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Decision-Tree Based Methodology Aid in Assessing the Sustainable Development of a Manufacturing Company

Justyna Patalas-Maliszewska [1,*], Hanna Łosyk [1] and Matthias Rehm [2]

[1] Institute of Mechanical Engineering, University of Zielona Góra, 65-417 Zielona Góra, Poland; h.losyk@iim.uz.zgora.pl
[2] Professorship Production Systems and Processes, Chemnitz University of Technology, D-09107 Chemnitz, Germany; matthias.rehm@mb.tu-chemnitz.de
* Correspondence: j.patalas-maliszewska@iim.uz.zgora.pl

Abstract: Nowadays, achieving the objectives of sustainable development (SD) within a manufacturing company, through introducing and integrating sustainability into a development strategy, is a key parameter in gaining a competitive advantage in the market. The objective of this study was to develop a decision-tree based methodology to facilitate SD assessment in a manufacturing company, which consists of five main components: (1) Determination of SD indicators based on literature analysis, (2) Using the Analytic Hierarchy Process (AHP) method which determines the priority of the SD criteria, (3) Collecting data to determine the values of the key objectives SD, (4) Using a decision tree to build scenarios of possible actions to increase the level of SD, (5) Indicating recommended actions for continuous monitoring of progress towards reaching SD objectives. In the proposed approach, the use of the AHP method allowed for indicating the most important SD indicators, which made it possible to limit the number of queries to manufacturers on data from real companies regarding the values of SD indicators. Finally, the methodology was applied and verified within a real manufacturing company in order to assist the Management Board in making projections about future actions regarding an increase in SD level.

Keywords: sustainable development; assessing the sustainable development; manufacturing company; fuzzy rules for a decision-tree (DT) based model; a case study

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1. Introduction

The importance of sustainable manufacturing (SM) is continuously increasing, as a solution to the scarcity of resources, the global willingness to reduce CO_2 emissions, and customer attraction to environmentally friendly products [1]. In accordance with this, all the emerging technologies should be exploited either to achieve this aim or to embed sustainability in design. Moreover, the goal of SM is to gain a competitive advantage, thanks to the balance between environmental, social, and economic dimensions within a company [2]. In order to achieve the status of SM, the analysis of the level of the sustainable development (SD) of a manufacturing company should be provided [3].

The concept of SD has become a key factor in the strategy of manufacturing enterprises. The use of SD assessment tools, in practice, also encounters many methodological problems. The literature on the subject presents many tools for assessing SD, but none of them offer an integrated or comprehensive assessment of results in this area [4]. In the publication [5] for assessing sustainability in Multitier, Supply Chains (MtSCs) a hybrid approach, consisting of an empirical study and the fuzzy expert system, was used. A different approach to assessing SD can be found in the publication [6] where the leveraging, multi-Echelon, Bayesian Network is applied.

The paper of Azapagic et al. [7] indicates the application of MCDA methods (Multicriteria decision analysis) in the energy sector to design sustainable production plants and develop strategies for SD. It was argued [7] that bringing about sustainable production and consumption requires a systems approach underpinned by life cycle thinking as well as an integration of economic, environmental, and social aspects. In an attempt to aid this process, a novel decision-support framework DESIRES has been developed comprising a suite of tools, including scenario analysis, life cycle costing, life cycle assessment, social sustainability assessment, system optimisation, and multi-attribute decision analysis. The aim of the article [8] is to select a sustainable supplier through the use of multi-criteria analysis. The following methods and tools were used in the article: fuzzy set theory (FST), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), and Multi-Criteria Decision Making (MCDM). In the paper was selected the right sustainable supplier concerns nine criteria and thirty sub-criteria for an automotive spare parts manufacturer. The proposed approach was implemented with a real-world case study. The proposed approach provides an accurate sustainable ranking of suppliers and a reliable solution for sustainable sourcing decisions. In turn, the authors of the paper [9] indicate that intellectual capital, occurring in the form of human capital, relational capital, and structural capital, can play a double role in improving the sustainable production of the company. It is assumed that human capital contributes to sustainable production directly and indirectly by adopting blockchain-based supply chain management. However, the results of the research work showed a slight direct impact of human capital on sustainable production, but a significant impact in the context of indirect impact. The paper [10] deals with the issues of integrating resilience and sustainability in managing production systems during COVID-19. The proposed framework for supporting the decision process has made it possible to identify the changes implemented in the company in order to mitigate the risks/effects resulting from COVID-19.

Moreover, Industry leaders use a set of Key Performance Indicators (KPIs) to measure the SD level within an organisation, while SD reports are compiled according to various international standards. However, the published reports do not compare the values obtained with the target values and the assessed KPIs are assessed without interdependencies and without a comprehensive view of the implementation of all aspects of SD.

The development of new models and methods for helping managers in making projections about future actions regarding an increase in SD level is an important research area. Our research focusses on building a model for assessing SD in a manufacturing company, based on the decision-tree approach. In order to define the research gap, Table 1 presents the overview of the related works and is discussed by pointing out the additional contribution of the research to the recent state of the research field. It enriches the main contribution of the presented paper with respect to the analysed state of the art.

Table 1. The overview of the related works.

Source	Application in SD	Decision Support Methods and Tools	Manufacturing	Limitations
[7]	Designing sustainable production plants. Strategies for SD.	Multicriteria decision analysis.	No, electricity supply.	A large number of decision-makers.
[8]	Supplier selection.	Fuzzy set theory (FST); Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	No.	Lack of interdependencies among criteria and sub-criteria.
[9]	Supply chain and sustainable Production.	Blockchain-driven supply chain; Partial Least Square-Multi Group Analysis	Yes, different.	Lack of comparison of the groups based on the observed heterogeneity.

Table 1. *Cont.*

Source	Application in SD	Decision Support Methods and Tools	Manufacturing	Limitations
[10]	Increased supply chain resilience to negative activities related to COVID.	Key Performance Indicators (KPIs); Plan-Do-Check-Act (PDCA cycle)	Yes, food production sector	-
Our paper	Determination of key SD indicators. Supporting and monitoring the achievement of SD goals.	Analytic Hierarchy Process (AHP); Fuzzy rules Decision Tree	Yes, metal sector	The need of selecting key SD indicators for re-testing.

This study adds to the literature in two significant ways. First, to the best of our knowledge, the study offers the first DT-based model aid in assessing the SD of a manufacturing company. Second, the study provides an empirical foundation for the assumption for the recommended action in order to enhance the SD level within a manufacturing company, the metal sector.

The use of the decision-tree approach, in SD in manufacturing enterprises, can help improve the company's performance in three aspects: environmental, social, and economic, while simultaneously supporting production process activities, along with activities dealing with product development and product durability. Besides, the usage of a decision tree provides an opportunity to save time [11]. Literature analysis shows applications decision-tree (DT) based, decision support in the SD area [12]. The work aims to evaluate the energy efficiency of the Machine Learning algorithms to identify their energy hotspots. The authors conducted a series of experiments using 27 different datasets, two decision tree algorithms, and two ensembles for classification and regression. The other paper points to research in the field of sustainable transport. Work Keyvanfar et al. [13] develops the path walkability assessment (PWA) index model which evaluates and analyses path walkability in association with the pedestrian's decision-tree-making (DTM). Jung et al. [14] investigated the predictive capabilities of various machine learning models to optimize production efficiency. This is particularly important because sustainable management in Industry 4.0 requires adapting artificial intelligence techniques. At work using several machine learning algorithms such as tree-based algorithms, regression-based algorithms, and autoencoder. The authors confirmed that machine learning models capture the complex relationship.

It is, therefore indicated that due to the need to assess SD in the context of a multi-criteria problem, tools to support SD decisions are sought. The research question that we address is, therefore, "How the SD of a manufacturing company can be monitored and how activities leading to an increase in the SD level can be planned?".

Schulte and Knuts [15] developed a tool based on risk management with a strategic sustainability perspective. The proposed approach can be used to enable strategic proactivity by exposing the potential consequences of sustainability-related decisions. Authors used the Framework for Strategic Sustainable Development, which includes a strategic perspective by explicitly including different time perspectives and by enabling backcasting thinking from a vision framed by eight basic, first-order principles for sustainability. In article [16], a technique for a Preliminary Sustainability Analysis of the Enterprise-PSAE is proposed. The PSAE makes it possible to identify "Actions for Sustainability-AS's" and evaluate their impacts on the three pillars of sustainability (economic, environmental, and social). The proposed tool is a valuable source of information in the decision-making process of engineering managers in the direction of the company's sustainability policy. Paper [17] puts forward an approach for top and middle management in manufacturing companies to build capabilities for SM by assessing their organisational sustainability readiness. This model evaluates capabilities representing manufacturers' potential in realising their desired sustainability strategy. Target users are decision-makers with top and middle management positions. Machado et al. [18] in their work present a proposal for a checklist to assess the sustainability performance of additive manufacturing adoption and exploitation. The case analysis indicates that AM processes can result in more sustainable operations, which however need to be supported by a strategy that considers the sustainability impacts in all life cycle phases.

Despite the development of solutions and tools aimed at SD, to the best of our knowledge, there is no so-called DT-based support model supporting the activities of the organization in order to increase the level of SD, which consists of five main elements: (1) Determination of SD indicators based on literature analysis, (2) Using the Analytic Hierarchy Process (AHP) method which determines the priority of the SD criteria, (3) Collecting data to determine the values of the key objectives SD, (4) Using a decision tree to build scenarios of possible actions to increase the level of SD, (5) Indicating recommended actions for continuous monitoring of progress towards reaching SD objectives. In the proposed approach, the use of the AHP method allowed for indicating the most important SD indicators, which made it possible to limit the number of queries to manufacturers on data from real companies regarding the values of SD indicators.

So, the main contributions of the work can be summarized as follows:

- The overview of the related works is presented and discussed by pointing out the additional contribution of the research to the recent state of the research field.
- The methodology for developing a model aid in assessing the level of SD of a manufacturing company based on the developed objectives and indicators of SD is proposed in this paper.
- The fuzzy rules for a decision-tree (DT) based support model was developed in collaboration with manufacturing experts.
- The presented model involves decision tree theory for the purpose of creating the recommended decisions for the Management Board in order to increase the level of SD within a manufacturing company.
- The proposed model is explained by an example of a real-life manufacturing company.

2. Materials and Methods

2.1. Analytic Hierarchy Process (AHP) Method and Decision-Tree (DT)

Due to the multi-criteria nature of SD, MCDM/A methods were used in the research. It is pointed out that, unlike classic operational research techniques, multi-criteria methods do not give “the objectively best” solutions but seek compromise solutions taking into account both the adopted criteria and the preferences of decision-makers. Preliminary research was conducted using the Analytic Hierarchy Process (AHP) and the Fuzzy Technique for Order Preference using Similarity to Ideal Solution (F-TOPSIS). This is justified by the fact that the AHP method is known as the most commonly used MCDM method in the area of SD, as it accounts for as much as 27% of applications. In turn, the F-TOPSIS method is a method that is recommended for solving complex decision-making problems based on group decision-making. In our approach, the problem of assessing and measuring the level of SD in manufacturing enterprises covers three main areas of SD characteristics of the metal sector: the production process, product durability, and product development. Therefore, the AHP method was used to build a ranking of indicators for measuring and evaluating SD. This method was chosen due to the possibility of decomposition of a complex decision problem (in our approach three analysed areas: A1, A2, A3) and the possibility of building a ranking for a finite set of variants (in our case, a ranking of indicators). A detailed justification for the choice of method can be found in our previous work [19]. It was therefore assumed that the method would be suitable for setting key objectives and indicators of SD.

The use of the decision tree (DT) is one of the most popular classification models in machine learning and data mining [20]. Trees have been a very widely used approach for classification owing to their advantages which include smooth handling of various types of features such as numerical and categorical, and the capability of capturing nonlinear and non-additive relationships between features while they remain easily interpretable [21]. A decision tree is a supervised, expressive classifier that consists of the collecting of nodes where internal nodes are testing nodes and leaf nodes are decision nodes. The key challenge, when implementing the decision tree is to discover which attributes need to be selected at each level [22]. The classic DT includes CART, C4.5, C5.0, NBTree, and the BFTree.

2.2. The Methodology for Developing a Methodology Aid Assessing a Level of SD

The methodology developed includes the five following stages:

(1) Determination of SD indicators based on literature analysis.

A review of the literature on the indicators and objectives of the SD for manufacturing companies indicates their large diversification. Our analysis of the literature allowed us to determine some niches taking into account the following aspects of SD:

- economic, including activities related to production, distribution, supply, and consumption [23]. The SD indicators in the economic aspect include, e.g., [23–27] total space, new investments, total sales, total tax paid, innovations created through supplier partnerships, energy consumption, turnover, absenteeism, return on investment, service cost, labour costs, zero customer complaints or product returns, quality, production rate/productivity, stakeholder review and participation in decision-making.
- social, which relates to human activities, including job vacancies, safety, and protection of workers and the public during production processes [23]. The SD indicators in the social aspect include, e.g., [23–28]: annual number of recordable accidents per employee, average annual training time per employee, increasing employment opportunities for the local community, green image, health and safety, and employee compensation.
- environmental, which refers to the conditions surrounding human life [23]. The SD indicators in the environmental aspect include e.g., [23–26,28,29]: material consumption, water consumption, air emissions, waste segregation, waste minimization, number of implemented ISO standards, the share of facilities using renewable energy, biodiversity, GHG emissions, recycled materials, reprocessed materials, hazardous waste, design of green products, biodegradable packaging.

The set of the presented objectives and indicators shows the need to order them in the context of manufacturing companies. Preparing such a set of quantitative objectives and indicators can be a big challenge for an organization, thus it is recommended to narrow down the set, which will significantly facilitate the practical implementation of activities for SD and their control in manufacturing companies. It was also assumed that setting key SD objectives will allow for determining the main strategic indicators in a given area and then indirect indicators, the implementation of which, in line with enterprises' priorities, will allow for an increase in the level of SD.

Based on our previous work [19], firstly, the following three areas of SD in a manufacturing company should be distinguished:

- A1: production processes involve the re-assignment of a number of resources according to market needs. This re-assignment of resources is carried out by using buildings, machines and equipment, computers, and people. In this area, the main parameters are energy and water consumption, production and labour costs, the level of pollution resulting from production, production efficiency, and the efficiency of the machinery and equipment.
- A2: product durability is primarily a need for creativity, resources, and time. An important parameter in this area is the quality that maps the use of the product. Reliability and durability are equally important parameters in this area.
- A3: product development refers to all stages of product creation, from product design to launch. An important aspect here is customer satisfaction, the environmental impact of the product as well as its price and quality, as compared to that of the competition.

(2) Using the Analytic Hierarchy Process (AHP) method which determines the priority of the SD criteria.

The use of the AHP method made it possible to examine and evaluate a set of sustainability indicators, consequently ordering them in defined areas of the SD activities typical for manufacturing enterprises. Preliminary studies provided the basis for harmonising the assessment of SD in the production environment. Therefore, in order to investigate the model aid in assessing the SD level, the SD objectives and SD indicators (Table 2) were selected by carrying out the AHP method [19]. The AHP method was applied in the following steps:

Step I: Development of a pair comparison matrix;
Step II: Calculation of weights for individual variants;
Step III: Determination of the inconsistency index ƛmax;
Step IV: Determination of the value of the compatibility factor of the CI matrix;
Step V: Determination of the value of the non-compliance factor CR.

Table 2. Adopted SD objectives and SD indicators [19].

Area	SD Objective	SD Indicators
A1-Production processes	Reduced energy consumption ($O_{pp}1$)	I_{pp1}—Energy consumption I_{pp2}—Renewable energy
	Increasing innovation ($O_{pp}2$)	I_{pp3}—Modernisation of the machinery park
	Improved quality of the process ($O_{pp}3$)	I_{pp4}—Number of complaints I_{pp5}—Number of defective products
	Reduction in generating loss ($O_{pp}4$)	I_{pp6}—Level of waste recycling (kg)
A2-Production durability	High quality of the product compared to that of the competitors ($O_{pd}1$)	I_{pd1}—Quality of product compared to that of the competitors
	The possibility of reprocessing the product ($O_{pd}2$)	I_{pd2}—Possibility of recycling products after use
	Service/repair ($O_{pd}3$)	I_{pd3}—After-sales service
A3-Development product	Customer satisfaction ($O_{dp}1$)	I_{dp1}—Customer satisfaction I_{dp2}—Client retention
	Safe working conditions ($O_{dp}2$)	I_{dp3}—Number of accidents at work per month
	Safe products and production processes ($O_{dp}3$)	I_{dp4}—Use of hazardous chemicals in the production process I_{dp5}—Use of hazardous chemicals in the product
	Climate protection ($O_{dp}4$)	I_{dp6}—Develop a climate-related risk management strategy I_{dp7}—Actions to reduce the risks associated with climate change

These steps of the AHP method were applied to three selected areas: production processes (A1), product durability (A2), and product development (A3).

The use of the AHP method served as pilot research to set key SD objectives and indicators in three areas. The evaluation of SD objectives and indicators was carried out by selected experts within manufacturing companies: namely: an owner of a manufacturing company in the metal industry and a manager. Table 2 reports information on the most important SD indicators based on the literature research results (stage 1) and the use of the AHP method according to the presented research results in our previous work [19].

(3) Collecting data to determine the values of the key objectives of SD

In order to collect data on the adopted SD objectives and indicators, data are obtained from available databases of information systems implemented in the manufacturing company and from experts.

(4) Using a decision tree to build scenarios of possible actions to increase the level of SD

In order to build a based support model, the following levels of management within a company should be adapted to translate the theoretical SD objectives and SD indicators (Table 1) into their practical location and application at different levels of the company's activities. Therefore, three types of SD indicators are assumed: Benefit (if SD indicator = Benefit, then the higher the value of the indicator, the better) or Cost (if SD indicator = Cost, the smaller the value of the indicator, the better) or not applicable, where SD indicator does not take a numeric value.

Next, fuzzy rules were built, in collaboration, therefore, with the experts selected and according to the following variables:

- Variable 1: SD Indicators (Table 1), where: $I_{pp} = \{I_{pp1}, I_{pp2}, \ldots, I_{pp6}\}$, $I_{dp} = \{I_{dp1}, I_{dp2}, I_{dp3}\}$, $I_{pd} = \{I_{pd1}, I_{pd2}, \ldots, I_{pd7}\}$.
- Variable 2: area, where: 1—Production processes, 2—Production durability, 3—Development product
- Variable 3: Level of management, where 1—Strategic, 2—Tactical, 3—Operational
- Variable 4: Indicators Type, where: 1—Cost, 2—Benefit, 3—Not applicable.
- Variable 5: Value, where the values are obtained from a company.
- Variable 6: Reference value
- Variable 7: Action, where: 1—Go to Recommended actions, 2—The indicators are at a good level. Continue activities and monitor progress.
- Variable 8: Recommended actions

The 28 fuzzy rules are defined, based on the variables according to the following scheme: if (Area = "A1 or A2 or A3") and (Indicators = "I_{pp}") and (Level = "1 or 2 or 3") and (Type of indicators = " or 2 or 3") and ("Value" < or > or = "Reference value") and (Action = "1 or 2 or 3") then (Recommended decision = "ECO and ENV and SOC") (please see Appendix A).

In order to implement the defined rules, the following projections about future actions regarding the SD level increase in three areas: economic, social, and environmental, were developed:

- RA1-ECO: Optimisation of machinery and equipment; ENV: Implementation of design for recycling to increase the use of production waste; SOC: Customer service training
- RA2-ECO: Optimisation of machinery and equipment; ENV: Implementation of design for recycling to increase the use of production waste; SOC: Customer service training
- RA3-ECO: Robotisation of manual processes; System optimisation and development; SOC: Operation training
- RA4-ECO: Introduction of daily monitoring of the course of control and technological parameters; SOC: Constant contact with the client
- RA5-ECO: Quality controls: receipt of qualitative product during production, after the end of the production process, and also in circulation trademark; ENV: Removal of non-conformities/reclassification of the product; SOC: Quarterly operator training
- RA6-ECO: Sale of post-production waste; ENV: Analysis of work organisation and production schedule to stabilise the processes; SOC: Employee education
- RA7-ECO: Customer-oriented marketing strategy; ENV = Product quality control; SOC = Employee communication training, raising customer service competences, raising employee qualifications
- RA8-ECO: Discounts for regular customers; ENV = Electronic newsletter; e-invoices; SOC = Internal incentive system
- RA9-ECO: Systematic inspections of machines and devices, Systematic inspections of fire protection systems; SOC: Increase in the frequency of training in the field of occupational safety and fire hazards, Employee involvement in creating safe working conditions, Ergonomic organisation of workstations
- RA10-ECO: Customer-oriented marketing strategy; ENV = Product quality control; SOC = Employee communication training, raising customer service competences, raising employee qualifications
- RA11-ECO: Discounts for regular customers; ENV = Electronic newsletter; e-invoices; SOC = Internal incentive system
- RA12-ECO: Systematic inspections of machines and devices, Systematic inspections of fire protection systems; SOC: Increase in the frequency of training in the field of occupational safety and fire hazards, Employee involvement in creating safe working conditions, Ergonomic organisation of workstations

- RA13,14-ENV: Hazard Assessment of Hazardous Substances, Implementation of an Internal Chemical Control System; SOC: Hazardous Substances Training
- RA15,16-ECO: Energy efficiency; ENV: Environmental risk analysis, Assessment of climate risks and opportunities in the short, medium, and long term, Systematic reporting of climate change/environmental change issues, Waste reduction, Reduction of CO_2 emissions; SOC: Promoting pro-ecological solutions.

The action scenarios developed for each indicator have been the Global Reporting Initiative (GRI), ISO 14001, and ISO 37120.

(5) Indicating recommended actions for continuous monitoring of progress towards reaching SD objectives

Finally, data collected from manufacturing should be applied in the Data Mining panel that runs the CHAID Model, where a dependent variable and qualitative and quantitative predictors are selected (in our research Statistica 13.1 was introduced). In the next step, a scenario for increasing SD in three areas can be simulated. By using the DT-based, aid support model in the assessment of SD, it is possible to monitor progress towards SD objectives in a manufacturing company.

In order to assess the level of SD, the values of individual indicators are compared with the reference values assigned to them. On the basis of the compliance level between the actual values of the benchmarks and the reference values, the level of SD in a given enterprise is assessed.

The developed recommendations for action take into account three areas of SD: social, environmental, and economic in the defined areas typical for manufacturing enterprises. Action scenarios aimed at supporting the achievement of the SD objectives are based on:

- implementation and continuous improvement of a management system in accordance with ISO 9001:2015 and ISO 14001:2015 standards,
- an analysis of customer needs and keeping up with growing customer requirements,
- a full engagement of the management and all employees in achieving the company's SD objectives,
- ensuring appropriate resources and infrastructure to achieve compliance of the offered products and services with customer expectations and legal requirements,
- educating staff in the area of SD and occupational safety and improving their competences and qualifications.

3. Research Results

The proposed methodology can be applied to any manufacturing company that has collected data on the SD indicators values. The stages presented can serve as a comprehensive overview of the assessment of the SD level. As a central point, it is important to regard the potential of the model presented, as an opportunity for action (RA) the implementation of which will guarantee the value of increasing SD levels within a company.

It is proposed that enterprises should initiate the following activities to enhance the level of SD. An overview of applying the proposed methodology is presented in Figure 1.

The methodology developed (Figure 1) includes: stage 1: defining three areas of SD, stage 2: collecting the data based on the values of the adopted SD indicators, and finally stage 3: applying a decision-tree based support model aid in assessing the SD of a manufacturing company and thus develop the activities the implementation of which will lead to an increase SD level within a company. Stage 1 of the proposed methodology is constant, which means that the defined SD objectives and indicators (Section 2) should be adopted, and their prioritization is constant. In our previous work, a detailed analysis of the literature on the subject was made, and therefore a large set of SD objectives and indicators was obtained [19]. The use of the AHP method allowed for indicating the most important SD indicators, which made it possible to limit the number of queries to manufacturers on data from real companies regarding receiving the values of SD indicators. In stage 2, it is necessary to acquire the data to obtain the values of the defined SD objectives and indicators from databases of information systems implemented in the manufacturing company and from workers. In order to build the DT-based aid support model in the assessment of SD (Stage 3) the data on the adopted SD objectives and indicators should be implemented according to developed fuzzy rules (Appendix A). The proposed methodology can be applied to all manufacturing enterprises upon completion of entering the collected data.

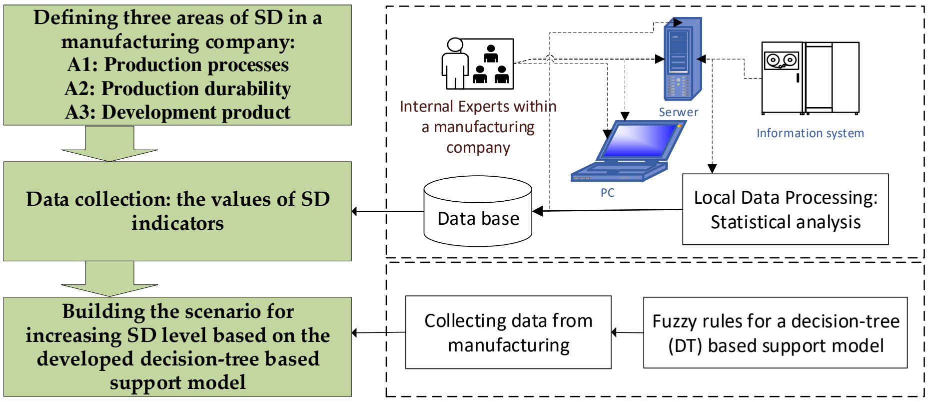

Figure 1. The methodology for applying a methodology aid in assessing a level of SD.

Our research was carried out in a Polish manufacturing company in the metal industry. The company focusses its activities on the concept of long-term SD. The company's priority is to reduce the negative impact on the natural environment and to ensure a high standard of customer service. Our methodology was applied according to the stages. The following data were collected (Table 3).

Table 3. Entered data from the real-life manufacturing company.

	Variables							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Cases	I_{pp1}	1	1	1	60,800	−10%	1	RA1
	I_{pp2}	1	1	3	No	Yes	1	RA2
	I_{pp3}	1	1	3	Yes	Yes	2	RA3
	I_{pp4}	1	1	1	0	0	2	RA4
	I_{pp5}	1	1	1	1	0	1	RA5
	I_{pp6}	1	1	2	9300	9500	1	RA6
	I_{pd1}	2	2	2	Very high	Very high	2	RA7
	I_{pd2}	2	2	3	No	Yes	1	RA8
	I_{pd3}	2	2	3	No	Yes	1	RA9
	I_{dp1}	13	1	2	Over 90%	Over 90%	2	RA10
	I_{dp2}	3	1	2	The customer comes back	The customer comes back	2	RA11
	I_{dp3}	3	1	1	0	0	2	RA12
	I_{dp4}	3	1	1	Yes	No	1	RA13
	I_{dp5}	3	1	1	No	No	1	RA13
	I_{dp6}	3	1	3	No	Yes	2	RA14
	I_{dp7}	3	1	3	No	Yes	2	RA14

During stage 3, as per our methodology, the fuzzy rules were developed (Appendix A). Therefore, it was possible to build many variants of the DT-based aid support model in the assessment of SD, depending on the settings. The decision model was applied in Statistica 13.1, along with the Data Mining panel and the CHAID Model. Figure 2 presents a decision tree built for a case study that = divided the SD indicators and assigned defined actions (RA) to them, considering the type of an SD indicator (1, 2, or 3).

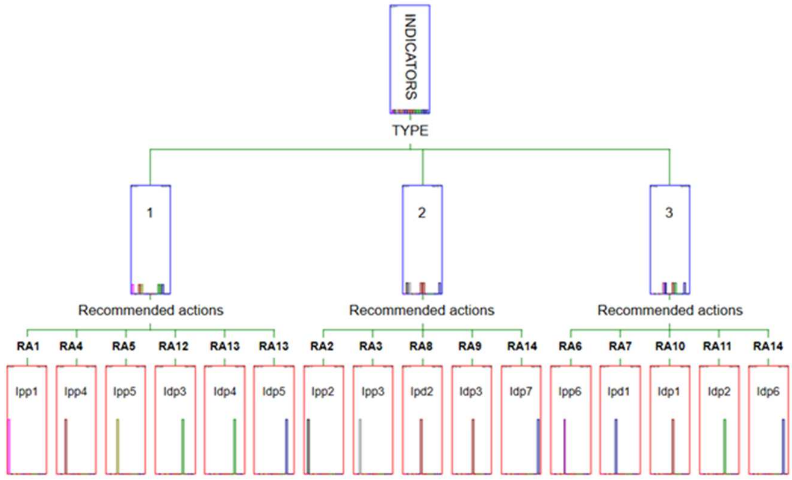

Figure 2. Decision tree graph Type-RA-Indicators.

Using DT in the learning process, a division of the adopted SD indicators into the management level was assigned. As in the example above, this also indicates recommendations for the indicator data. The allocation of SD indicators to those at the management level indicates to the management the point at which the scenario should be implemented and allows a real-time horizon to be adopted in order that implementation of the actions might be achieved (Figure 3).

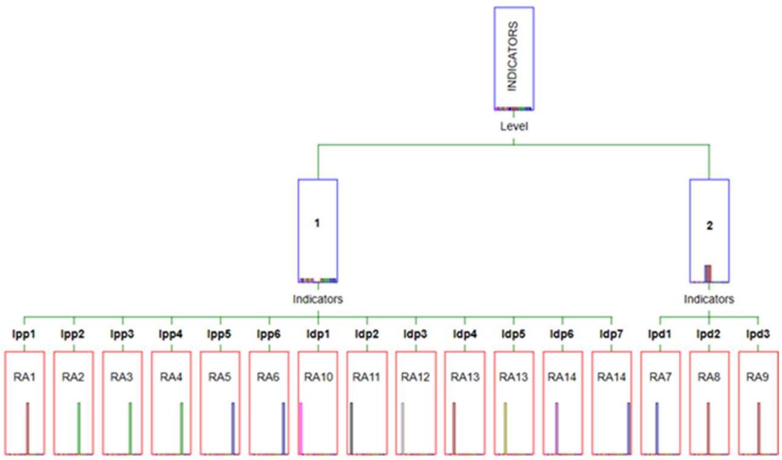

Figure 3. Decision tree graph Level-Indicators-RA.

Figure 4 shows the breakdown of indicators (1 or 2) taking into account the area of sustainable development (1, 2, or 3). Such a division allows you to identify the weakest area of sustainable development in a given organization. In the case study, the strongest area is A3, because five out of seven indicators in this area are at a good level (in line with the reference value), while the weakest area is A1, where as many as four out of six indicators require the implementation of recommended actions.

In the final stage, in order to calculate the points scored in the three studied areas, a tree was generated to determine the level of SD (Figure 5). For the examined case study, the decision-making tree indicates the need to implement recommendations for actions for 10 indicators, including:

O1: I_{pp2} (RA2), I_{pp4} (RA4), I_{pp5} (RA5), I_{pp6} (RA6),
O2: I_{dp1} (RA7), I_{dp3} (RA9),
O3: I_{pd2} (RA11), I_{pd4} (RA13), I_{pd6} (RA14), I_{pd7} (RA14).

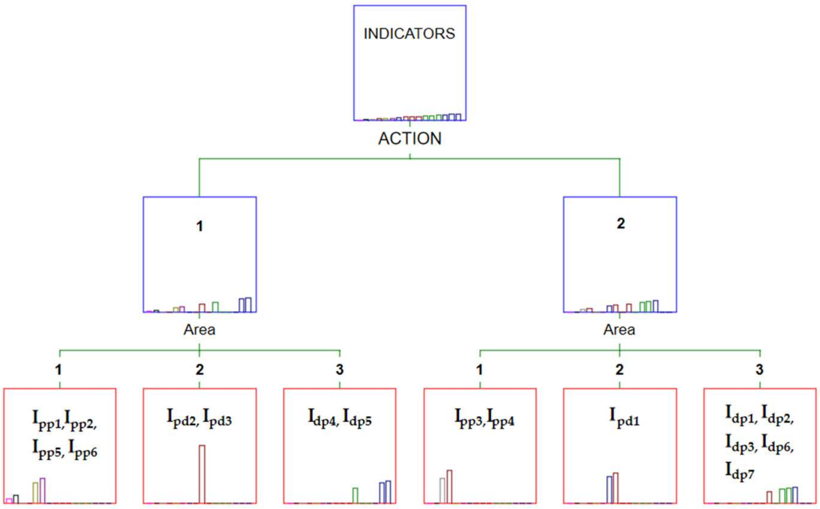

Figure 4. Decision tree graph Action-Area-Indicators.

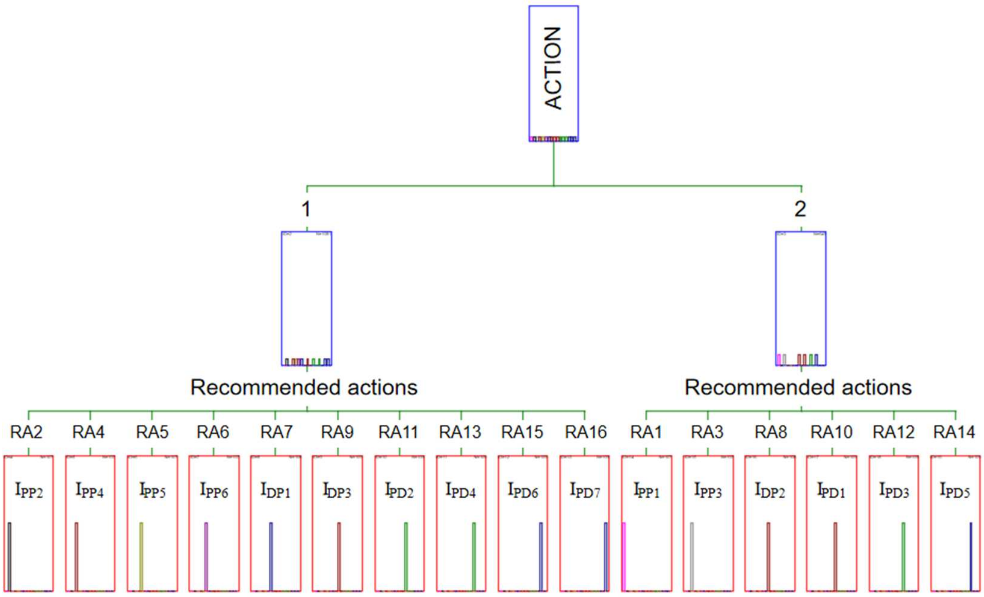

Figure 5. Decision tree graph Action-RA-Indicators.

The implementation of SD should be conducted within a specific time horizon, taking into account the financial, technical, and organizational capabilities of a given enterprise (time horizon recommended in accordance with the guidelines for individual types of management).

4. Discussion

The proposed model is a useful tool for assessing SD in an enterprise, taking into account the specificities of manufacturing companies. The tool allows the Management Board to automatically indicate recommended actions for indicators in three defined areas (A1, A2, A3). The proposed DT-based, aid support model in the assessment of SD can be used to continuously monitor progress towards SD objectives.

The literature review allowed for the analysis of available methods and tools for assessing the level of SD in manufacturing companies. One of the methods for assessing the level of SD is presented in the paper [30]. The presented method is based on the determination of key performance indicators of SD using the AHP and KPI methods. The proposed method allows us to determine the weighting of indicators and determine the level of SD in three traditional areas: environmental, economic, and social. The paper [31] presents a method for assessing the level of SD based on the integration of Lean Manufacturing tools (mapping of value streams-VSM) and sustainability indicators. It was pointed out that VSM tools allow for improve many aspects of the organization's functioning, including performance indicators, financial results, or implementation of SD assumptions. In the course of the research, SD indicators were determined using surveys carried out in manufacturing enterprises. In addition, indicators have been integrated into the VSM. Subsequently, the developed framework made it possible to assess the SD and identify possible improvements in the organization. Another concept of a framework for assessing the level of SD is presented in [32]. It was assumed that the implementation of the strategy in the area of circular economy will allow increasing the efficiency of the level of SD in the organization. The LCA tool was used in the paper. The assessment of the proposed methodology allows for determining the activities of the organization in the field of SD growth. Interesting work in the field of SD assessment is presented in the paper [26]. The authors point to the need to rank SD indicators taking into account 3BL in order to harmonize the SD assessment process in the production environment. The paper used a survey questionnaire based on the Best-Worst Scaling (BWS) approach to determine the set of indicators, followed by a multi-criteria analysis (MCDA) method.

Table 4 summarizes the main features that distinguish the proposed work from existing related works and indicates the research gap.

Table 4. Comprising the proposed approach from existing related works.

Methodology Aid in Assessing SD	Used Methods and Tools	Used in Manufacturing	Area of SD	Achieved Results of Assessment of SD	Ref.
Sustainability evaluation employing indicators	AHP; KPI	Yes	Environmental	Indication of the most important indicators the sustainability index for assessing the level of SD	[30]
Sustainability evaluation employing indicators	3BL; survey questionnaire based on Best-Worst Scaling; MCDA	Yes	Economic, Environmental, Society	A basic set of indicators constituting a basis for determining the level of SD	[26]
An effectiveness SA framework	LCA; expert opinion	Yes	Environmental	A scoring matrix of performance of different indicators relative to their absolute limits	[32]
3BL	open-ended questionnaire; VSM; experts opinons; KPI	Yes	Economic, Environmental, Society		[31]
Decision-tree based methodology aid in assessing SD	AHP Fuzzy rules Decision tree	Yes	production processes, product durability, product development	Scenarios of possible actions to increase the level of SD, Indicating recommended actions for continuous monitoring of progress towards reaching SD objectives	Our paper

To the best of our knowledge, and as already highlighted in the state-of-the-art analysis, none of the existing works supports all the presented features. Moreover, to illustrate the Managerial implications of our research results, the proposed model was applied at a real manufacturing company, in order to assist the Management Board to make projections about future actions regarding SD level increases.

In further directions of work, the authors consider the application of the concept of spherical fuzzy set (SFS) and T-spherical fuzzy set (T-SFS). In the absence of rigid evaluations of the criteria, the choice of these concepts seems justified, especially since SFSs have their importance in a situation where opinion is not only restricted to yes or no [33].

However, the categorisation of SD indicators affecting the increasing level of SD in the developed methodology has some limitations. Firstly, selecting key SD indicators for re-testing should be conducted. Secondly, our DT-based model should be implemented in other real manufacturing companies in order to indicate further scenarios of actions necessary to increase the SD level.

5. Conclusions

The methodology presented can serve as a comprehensive overview of the assessment of the SD level. As a central point, it is important to regard the potential of the DT-based support model presented, as an opportunity for action (RA) the implementation of which will guarantee the value of increasing SD levels within a company. Additionally, the practicality of the proposed approach of providing sustainable manufacturing activities monitoring was highlighted.

There are examples in the literature as described in the discussion section on the use of MCDA in similar cases. Moreover, the authors of the work [34] through the use of Multi-Criteria Decision Analysis (MCDA) attempted to combine the needs and expectations of the management with the criteria of the performance regarding production materials in the industrial sector. The results of the proposed approach indicate possible alternatives to the selection of production materials based on the objectives and assumptions of SD as well as the needs of the managerial staff. Furthermore, the importance of evaluating decisions in the management of engineering and environmental projects is illustrated in [35]. The authors in their work point to the need for multidisciplinary analysis using MCDA methods and tools. Case studies in the field of environmental management and engineering were presented based on advanced MCDA techniques, which allowed for the development of decision models. Our developed model involves DT for the purpose of creating the recommended decisions for managers in order to increase the level of SD within a manufacturing company. The suggested approach enables an automated process of evaluating indicators in three adopted SD areas (A1, A2, A3). The division into areas (A1, A2, A3) enables us to determine the area in which the companies obtain the best results in the implementation of SD, thus indicating to enterprises their weakest points (SD indicators). The breakdown of indicators by management indicates the recommended time horizon and the scope of actions to be taken according to the identified action scenarios. The DT-based, aid support model in the assessment of SD can be used to continuously monitor progress towards SD objectives.

Further research targeting the increasing SD level should be conducted on the totality of business models, building on SD aspects, especially in the context of Industry 4.0.

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Appendix A

Fuzzy rules for a decision-tree (DT) based support model:

- If (Area = "Production processes") and (Indicators = "I_{pp1}") and (Level = "Strategic") and (Type of indicators = "Cost") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Optimisation of machinery and equipment; ENV: Implementation of design for recycling to increase the use of production waste; SOC: Customer service training")
- If (Area = "Production processes") and (Indicators = "I_{pp1}") and (Level = "Strategic") and (Type of indicators = "Cost") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Production processes") and (Indicators = "I_{pp2}") and (Level = "Strategic") and (Type of indicators = "Not applicable") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Optimisation of machinery and equipment; ENV: Implementation of design for recycling to increase the use of production waste; SOC: Customer service training")
- If (Area = "Production processes") and (Indicators = "I_{pp2}") and (Level = "Strategic") and (Type of indicators = "Not applicable") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Production processes") and (Indicators = "I_{pp3}") and (Level = "Strategic") and (Type of indicators = "Not applicable ") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Robotisation of manual processes; System optimisation and development; SOC: Operation training")
- If (Area = "Production processes") and (Indicators = "I_{pp3}") and (Level = "Strategic") and (Type of indicators = "Not applicable") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Production processes") and (Indicators = "I_{pp4}") and (Level = "Strategic") and (Type of indicators = "Cost") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Introduction of daily monitoring of the course of control and technological parameters; SOC: Constant contact with the client")
- If (Area = "Production processes") and (Indicators = "I_{pp4}") and (Level = "Strategic") and (Type of indicators = "Cost") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Production processes") and (Indicators = "I_{pp5}") and (Level = "Strategic") and (Type of indicators = "Cost") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Quality controls: receipt qualitative product during production, after the end of the production process and also in circulation trademark; ENV: Removal of non-conformities/reclassification of the product; SOC: Quarterly operator training")
- If (Area = "Production processes") and (Indicators = "I_{pp5}") and (Level = "Strategic") and (Type of indicators = "Cost") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Production processes") and (Indicators = "I_{pp6}") and (Level = "Strategic") and (Type of indicators = "Benefit") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Sale of post-production waste; ENV: Analysis of work organisation and production schedule to stabilise the processes; SOC: Employee education")
- If (Area = "Production processes") and (Indicators = "I_{pp6}") and (Level = "Strategic") and (Type of indicators = "Benefit") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")

- If (Area = "Production durability") and (Indicators = "I_{pd1}") and (Level = "Strategic") and (Type of indicators = "Benefit") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Implementation of activities in accordance with the PN EN ISO 9000: 2015 standard; ENV: Use of safe, high-quality materials; SOC: Building relationship relationships with customer")
- If (Area = "Production durability") and (Indicators = "I_{pd1}") and (Level = "Tactical") and (Type of indicators = "Benefit") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Production durability") and (Indicators = "I_{pd2}") and (Level = "Tactical") and (Type of indicators = "Not applicable") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Implementation of activities in accordance with the PN EN ISO 9000: 2015 standard; ENV: Use of safe, high-quality materials; SOC: Building relationship relationships with customer")
- If (Area = "Production durability") and (Indicators = "I_{pd2}") and (Level = "Tactical") and (Type of indicators = "Not applicable") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Production durability") and (Indicators = "Ipd3") and (Level = "Tactical") and (Type of indicators = "Not applicable") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: After-sales service; ENV: Spare parts offer; SOC: Development of transparent website rules; availability of spare parts")
- If (Area = "Production durability") and (Indicators = "I_{pd3}") and (Level = "Tactical") and (Type of indicators = "Not applicable") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Development product") and (Indicators = "I_{dp1}") and (Level = "Strategic") and (Type of indicators = "Benefit") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Customer-oriented marketing strategy; ENV = Product quality control; SOC = Employee communication training, raising customer service competences, raising employee qualifications")
- If (Area = "Development product") and (Indicators = "I_{pd1}") and (Level = "Strategic") and (Type of indicators = "Benefit") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Development product") and (Indicators = "I_{dp2}") and (Level = "Strategic") and (Type of indicators = "Benefit") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Discounts for regular customers; ENV = Electronic newsletter; e-invoices; SOC = Internal incentive system")
- If (Area = "Development product") and (Indicators = "I_{pd2}") and (Level = "Strategic") and (Type of indicators = "Benefit") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Development product") and (Indicators = "I_{dp3}") and (Level = "Strategic") and (Type of indicators = "Cost") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ECO: Systematic inspections of machines and devices, Systematic inspections of fire protection systems; SOC: Increase in the frequency of training in the field of occupational safety and fire hazards, Employee involvement in creating safe working conditions, Ergonomic organisation of work stations")
- If (Area = "Development product") and (Indicators = "I_{pd3}") and (Level = "Strategic") and (Type of indicators = "Cost") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")

- If (Area = "Development product") and (Indicators = "Ipd4" and/or "I_{pd5}") and (Level = "Strategic") and (Type of indicators = "Cost") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "ENV: Hazard Assessment of Hazardous Substances, Implementation of an Internal Chemical Control System; SOC: Hazardous Substances Training")
- If (Area = "Development product") and (Indicators = "I_{pd4}" and/or "I_{pd5}") and (Level = "Strategic") and (Type of indicators = "Cost") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress")
- If (Area = "Development product") and (Indicators = "I_{pd6}" and/or "I_{pd7}") and (Level = "Strategic") and (Type of indicators = "Not applicable") and ("Value" < "Reference value") and (Action = "Go to Recommended actions") then (Recommended decision = "(ECO: Energy efficiency; ENV: Environmental risk analysis, Assessment of climate risks and opportunities in the short, medium, long term, Systematic reporting of climate change / environmental change issues, Waste reduction, Reduction of CO2 emissions; SOC: Promoting pro-ecological solutions")
- If (Area = "Development product") and (Indicators = "I_{pd6}" and/or "I_{pd7}") and (Level = "Strategic") and (Type of indicators = "Not applicable") and (Value = "Reference value") then (Action = "The indicators are at a good level. Continue activities and monitor progress").

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