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The Use of Artificial Intelligence for Assessing the Pro-Environmental Practices of Companies

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Featured Application: Potential applications of the research concerns AI-supported eco-design and eco-production.

Abstract: In the present study, the authors analyze, supported by the use of artificial intelligence, the environmental solutions implemented in selected manufacturing companies using the example of the Great Poland Voivodship. The companies analyzed were selected from different industry sectors and were of different sizes, divided into two groups: small- and medium-sized enterprises (SMEs) and large enterprises (LEs). The authors observed the environmental activities of these two groups of companies, paying particular attention to the differences that were evident. The study is based on a questionnaire survey. All survey questions referred to the life cycle of a product, ranging from design, production, and use to recycling processes. We discuss the environmental solutions proposed by enterprises of different sizes and at different stages of the product's life cycle. The goal of this study is three-fold: (1) To investigate the differences in the introduction of environmental issues in SMEs and LEs in the Greater Poland Voivodship, Poland; (2) to examine whether companies in this Voivodship are equally aware of the impact of their business activities and their products on the environment; and (3) to discover novel, more rapid, and simpler methods to analyze the environmental sustainability of companies, including efficient models based on artificial intelligence. An analysis based on ANNs (artificial neural networks) was performed. The novelty of the proposed approach lies in the use of a combination of research data and methods using artificial intelligent tools to develop and scalable conclusions. This approach is unique and has no equivalent in the literature. An analysis was conducted via two perspectives: (1) The level of environmental solutions implemented at successive stages of the product's life cycle and (2) the size of the company. The results show significant differences between the environmental practices of small, medium, and large Polish enterprises, and reveal the emerging trends in enterprise operations, which will be subject to an AI-based analysis.

Keywords: eco-product; production; computational analysis; automatic method; neural networks

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1. Introduction

Environmental protection has been extensively discussed in the scientific research. However, many entrepreneurs, especially those in the small-business sector, underestimate the environmental impact of their activities. When running a small business, they are convinced that they leave a small or no environmental footprint. The statistics show that SMEs compose a significant part of the world's economies, including Poland's. Their ecological awareness manifests itself by taking responsibility for their actions in the context of environmental protection and preservation of natural resources and the active participation in environmental protection activities. This ecological attitude is created by processing the acquired knowledge concerning environmental protection and transforming it into appropriate daily habits [1] used in everyday industrial and service activities. This allows for a better targeting of government and local government support, as well as prevention and intervention activities. However, more importantly, this is being put into practice more frequently in many manufacturing companies. Footprints with a negative impact on the environment, ignored for many years, are finally being reduced. Numerous preventive measures minimizing the environmental impact of economic development have been developed.

This paper presents an analysis of the environmental solutions implemented in select manufacturing companies. The analysis was conducted in the Greater Poland Voivodship, Poland, which has one of the highest rates of gross domestic product (GDP) per capita and is Poland's second largest province. The province is economically varied, with agriculture and manufacturing as the leading sectors. Approximately 30% of its population is employed in the manufacturing industry. Approximately 97% of businesses are small- and medium-sized enterprises [2]. This paper is dedicated to the presentation of research on the environmental solutions implemented in the selected manufacturing companies, since, to date, little analysis has been conducted on the environmental awareness of businesses. Such research is of great scientific and practical importance, including motivating entrepreneurs to be more conscious of the harm being inflicted on the environment.

1.1. Review of the Literature

Environmental awareness is not only the responsibility of individuals, but also businesses. The growth of social environmental awareness and environmental organizations in the 1980s led to the origin of corporate social responsibility. The European Commission defines corporate social responsibility as the responsibility of enterprises for their impact on society [3]. Corporate social responsibility includes, without limitations, purposeful activity undertaken by enterprises to reduce their negative impact on the environment [3]. The results of the studies presented in the *Innovation and CRS at SMEs* report [4], commissioned by the Innovation Development Agency, show that many businesses fail to realize what beneficial impact their activity could have on the environment if it was conducted on a large scale. Employees have little knowledge of environmental protection factors. They do not have the tools to incorporate good environmental practices into their business [1].

Many studies have been conducted to examine the environmental awareness present in enterprises. Van Hemel and Cramer [5] analyzed motivation and barriers in the implementation of eco-design in 77 SMEs in the Netherlands. Cote et al. [6] examined eco-efficiency in 25 SMEs in Canada. Erkko et al. [7] examined the use of eco-efficiency strategies in 40 British businesses on the basis of Eco-Management and Audit Scheme (EMAS) reports. NetRegs surveyed 5554 SMEs in Scotland by phone to examine their eco-minded practices [8,9]. Capuz et al. [10] conducted research on environmental performance in 146 SMEs in Spain. Fernandez-Vine et al. [9] studied eco-efficiency in SMEs in Venezuela.

Being part of corporate social responsibility, environmental aspects are often addressed by the research as corporate social responsibility practices conducted by different enterprises (e.g., studies on the performance of SMEs in select countries of South America, [11]). An eco-minded approach has also been adopted in product design. Stoyell et al. [12] analyzed the degree to which environmental aspects are taken into consideration in a concept design at two large enterprises. Guzman [13] examined environmental aspects at 96 businesses in Mexico. Most of the studies conducted on the environmental awareness of entrepreneurs address factors that generate environmental pollution and result directly from the operational activity of the enterprise, such as air pollution, dangerous waste, and energy consumption. The research discussed in this paper points to the fact that, apart from the above-mentioned factors, a business presenting great environmental awareness should consider the environmental impact of their products. Reports on the research conducted on the implementation of eco-design can be observed in the literature [14]. The paper referred to in the previous sentence discusses the research conducted in enterprises that have implemented eco-design, and it identifies the related challenges. Other publications in which the implementation of eco-design is examined include Cai and Zhou [15], Bey et al. [16], Kara et al. [17], and Akman et al. [18]. Many of these papers report single case studies or studies based on a small sample of firms (usually no more than three) implementing eco-design approaches. None of the above-mentioned studies address the environmental impact of the company's operational activity.

The increasing demand for pro-environmental solutions in companies is the driving force behind the development of pro-environmental business solutions [19]. Enterprises face increasing demands from the modern economy concerning environmental protection. Seeking to meet these requirements, companies implement solutions that minimize their negative environmental impact. Pro-environmental behavior has attracted a considerable amount of attention in recent years. In order to build their image and competitive edge, companies often follow new trends [17,20,21]. Properly implemented environmental solutions should cover all company departments. In general, the changes implemented in the manufacturing sector have the most significant impact [22]. However, tangible results can be obtained only through action covering all areas of operational activity. Environmental awareness must be increased among all employees to achieve the objective of minimizing a negative environmental impact. Only a thorough understanding of the actions performed at all organizational levels will translate into real financial profit and improvement of the overall company image.

Pro-environmental practices in business should be analyzed and improved across the product development process, as only then will it attain the desired results [23]. Approximately 80% of a product's sustainability performance is defined during the early stages of its development [24]. In order to include environmental factors in the design process, it is necessary to identify the product-related environmental aspects and incorporate them into the design process during the early stages of product development [25]. This approach is referred to as eco-design, design for the environment, or a design compliant with the principles of sustainable development [26–31].

More precisely, eco-design involves the selection of materials aimed to reduce the negative environmental impact of products [32]. Its many aspects, which may have a physical impact on manufacturing conditions, include the selection of materials (non-toxic and recyclable), manufacturing processes (taking into consideration the amount of waste and emissions), determination of the level of the product's energy consumption when in use, and removal of the product from service (i.e., repair and recycling processes) [33–37].

At an early stage, investment in environmental solutions generates costs. In the long term, however, it may become a source of increased profit stemming from savings of materials and resources, reduced waste, increased profitability, compliance with applicable regulations (i.e., no fines), increased work safety, lower insurance premiums, improved ratings for investors, better competitive edge, retaining existing customers, and gaining new customers.

Many strategies and ways of integrating pro-environmental activities have been developed [27,28,38,39]. New methods and tools supporting the implementation of pro-environmental solutions have been introduced, from the integration of eco-design into product development practices to advanced systems that analyze the environmental performance of finished products [29,38]. According to Baumann et al. [19], there were more than 150 eco-design tools available on the market in 2002. Pro-environmental activities are supported with a number of directives that force companies to perform environmentally friendly practices [40,41]. Moreover, the increasing environmental awareness translates into increasing customer demands concerning environmentally friendly products. On the other hand, enterprises seek to build their competitive edge by changing their approach to environmental issues [5,42,43]. However, the last twenty years of studies conducted on eco-design [44] and development of related tools [43,45–47] have shown that environmental protection is insufficiently incorporated into the design process. Enterprises implement various solutions, depending on their needs and capabilities [29], but some of them fail to utilize all their functionalities. The most common barriers include insufficient funds, a lack of knowledge, or a dislike for novel forms of technology, as well as tools poorly adjusted to the requirements of designers [48–50]. Sihvonen and Partanen [44] analyzed factors that have an impact on the implementation of eco-design in enterprises on micro-, mezzo-, and macro levels. According to them, the factors are "a combination of organizational, engineering design and new product development perspectives within the eco-design domain". Other authors [42,51] claim that the implementation of eco-design in enterprises is impeded by a lack of market demand.

A review of the literature indicates the great value of the Millennium Ecosystem Assessment (MA) established in 2001, using a new conceptual framework to analyze and understand the impacts of environmental change on ecosystems and human well-being, placing the concept of ecosystem services at the center of the discussion. It is possible to combine the MA concept (through decomposition) with the analysis structure presented in this article. Indirect factors, such as changes in technology (input), can lead to changes in factors directly affecting ecosystems. The resulting changes in the ecosystem lead to changes in ecosystem services, thereby affecting human well-being (output) [52–54].

Despite the aforementioned popularity of the topic, there is still a lack of publications on the application of artificial intelligence in this area. In particular, this concerns models based on machine learning (in particular, traditional, or deep artificial neural networks) that allow for the extraction of rules from the data. This is important in situations where the mechanisms are not fully understood, including as a result of uncertain, incomplete, or inhomogeneous data.

1.2. Reference to Greater Poland

The authors analyzed the environmental solutions implemented in select manufacturing companies. The local companies in the Greater Poland Voivodship operate in various industries and vary in terms of manufacturing methods, complexity of processes, scale of activity, and organization of work. The analyzed companies were selected from various industry sectors and of various sizes, divided into two groups: small- and medium-sized enterprises (SMEs) and large-sized enterprises (LEs). The authors observed the environmental activity of the two groups of enterprises, with a focus on their differences. The study was based on a questionnaire survey. All survey questions referred to the product's life cycle, from the stage of design, through the manufacturing process and use, and recycling. The success of the study depended on the collaboration of the respondents and their willingness to provide information to the authors that would help them understand how the enterprises function. The results of the survey were analyzed. The ordering of the questions, which follows the stages of the product's life cycle, enabled the authors to break down the results by the level of implementation of environmental solutions during particular life cycle phases. The results were also broken down by the size of the enterprises under analysis and used for a comparison of the pro-environmental behavior of enterprises of various sizes.

To date, a limited number of papers have considered issues of ecological activities of companies in Poland [55].

The effect of pro-environmental practice is company-wide and addresses various areas of operation, such as the following:

- Finance—an area in which pro-environmental action is aimed at securing better economic results;
- Customers—an area in which the needs of beneficiaries are taken care of, safe work conditions are provided to internal customers, and a competitive edge of the enterprise is built;
- Environmental protection-related operational activity—an area of economic resource management and mitigation of environmental impacts;
- Knowledge and development—continuous improvements performed in the areas of finance, customers, and environmental protection [56,57].

A classification of factors that comprise particular areas of pro-environmental activity is presented in Table 1.

Table 1. Areas and factors of pro-environmental activity; own work based on [56].

Area	Factors
Knowledge and development	Optimum level of capital expenditures on environmental protection Implementation of an environmental management system Having environmental protection programs in place and planning environmental protection activities Motivating employees to comply with the environmental rules and assessment of their performance in this respect
Environmental protection-related operational activity	Efficient consumption of resources and materials Use of renewable energy sources Compliance with laws on environmental protection Reductions in SO_2, NO_2, greenhouse gases, and dust emissions Reduction in the amount of waste and wastewater produced
Customers	Maintaining good relations with local communities—reductions in waste, pollution, and noise Organization of social initiatives Competitiveness Ability to gain and retain customers
Finance	Economic efficiency of the use of the environment Good cost/benefit balance in the area of environmental protection Optimization of the cost of resources

The literature on the subject provides characteristics of possible environmental activities that can be performed in various areas enterprise-wise. However, this classification does not take into account the significance of the changes introduced in particular areas of operation, depending on the size of the enterprise, the industry in which it operates, and its capabilities. Nevertheless, the most beneficial pro-environmental solutions are those that address the largest number of areas of operation.

The survey presented in this paper aims to present the stages of implementation of eco-design in select manufacturing companies based in the Greater Poland Voivodship (30 respondents). The objective of the study is the assessment of ecological activities conducted in manufacturing companies with regard to the size of the company and product life cycle phases.

The goal of this study is three-fold:

- To investigate whether there are differences in the introduction of environmental issues in SMEs and LEs in the Greater Poland Voivodship;
- To examine whether companies in the Greater Poland Voivodship are equally aware of the impact of their business activities and their products on the environment;
- To discover novel, more rapid, and simpler methods to analyze the environmental friendliness of companies, including more efficient models based on artificial intelligence.

The contribution of this research will enhance the computational support for business planning and management, design, and manufacturing, including within the "Industry 4.0" paradigm, to perform analyses and predictions beyond the scientific knowledge and engineering experiences that exist to date.

The study involved an analysis based on artificial intelligence (AI), specifically artificial neural networks (ANNs), which are part of a machine learning (ML), data-driven approach. The novelty of the proposed approach lies in combining the use of survey data, novel methods of analyzing it with the use of traditional and AI tools, in order to develop results in a transparent and scalable way. To date, this approach, in relation to corporate pro-environmentality, is unique and has no equivalent in the literature. The analysis was conducted simultaneously in two directions, with the first observing the level of pro-environmental solutions implemented at successive stages of a product's life cycle, and the second analysis taking into account the size of the company.

2. Materials and Methods

2.1. Material

The study focused on different manufacturing companies. Ninety-four companies operating in the Greater Poland Voivodship were contacted. Fifteen companies classified as SMEs, and fifteen as SEs, were taken into account. The results were obtained due to the lack of answers provided, a refusal to participate in the survey, or inconsistent answers that were impossible to clarify. The SMEs represented the following industries: clothing, building, household appliances, heating, medical, cooling, tire manufacturing, rubber and rubber-and-metal products, plastic packaging, injection molds, corrugated packages, rubber products, and aluminum profile systems. The LEs represented industries such as household appliances, automobile, agricultural machinery, transport equipment, medical equipment, flexible packaging, and window fittings.

Surveys were conducted in person at the company, by email and by telephone, with direct surveys providing the best results: 100% of the responses were obtained during the first contact period and presented the least inconsistent data. In the case of inconsistent data, the company, if possible, was asked to clarify the answers after being contacted again. In addition, direct contact with the respondent provided us with an opportunity to obtain a large amount of additional information that provided insights into the company's operations and its approach to environmental issues.

2.2. Methods

The study was conducted as a questionnaire survey [58]. The questionnaire was developed by Piechowiak and Kowalski [59]. At stage one, the study problem was specified in detail. One of the important decisions concerned the subject area. The aim of the questionnaire was to collect data on the environmental solutions applied in select manufacturing companies. The implementation of environmental solutions provided the best results when it the entire product life cycle. Therefore, the questionnaire was divided into particular areas [60], with each area addressing a different stage of the product's life cycle.

The questionnaire opened with an introduction and a set of questions concerning the enterprise, such as the company's name and industry of operation, as well as questions on the basis of which the companies were classified into the groups of SMEs and Les. For the further analysis of the relations between the enterprises, a set of questions concerning the market of operation and type of production was also included.

The main body of the questionnaire contained questions grouped by the stages of the product's life cycle. The "Product design" group included questions regarding the selection and compatibility of materials, joints, analyses conducted at the development phase, and the supporting tools used. The "Product manufacturing" group contained questions concerning waste management activity and compliance with the applicable laws. The "Product use" set of questions aimed to collect information on the environmental performance of the manufactured products and the company's approach to eco-design. The "Product recycling" group contained questions regarding the handling of products after the end of their life cycles, i.e., the disassembly or segregation of used products. The questionnaire also examined the environmental education of employees with a set of questions concerning environmental training sessions.

2.3. Statistical Analysis

The results obtained are presented in percentage values in comparison with the maximum number of possible positive results (Table 2). This breakdown of results permits an observation of the differences in the environmental activity between companies of various sizes, as well as the differences in the environmental engagement of companies at various stages of the product's life cycle [61,62]. Each respondent could obtain a maximum of m_{pd} positive answers in the "Product design" (as the first stage of the product's life cycle) group of questions (if all answers to the questions in this group would be "Yes" for questions with "yes/no" answers), or all the answers would be selected (for the remaining questions in this group). The numbers of the surveyed companies are denoted as n_{SME} and n_L; thus, the result of the equation $z_{pd,\ SME}= m_{pd,\ SME}\ n_{SME}$ equals 100% of positive opinions for SMEs surveyed during this stage. The same concerned the LEs ($z_{pd,\ L}= m_{pd,\ L}\ n_L$). The proportion of positive answers provided by the respondents to the maximum number of possible positive answers provided a percentage value that represents the level of fulfilment of environmental requirements at a certain stage of the product life cycle. The same calculations were used for the remaining stages of the product's life cycle (z_{pm} product manufacturing, z_{pu} product use, and z_{pr} product recycling).

Table 2. The proportion of positive answers to the maximum possible number of positive answers.

Proportion of Positive Answers to the Maximum Possible Number of Positive Answers		
Product Design	**Small and Medium-Sized Enterprises**	**Large-Sized Enterprises**
Positive	165	245
Neutral	31	14
Negative	53	31
Final result	165 − 53 = 112	245 − 31 = 214
Obtained	112	214
Max	525	525
Percentage value	112/525 × 100% = 21%	214/525 × 100% = 41%
Product manufacturing	Small and medium-sized enterprises	Large-sized enterprises
Positive	92	114
Neutral	12	10
Negative	13	9
Final result	92 − 13 = 79	114 − 9 = 105
Obtained	79	105
Max	300	300
Positive	79/300 × 100% = 26%	105/300 × 100% = 36%
Product use	Small and medium-sized enterprises	Large-sized enterprises
Positive	117	130
Neutral	6	4
Negative	28	41
Obtained	89	89
Max	450	450
Percentage value	89/450 × 100% = 20%	89/450 × 100% = 20%
Product recycling	Small and medium-sized enterprises	Large-sized enterprises
Positive	59	73
Neutral	6	7
Negative	3	0
Final result	59 − 3 = 56	73 − 0 = 73
Obtained	56	73
Max	240	240
Percentage value	56/240 × 100% = 23%	73/225 × 100% = 29%

2.4. Computational Analysis

Artificial neural networks (AANs) as a data-driven approach are increasingly used in the research conducted on various aspects of sustainable development, including the circular economy [63], estimating evapotranspiration and soil–water–air balance [64,65], water management [66], or forecasting water quality [67] or energy production values [68,69]. In the area of production, ANNs were used for the analysis and optimization of processes, including materials in 3D-printed exoskeletons [70,71] and health diagnostics in various diseases [72,73].

ANNs can improve the efficiency, accuracy, and speed of manufacturing processes, including their environmental friendliness. The research conducted on the use of ANNs was performed both in the areas of big and small data sets. This made it possible to identify the major cause–effect relationships or understand the behavior complex system, including the appearance of a production error [74,75].

The study used a three-layer neural network (multi-layer perceptron (MLP)), a back-propagation algorithm (BP), and a perceptron linkage optimization kit to perform minimal multi-layer diagnostics focused on determining the mean square error (MSE) and naive initialization techniques. BP is a widely used algorithm for training feed-forward artificial neural networks because it is fast, easy to implement, highly adaptable, efficient in most cases, and does not require any prior knowledge of the network.

The tool used to construct the ANN model was MATLAB R2021b with the Neural Networks Toolbox (MathWorks, Natick, MA, USA). As an alternative to the traditional approach based on the previous authors' research, the "hit and miss" tests presented in this article were genetic algorithms (GAs) attaining the best solution in a given solution space. The fitness evaluation function of the GA is defined as

$$F = MSE + (1 - \alpha) \times (w/w_n) \times 10^{-5} + \alpha \times (n/n_n) \times 10^{-5} \tag{1}$$

where

MSE—mean square error of the ANN;
α—weight constant, which is set to 0.8;
w—number of weighted interconnections between the input and hidden layer;
w_n—maximum number of all interconnections;
n—number of neurons in the network;
n_n—maximum number of neurons in the network;
10^{-5}—synaptic weight constant.

The value of the above-mentioned fitness function was assessed after 1000 epochs on the basis of the error and penalty value for the network complexity.

As input variables, 27 open, closed, semi-closed, yes/no, and filtering questions were used, including 12 questions on product design, 6 questions on product manufacturing, 5 questions on product use, and 4 questions on product recycling practices. The 28th input was the company's size. As output variables, 4 (product design, product manufacturing, product use, and product recycling) were used (Figure 1).

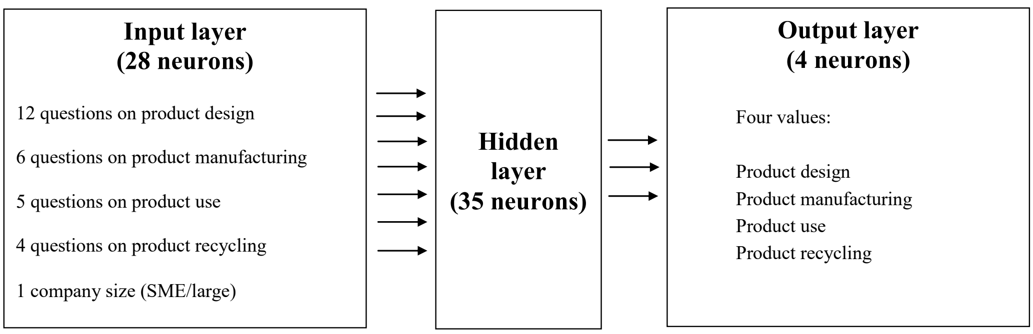

Figure 1. Artificial neural network (ANN) structure: inputs and outputs.

The selection of the input parameters resulted from the homogeneity of their values, the possibility of their simple retrieval from the questionnaire, and the ability to calculate the required output variables from them. We applied the scaling of the input variables in order to maintain uniformity in the interpretation of all signals in the network and the associated weights. We used the division of the data set: 70% (training set) and 30% (testing set). ANN weights were pre-set in such a way as to avoid a convergence that was too slow and falling into the trap of local minima.

3. Results

3.1. Analysis of Data Obtained from the Questionnaires

The results were analyzed in scoring tables presented as Supplementary Materials. The column headings represent the questionnaire number, and the rows represent the criteria corresponding to the survey questions. The tables present the original grouping of the questions by the stages of the product's life cycle, which is of key importance for the problem under analysis. The main objective of the development of the scoring tables was to compare the involvement of manufacturing companies in environmental activity at various stages of the product's life cycle. Two identical tables were composed—one for SMEs and one for LEs. Table S1 in the Supplementary Materials presents the assessment of pro-environmental solutions implemented in small- and medium-sized enterprises (SMEs). Table S2 in the Supplementary Materials presents the assessment of pro-environmental solutions implemented in large-sized enterprises (LEs). They contain a summary of results of pro-ecological activities of companies to date from the point-of-view of product life cycles (27 questions—Sections I–IV of the questionnaire). The results concerning the plans and future activities of the companies not connected with the product's life cycle are presented and described in Chapter 5.6. In order to make these tables more readable, the criteria were presented in a short form. In the case of single-choice questions, the exact answer was presented ("yes", "no", or 0, if the answer was not obtained or obtaining an answer was not possible, e.g., the question was irrelevant to the respondent's business activity). In case of multiple-choice questions, where more than one answer was possible (the company meets more than one of the criteria provided), the number provided was the sum of the marked entries. The positive value of the sum represents a positive influence on the environment; a negative value represents a negative influence on the environment.

Each respondent could obtain a maximum of m_{pd} = 35 positive answers in the "Product design" (as the first stage of the product's life cycle, Table 2 above) group of questions if all answers to the questions in this group were "yes" (for questions with "yes/no" answers) or all the answers would be selected (for the remaining questions in this group). The number of surveyed SMEs is n_{SME} = 15, i.e., the result of equation $z_{pd,\ SME} = m_{pd,\ SME}\ n_{SME} = 35 \times 15 = 525$ equaled 100% of the positive opinions provided for SMEs surveyed during this stage. The number of surveyed LEs was n_L = 15, i.e., the result of equation $z_{pd,\ L} = m_{pd,\ L}\ n_L = 35 \times 15 = 525$ equaled 100% of the positive opinions expressed for the LEs surveyed during this stage. The same calculations were used for the remaining stages of the product's life cycle ($z_{pm,\ SME}$ = 300 and $z_{pm,\ L}$ = 300 for product manufacturing, $z_{pu,\ SME}$ = 450 and $z_{pu,\ L}$ = 450 for product use, and $z_{pr,\ SME}$ = 240 and $z_{pr,\ L}$ = 240 for product recycling).

A preliminary analysis of the data was conducted to reveal the implementation of environmental solutions at certain stages of the product's life cycle. This presents the significance of the life cycle phases for both SMEs and LEs and permits the observation of the differences in pro-environmental activities in companies of various sizes (Figure 2).

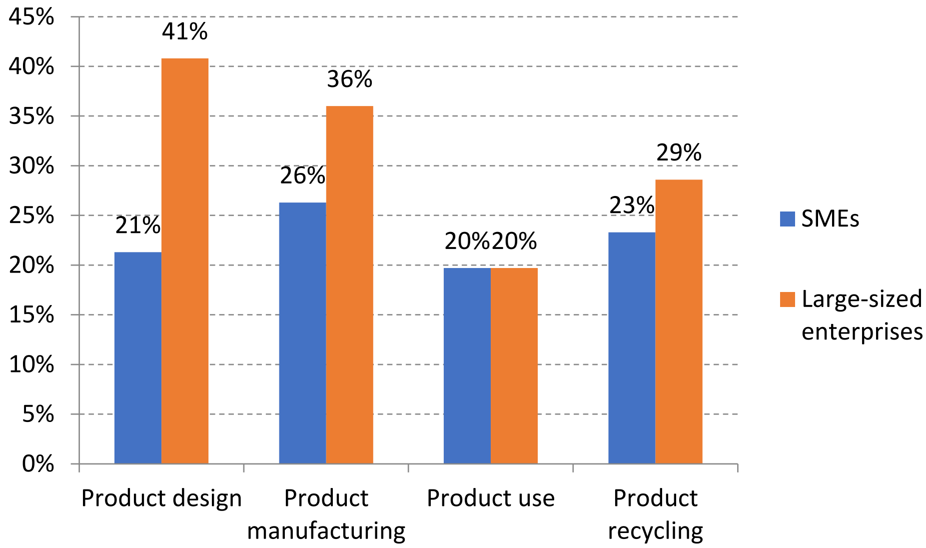

Figure 2. Implementation of environmental solutions in enterprises.

LEs presented a high level of implementation of environmental solutions at the product design and manufacturing stages. The significance of the other stages of the product's life cycle for LEs was relatively steady—all the results are equal to or higher than 20%. The existence of a certain environmental equilibrium is typical for LEs. Most of them have sufficient funds to consider the implementation of environmental solutions at all stages of the product's life cycle. The fact that the number of positive answers is far from the maximum reflects the specific character of business activity or the company's industry of operation—the implementation of only certain environmental solutions is sufficient from the perspective of environmental protection.

In the group of SMEs, the results are comparable in all stages of the product's life cycle. The differences present in the implementation of environmental solutions at different stages are not great. The questions in the area of design are often referred to as highly advanced solutions, which are not in frequent use in SMEs. The questions referring to the "Product recycling" area were designed to obtain information on how the manufacturing companies are involved in handling products at the end of the life cycle and how much they understand regarding the handling of products after they are withdrawn from use. The participation of SMEs in recycling activities is minor.

The results show that LEs are more advanced than SMEs in the implementation of environmental solutions. The most pronounced differences were observed during the "product design" stage. The LEs scored almost twice the score of SMEs. The stage of "Product use" was treated equally in both types of enterprises (the difference in the results is insignificant). On many occasions, the survey was conducted in the form of an interview. During the conversations, the respondents often revealed that little or no environmental activity in SMEs was often caused by insufficient funds or human resources. SMEs cannot afford to implement environmental solutions or have no qualified personnel to take charge of the implementation. Unlike SMEs, most of the LEs have personnel dedicated to environmental issues.

Such an analysis of the results aims to present the level of environmental activity of the respondents at various stages of the product's life cycle, and the differences between SMEs and LEs in this respect.

3.2. Computational Analysis

ANNs directly convert survey data linked to company size into a set of percentages for four categories of company descriptions: (1) product design, (2) product manufacturing, (3) product use, and (4) product recycling. It is therefore used not only to simply extract rules linking output to input data and rapidly estimate the survey results, but to also automatically or semi-automatically predict the state of the enterprise in the above-mentioned four categories with deliberate or independent modifications of one or more input parameters. This lays the foundation for a digital twin of the environmental friendliness of the enterprise, fed automatically with data within the Industrial Internet of Things (IIoT), on which future modifications can be tested without the need to switch, for example, the entire production line.

In the model, each layer of the network contained neurons with the same activation function (Table 3): a sigmoidal type due to its high flexibility (non-linear, continuous, and differentiable functions). The results of using a linear function were significantly worse.

Table 3. The best MLP network models for diagnostic measures.

ANN Structure	Activation Function in the Hidden Layer	Activation Function in the Output Layer
MLP 28-25-4	Sigmoid	Sigmoid
MLP 28-30-4	Sigmoid	Sigmoid
MLP 28-35-4	**Sigmoid**	**Sigmoid**
MLP 28-40-4	Sigmoid	Sigmoid
MLP 28-45-4	Sigmoid	Sigmoid

The ANN learning process consisted of repeated patterns and weight modification until the network reached its target MSE after no more than 1000 epochs (Figure 3).

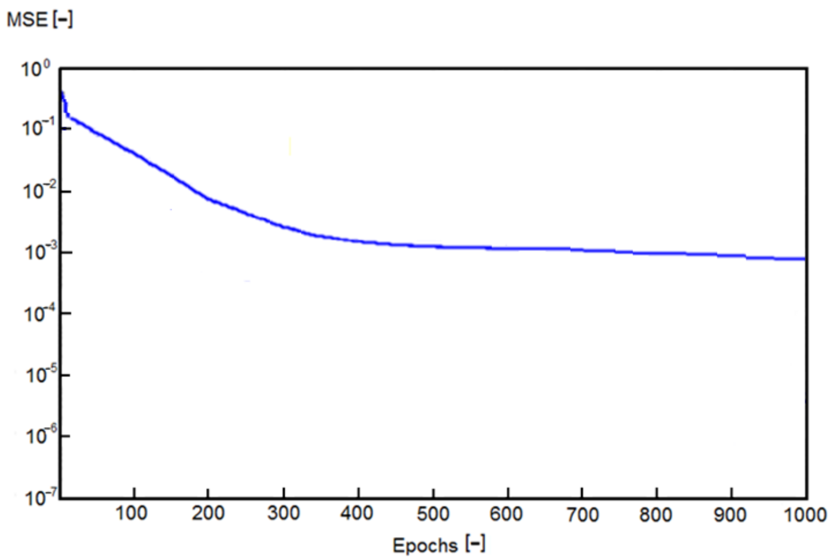

Figure 3. Values of mean square error (MSE) during learning.

The best results were obtained for the network structure parameters: n = 28, m = 4, and 35 neurons in the hidden layer (i.e., MLP 28-35-4). The ANN was able to minimize the MSE for the training set data to very low values (ranging from 0.001–0.02) (Table 4, Table 5, best choice in bold).

Table 4. Selected ANNs quality assessment.

Network Name	Quality (Learning)	Quality (Testing)
MLP 28-25-4	0.8783	0.8871
MLP 28-30-4	0.8912	0.9042
MLP 28-35-4	**0.9318**	**0.9366**
MLP 28-40-4	0.8933	0.9089
MLP 28-45-4	0.8716	0.8823

Table 5. MSE values for the best MLP neural network.

Network Name	(R)MSE
MLP 28-25-4	0.02
MLP 28-30-4	0.01
MLP 28-35-4	**0.001**
MLP 28-40-4	0.01
MLP 28-45-4	0.01

The optimization method presented in this article (Table 5: bold type indicates the best result, other results are also presented in Table 6) is another step toward analyzing the parameters of production processes in Industry 4.0.

Table 6. Levels of environmental performance.

Value %	Environmental Performance
0–20	Definitely not
21–40	Rather not
41–60	Neutral
61–80	Rather yes
81–100	Definitely yes

ANN-based optimization is aimed at a relatively simple and rapid solution to the optimization problem, avoiding the definition of rules (e.g., in the absence of their knowledge), relying only on the input and output variables (data-driven approach). The proper selection of training data (sets of input and output parameters) also allows for the identification of non-obvious or previously unknown rules. This is useful for jobs with unchecked databases.

A neural network is used to assess companies in terms of their environmental performance. There are 28 questions in the input, the answers to which are entered, and then 4 percentages of the company's environmental performance in the areas of product design, product manufacturing, product use, and product recycling are obtained as the result.

A modified five-point Likert scale [76] was used to assess the environmental performance of the surveyed enterprises. A company can obtain one of five levels of environmental performance: definitely not ecological; rather not ecological; neutral; rather ecological; and definitely ecological. Table 6 presents a detailed analysis of the results.

Using this scale when analyzing the percentage values obtained at the output of the neural network, it is immediately apparent in which area the company's environmental performance needs to be improved. From these four values, an average can be formulated and an overall assessment of the company's environmental performance can be determined.

4. Discussion

4.1. Achieved Results

The decisions concerning the environmental activity of manufacturing companies are influenced by numerous factors, such as risks to the environment posed by the manufacturing processes, shortening of a product's life cycle, the increasing competition, and the increasing environmental awareness of customers. Therefore, companies undertake various environmental strategies and develop tools supporting eco-design. In this paper, we attempted to assess the environmental activity of manufacturing companies. For a successful outcome, the problem was thoroughly analyzed and the study objectives were defined. The authors focused on a comparison of the implementation of environmental solutions in enterprises of various sizes and at particular stages of the product's life cycle. The study was conducted as a questionnaire survey. The respondents were classified into SMEs and LEs. The questions were grouped by the stages of the product's life cycle, which made a comparison between the level of advancement of the implementation of solutions at each stage possible. For a thorough analysis, reliable data were required. The most important feature of the questionnaire was its universal character. The authors aimed to conduct the survey in companies operating in various industries, in order to obtain a reliable image of the level of environmental solutions implemented in manufacturing companies in the Greater Poland Voivodship. However, the varied character of the respondents turned out to be an obstacle, as some questions referred to a specific type of manufacturing process. For example, issues concerning the energy efficiency of products or types of joints used might only be considered by companies that produce energy-consuming devices or products in which components are joined. The authors might have decided not to include specialist questions in the questionnaire; however, these questions are highly related to the objective of the study. The data obtained through these questions provided insights into significant issues from the perspective of eco-design. Moreover, the questions were formulated on the basis of the rules of eco-design.

The questionnaire surveyed the level of environmental solutions in many areas of operation. The questions concerned the company's practices, tools, and systems supporting eco-design, as well as the legal aspects and methods used to raise environmental awareness. The universal character of the questionnaire produced thorough analyses and conclusions regarding environmental activity conducted by the reviewed companies.

An important part of the study was the assessment of the environmental awareness of the enterprises. This was achieved through the questions included in the section of the questionnaire concerning recycling and the information on training sessions provided by the company to its employees. The results show that the respondents commission external companies to handle waste and recycling activities. The authors sought information on the engagement of companies in the processes at the end of the product's life cycle and their level of knowledge concerning the handling of waste. As a result, an image was obtained of the level of liability of companies for their products. The section of the questionnaire concerning training sessions was aimed to verify the level of this type of activity and the willingness to constantly develop and improve in this area through the expansion of the environmental knowledge of employees and promoting environmental behaviors. Through a systematic approach to the survey data, many similarities and differences between the ways in which SMEs and LEs function were identified. Large enterprises were more advanced in the implementation of environmental solutions than SMEs. There were many areas of company operations in which an engagement in environmental activity could be improved. The decisions concerning environmental protection often pose certain risks, especially for small enterprises, which cannot afford costly investments in this area. However, eco-innovation is the key to improving a company's market position. Eco-innovation not only concerns the product, but also the environmental solutions applied at the manufacturing stage. Changes in this area not only require a certain number of investments, but also a thorough analysis of the company's strategy and providing opportunities to support their ideas.

4.2. Limits of the Study

No functional limitations were observed in the proposed AI solution compared to its traditional counterparts. Furthermore, no limitations affecting the robustness of the results were observed. Ecological changes in global production, including those occurring due to the limitations in the availability of the materials (raw materials, electronic parts), water, fuels, and electricity, are, at present, creating new challenges for ecological mass production and the simultaneous monitoring of the production system and the life cycle of recycled products using the Internet of Things, cloud computing, and AI.

4.3. Expected Impacts

The results of our research may have created the following impacts:

1. Social impacts:
    - Building public awareness of environmentally friendly products and services and pro-environmental producers;
    - Education regarding green order, respect for the environment and its resources, while harmoniously co-existing with human beings;
    - Shaping the behavior of environmentally conscious customer groups;
    - Research into the formation of a pro-ecological market, market preferences, and the promotion of pro-environmental behavior;
    - Shaping general global trends in the area of human smart cities as communities.
2. Impacts on research:
    - Inspiration for further research into innovative pro-environmental organizational processes, production, new products, and service families;
    - Sustainability as one of the key criteria in all scientific disciplines.
3. Impacts on industry and trade:
    - Adaptation of industrial processes utilized at present toward sustainability;
    - The emergence of novel functionalities, including those expected by from pro-eco customers;
    - Product development strategies through simple improvements or the replacement of modules rather than the replacement of entire products;
    - Personalized 3D printing using environmentally friendly materials;
    - The spread of the zero-waste paradigm in manufacturing.

The pro-environmental approach in production has a significant impact on the development of Industry 4.0 and the research into this paradigm towards sustainability. This is particularly true for the sustainable, intelligent use of biofuels, green energy sources within flexible production and closed-loop logistics focusing on customers with diverse, individual needs for innovative products and services.

4.4. Directions for Future Research

The subsequent stages of research will be concerned with optimizing the proposed approach to enhance the aforementioned social, scientific, and industrial implications. This includes both directly extending the life cycle of products and their recyclability, and indirectly by reducing resource consumption (materials, energy, water, air, etc.,) and reducing the environmental impact of production processes. This is particularly true for multi-material, multi-functional products with adaptable or programmable properties. A separate issue is their digital models, digital twins, allowing structural, physical, and chemical properties (and their combinations) to be optimized without wasting materials and other resources.

The process parameters were also efficiently estimated using ANNs. The study indicates the effectiveness of ANNs in conducting the research on novel, pro-ecological products: the prediction of eco-efficiency, green marketing, predictors of pro-environmental behaviors, the links between education and pro-environmental behavior, the use of ANNs in the inventory model in situations of uncertainty and inflation, and the benefits derived from utilizing maintenance technology with promotion and time-dependent degradation under fuzzy learning conditions (based on linguistically described parameters). The solutions presented in the present study are promising tools in the field of the computational analysis and design of environmentally friendly products. Our results confirm that such processes may be AI-based and optimized toward the successful and sustainable production of usable/functional products. The automation of the process of selecting the process parameters, technology, and materials used requires an appropriate tool (ANN). This not only improves the environmentally friendly nature of the products, but also improves the product quality and reduces the time required to prepare such an automatically created set of parameters. The selection process itself can be easily adapted to different technology/material combinations, and can be developed to create a more advanced tool, useful for mass production and continuous technical control within the Industry 4.0 paradigm. Easier modifications through the use of modifiable templates and faster production processes, as far as client satisfaction is concerned, are also of great importance and rapidly assessed.

Manufacturing processes can be optimized on the basis of AI toward the sustainable production of fully functional products, which is favored by the widespread automation of the selection of process parameters, technology, and materials employed. In this manner, environmental friendliness can be combined with the better quality and personalization of a product, as well as shorter time required to begin the production process with the use of a previously prepared and practiced technique on a virtual twins set of parameters. This also applies to the different combinations of technologies/materials that exist, which are valuable in times of crisis. The above-mentioned approach can significantly reduce production costs and increase the verifiable durability and efficiency of the production process. This study will increase the possibilities of computational design support options, including conducting analyses and forecasting beyond the engineering practices and scientific knowledge that exists to date.

AI-based analysis, inference, and prediction can significantly support environmentally friendly industrial activities, including manufacturing processes [77,78]. The wider-ranging use of the optimization and automation of process and material factors improves the cost-effectiveness of production, reduces material consumption and waste, and improves the ability to provide environmentally friendly products and services necessary for daily life activities [79,80]. Even simple, hybrid ANN/GA solutions offer improvement, providing a rapid and reliable second-opinion system for processing and optimizing production based on the data provided (data-driven, machine learning). Despite the initial complexity of the modeled processes, it is possible to reduce the number of parameters considered in the optimization process. In addition, the selection of characteristics and the number of neurons present in the hidden layer allows for the speed and accuracy of the inference and prediction to be influenced to suit the required needs (fast real-time inference vs. complex and accurate analytical processes requiring time and computing power). In the latter case, i.e., advanced analytical solutions, deep neural networks are worth considering. Such semi-automated or automatic pro-environmental analysis models can be used to develop an intelligent expert system to assist less experienced managers and engineers during production management.

The features, events, and processes (FEP) method [81] also relates to environmental analyses, and this can represent an extension of the research conducted on the impact of companies on the aspects mentioned in the Section 2. An additional method that can be used to conduct further research is the Millennium Ecosystem Assessment (MA) as a conceptual framework to analyze and understand the impacts of environmental changes on ecosystems and the well-being of human beings [52–54].

The results of this study can be used by authorities and policymakers to prepare strategies and regulations to increase the level of eco-awareness in manufacturing companies. They can also be used by industry professionals to determine the state of their companies at present in terms of their eco-awareness. The questionnaire prepared for the study can also be used as a tool to perform periodic evaluations in the company, and thus to measure the trend of environmental activities conducted in the company.

5. Conclusions

The overall result of the survey is positive: companies operating in the Greater Poland Voivodship want to pursue the objectives of a transparent environmental policy. This result is considerably shaped by LEs that apply numerous pro-environmental solutions and continuously improve their processes. In the analysis of the results obtained by SMEs, their lower financial and human resource capabilities should be taken into account. Many areas requiring improvements were revealed; however, the willingness of SMEs to develop their environmental activities was also demonstrated. An obvious conclusion determined from the survey is that the majority of respondents are attempting to implement environmental solutions on as large a scale as possible; therefore, we can expect significant improvements over time and the introduction of numerous environmental solutions in enterprises. Given the continuous development of environmental issues, there may be significant improvements in the area of environmental protection in the future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13010310/s1. The questionnaire. Table S1. Assessment of pro-environmental solutions implemented in small- and medium-sized enterprises (SMEs). Table S2. Assessment of pro-environmental solutions implemented in large-sized enterprises (LEs).

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