measures would enable the use of other statistical methods, which may be an incentive to extend the research.

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