Markers for Measuring the Sustainability of a Manufacturing Process

Cristian Ionel Păunescu[1,*], Mihai Hagiescu[1], and Alexandru Ștefan Velicu[2]

[1] Industrial Engineering and Robotics Doctoral School, National University of Science and Technology Politehnica, Bucharest, Romania
[2] Developer, DP Project SRL, Bucharest, Romania
Email: paunescu.cristian1996@gmail.com (C.I.P.); mhagiescu@gmail.com (M.H.); avelicu@datarecast.com (A.S.V.)
*Corresponding author
Manuscript received March 22, 2026; revised April 25, 2026; published May 27, 2026.

***Abstract*—This research paper presents a methodology that helps to increase the profitability of a classic manufacturing process through the energy indicator and the integration indicator. This solution was applied in a manufacturing company that uses distributed photovoltaic energy generation. The company produces its own products and injects energy into the grid. The prices obtained through each solution, the unit price of the manufactured product and the energy consumption per unit of product are taken into account. The results indicate that this methodology constitutes an optimal solution for the use of electricity obtained from photovoltaic systems. The profit achieved by the company is maximized. The methodology can be used by manufacturing companies by integrating components necessary for the work process into manufacturing.**

***Keywords*—measurement indicators/markers, product cost, non-renewable resources, objectives, sustainability strategy**

I. Introduction

Innovative strategies are needed to achieve and use sustainable manufacturing technologies. Processes and technologies are often understood as those capable of meeting the requirements of a product while minimizing the environmental impact. However, this minimization is a necessary but not sufficient condition for a sustainability strategy [1].

Three important components (objectives) of a sustainable manufacturing strategy can be defined, namely:

- Selecting and applying appropriate indicators to measure the sustainability of production
- Achieving a complete, transparent and repeatable assessment of the product life cycle
- Adjusting/optimizing the system to minimize environmental impact and costs based on the selected indicators/markers.

This research paper focuses on the first objective above and analyzes the development of the indicators appropriate for industrial processes. A sustainable manufacturing process must define the realization of products useful to society, through manufacturing routes with minimal environmental impact and economic efficiency.

II. Analytical Framework For Modeling and Assessing Sustainable Operation Paths

Green manufacturing processes are considered beneficial to solve the requirements of ecological products, minimizing the impact on the environment [2]. It is often observed that the analysis of the sustainability components is closely connected to the perspectives of experts and parties in the business. But the decision made must generate a sustainable path, Fig. 1. shows the path that should be followed to develop a sustainable process. The elements that support the sustainable process will be identified on the basis of relevant information about the process. Economic information = I_{Ec}, social information = I_{So}, environmental information = I_{En} and their mathematical modeling will be used for this purpose.

Besides these indicators, the society behavior must also be considered (economic, social and environmental problems, work process safety). All these components allow for a clearer identification of the sustainable development indicators of a classic production process [3, 4].

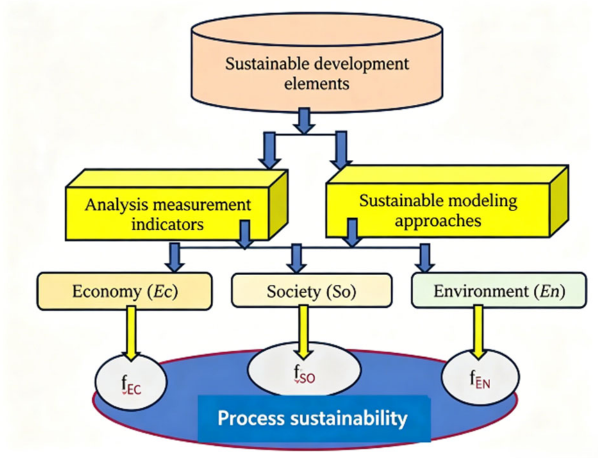

Fig. 1. Analyzing and assessing the development of a sustainable process.

When analyzing a manufacturing process, we consider a series of components/elements to generate a manufacturing strategy that defines a technological path with sustainable values.

It is very important to establish the indicators that define a manufacturing process. This will help to make suitable decisions on manufacturing, supply, technological path, jigs, fixtures and inspection gauges used, and production − sales system operation [4]. To estimate and assess the Sustainability (S) of an economic entity that uses a specific technological pathway to manufacture market-demanded products, we must identify the relevant indicators [4]. For a sustainable pathway, we start with the three characteristic pillars of sustainability, namely: Economic (Ec), social (So) and Environmental (En). Thus, sustainability (S) is defined and modeled by the following Eq。 (1) depending on the components and issues addressed in the manufacturing process.

DOI: 10.7763/IJMO.2026.V16.879

$$S = \begin{Bmatrix} E\,c \\ S\,o \\ E\,n \end{Bmatrix} = f(Ec, So, En) \tag{1}$$

Both technical and economic factors are taken into account when selecting target values for the relevant parameters of a manufacturing process. The aim is to keep an optimal level of a specific resource in the process (costs, energy requirements, raw materials, etc.) [5]. The relevant markers (minimum required indicators) for a sustainable manufacturing process can be identified at the intersection of information regarding manufacturing sustainability, social requirements, and environmental requirements, as shown in Fig. 2.

This area integrates indicators, energy-efficient solutions, reduced operating costs, recycling facilities, renewable resources, etc.

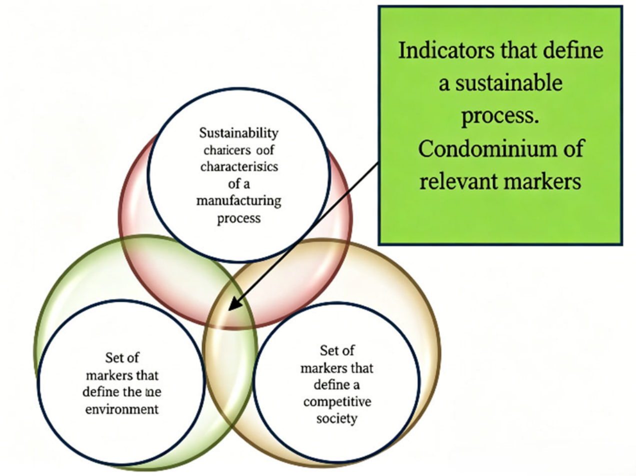

Fig. 2. Information area that shows the relevant indicators.

If we analyze only the factors or markers that have an impact on environment when assessing environmental sustainability, we see that these are not sufficient to classify a manufacturing process as sustainable. The elements that define a cost can be characterized by measurable values, like: value, weight, and the type of energy used per product [6].

Selecting meaningful indicators or markers that can clearly define a sustainable path for a product requires an analysis of its entire lifecycle, from concept to disposal [7, 8]. The careful selection of indicators or markers must take into account the objective of the production process assessment, the analysis, and the area of impact. Establishing the assessment objective—whether zonal (an area marked by known boundaries) or multi-zonal (with boundaries that can be anticipated)—will allow for the use of a methodology to select a limited number of sustainability, environmental, and social markers/indicators [9]. We can select a limited number with significant potential out of these markers or indicators. Through mathematical modeling, these ones can characterize the impact on the production process, environment (cost, non-renewable energy consumption, greenhouse gas emissions, high consumption of non-renewable resources). They also help to identify a balance between economic, work processes, social factors, and environmental protection, thereby synthesizing a sustainable technological path [10, 11] principles elements for building a mathematical model.

We are currently witnessing a rethinking of economic activity and society, in the pursuit of a better and more sustainable future. To justify this rethinking of economic reality, we must start by understanding two principles: value = labor, and value = utility. The new technological leap has led to an acceleration of beneficial effects (low-cost products − disposables, diversity, complexity, accessibility, etc.) but also to pollution, depletion of natural resources, and social dysfunction. All these components of the technological path center on the economic phenomenon of value, which shapes the dynamic state of economic activity and environment.

This study begins by analyzing the costs of raw materials, utilities, operating costs, and manufacturing technology, which together determine the value of the product.

To construct the analytical model, we will start with the following elements:

- From natural processes (P_n)
- From social processes (P_s)
- From technical potential (P_t)
- From the product, we analyze the quantity,
- Resources used in the process (Pep) and remaining
- Resources (not integrated into the product) from
- The manufacturing process (wastewater, shavings, etc.) (Pe_r)
- Information gathering: manufacturing process, environment, society
- Information processing: P_t, P_n, P_s, Pe_p, in accordance
- With the established production route and times:
- Start time t_0, production times: $t_1 \ldots t_n$.

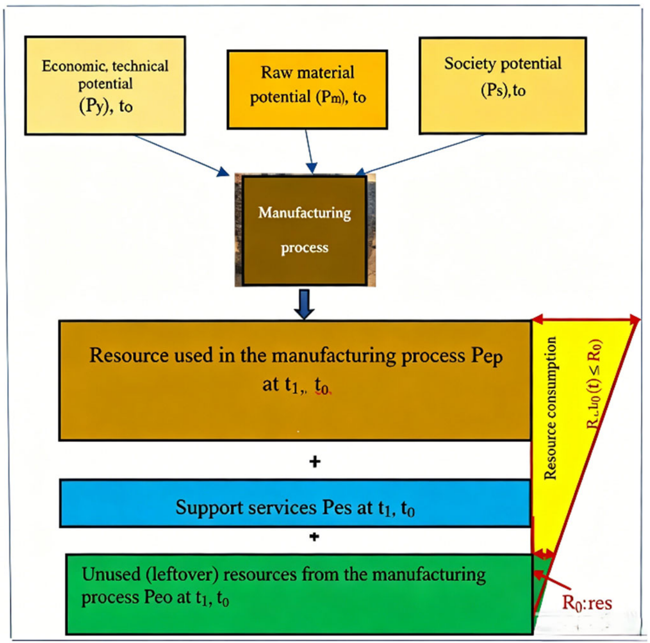

Fig. 3. Diorama of economic process analysis.

Using these elements, we can build a diorama (process model) that can simulate an ideal analysis pathway as close as possible to the actual one. We can establish a framework for making a decision that aligns the process with sustainable manufacturing practices (see Fig. 3).

The economic path, mathematically modeled, supports the understanding of the potential preserved as value in a future product. It establishes real indicators that can define sustainability, starting with information and ending with the product, a sustainable leap (the reintroduction into the productive chain of resources that remain unembedded, R_N

$_{MIN}$). The information revealed by analyzing the economic potential embedded in the product also reflects a transfer or a (minimal) dissipation of value to the environment or society (*Per*). The totality of the resources used can have maximum integration in the product (the triangle marked with yellow and noted with $R_{U\,Max}$), thus determining a sustainable process.

Taken as a whole, a manufacturing process is wasteful, and the transformation coefficient ($\eta < 1$) is always sub-unitary as a result of losses − Per (dissipated energy − heat, noxious substances, waste resulting from the semi-finished product - chips) [12].

The mathematical formulation of the transformations occurring in a manufacturing process, in accordance with the technology and profile of each economic entity, can be defined as follows:

$$Pe_p = (P_t + P_n + P_s) + Pe_s \tag{2}$$

$$P_T = Pe_p + Pe_r \tag{3}$$

where: P_T, represents total resource (energy, raw materials

- Equipment, etc.) in the time interval (t_1....t_n).
- PE_P, represents product (new structure) consisting of: energy, matter which sums up: value, utility and work (labor) in the time interval (t^1....t_n).
- Pe_r, represents losses/losses to the environment
- (pollution, noise, waste, heat, climate change), society (noise, reduction of green areas), economy (reduction of non-renewable resources) in the time interval (t_1....t_n).

If these elements, embedded in the resource unused in the product, P_{er}, are not minimized for reducing the entropic loss of the value embedded in the product, the economic entity will be penalized. So, the amount of the fine will increase the value of the product brought to market [13].

Some information that will be further called sustainability markers, will help to maintain the manufacturing route in an area that does not intersect with environmental legislation penalties.

III. Methodology for Selecting the Relevant Indicator to Ensure the Sustainability of a Conventional Manufacturing Process

We approach a research methodology that we structure in four subdivisions, necessary to determine elements capable to define a sustainable manufacturing strategy.

It should be noted that this methodology complies with the ISO14040 standards regarding the evaluation of a product through its life cycle. For analysis, we establish the evaluation objective and the scope, relevant constituents in defining some information, as shown in Fig. 4. This figure provides an overview of the process of selecting information (indicators-markers). The research aims to find suitable information for a sustainable work process. The methodology is intended to be flexible and modular. The relevant indicator is influenced by the company's capabilities, horizons of knowledge/approach, sustainability requirements addressed, market perspective, and wish for individual recognition. The selection of information will be the next step in creating a methodology for monitoring the established indicator – electrical energy from renewable sources [14]. Thus, we highlight the following steps: phases 1 and 2, which analyze the objective of the indicator, and phases 3 and 4, which analyze the scope.

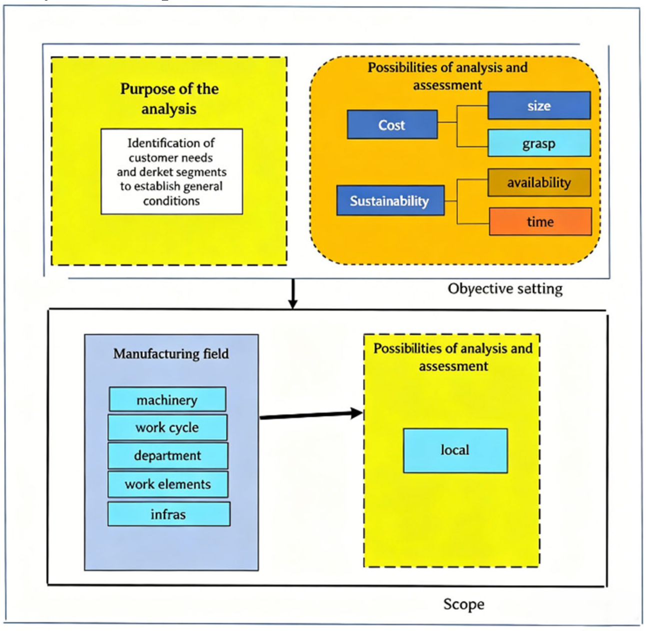

Fig. 4. Analyzing the work process; Key components.

Phase 1. Identification of information related to the manufacturing process, related to the sustainable processing objective.

Phase 2. Selection of relevant information, for making a decision to generate a sustainable path.

At the same time, we can establish as important information related to: process intensity (cost per product unit), profitability (expense efficiency at the product order level, compared to investment cost), formation of the related budget line.

Phase 3 and 4 focus on concerns related to the sustainability of the process, related to the raw material resources (non-renewable, renewable) available to the company. In this case, it is necessary to identify information that allows making a decision at the manufacturing process level, (see Table 1) [15].

Table 1. Elefant Information for a Manufacturing Process with its Own Energy Source

Phases	Relevant information	Stock	Formulations interpretation
1	Average incidence – sunny/cloudy (average impact on product cost)	total energy cost / cost of renewable energy used	environmental impact on cost per product (sun/cloudy)
2	Process efficiency % 1 (one) product (amount of energy produced / total amount of energy consumed)	renewable energy available / energy consumed	amount of energy produced / amount of energy consumed
3, 4	Energy availability index for 1 (one) product (sustainability process)	total amount of renewable energy for the order / total amount of energy consumed for the order	renewable energy cost per 1(one) order / total cost of energy consumed for 1(one) order

The analysis of decisions made within the company can take place at several levels (departments) and the information provided above can be helpful in implementing them.

Decision analysis areas follow the following levels:

- Machinery, devices, tools (regarding process technology) Energy consumption per product.
- Noxious emissions per process; environmental taxes.

The indicators/markers established at the manufacturing process level must comply with all national and international standards, as they can add relevant benchmarks in the manufacturing process. When establishing these indicators or markers, the scaling of the manufacturing line must be taken into account, in order to achieve perfect quality, minimize the use of electricity from the national grid, employ electricity from on-site sources, and eliminate activities that do not add value for the user [16]. To generate a sustainable manufacturing process, a cost CARTOGRAM will be used. This will include information on the costs of electricity supplier, the costs of electricity generated on the company's premises, the impact of environmental factors on the cost of self-generated energy, the energy efficiency of a product, on-demand energy availability index, other costs. This information will tailor the analysis of electricity costs in the manufacturing process, to determine the smallest possible batch that can be manufactured using renewable energy. The energy cost MAP will allow for an analysis of costs over time periods, and an estimate of renewable electricity costs depending on the weather forecast. This will determine an improvement in the organization of future product flows and an efficient budgeting of electricity costs, generating the sustainability of the production activity. The analysis of the energy sustainability indicator − I_{ES}, will constitute an important element in the preparation of the annual budget of revenues and expenditures, related to the product to be manufactured. This indicator is relevant as many companies implement green energy generation systems, becoming energy prosumers.

A. Mathematical Modeling of Energy Consumption Per Product

The mathematical modeling of the energy sustainability indicator, denoted by I_{ES}, plays a crucial role in allowing a company to reconcile environmental sustainability with financial performance in the context of the global energy transition. Thus, improving environmental efficiency through the use of renewable energy sources focused on sustainability can help support both climate goals and the company's economic resilience. Research into the evolution of this indicator is of particular importance in calculating the profitability of future orders, deadlines, and the need for eco-investments to maintain the sustainability of the manufacturing process [17].

To illustrate this point, we note that a supplier's billing for the electricity consumed (kWh) in a manufacturing process is linked to the equivalent CO2 emissions (global warming potential) and subject to a tax.

The energy sustainability indicator determines the formation of two development paths, as follows:

1) path *1*, defines the energy cost component of the electricity supplier, C_{FE};
2) path *2*, defines the energy cost component of the electricity prosumer, C_{PE}.

The amount of electricity consumed in the manufacturing process is made up of:

- Q_{ErP} − Amount of renewable energy – (prosumer) produces and consumes renewable energy, and
- injects the surplus into the grid), kWh;
- Q_{EnF} − Amount of energy purchased from the national electricity supplier, kWh.

The energy component cost C_{FE}, related to track 1, is defined as follows:

$$C_{FE} = Q_{EnF} / N_P \tag{4}$$

where:

- Q_{EnF} − supplier *energy* quantity;
- N_P − Number of products in 8 h (hours)

The energy component cost CPE, related to track 2, is defined as follows:

$$C_{PE} = Q_{ErP} / N_P \tag{5}$$

where:

- *QErP* − Quantity of renewable energy;
- *NP* − Number of products in 8 h

The energy sustainability indicator I_{ES} is defined as follows:

$$I_{ES} = C_{FE} / C_{PE} \tag{6}$$

By analyzing energy costs, the value stream, we will be able to define the sustainability of a manufacturing process, as follows:

if:

- I_{ES}, has a supra-unit value, the manufacturing process is sustainable.
- I_{ES}, has a *sub*-unit value, the manufacturing process is not sustainable.

By analyzing the costs of semi-finished products necessary for carrying out a sustainable activity in different fields, a decision can be made to integrate (manufacture) them within the company. This decision is effective if the process integration indices − I_{IP} are taken into account. This index argues for the sustainability of an internal manufacturing activity, to the detriment of its beneficial outsourcing to small and medium-sized companies. This sustainability indicator, generated following the analysis of a manufacturing process, helps a company to support the sustainability of the activity, reduce costs, emissions and maintain its place in the profile market.

Product integration indicator IIP is defined as follows:

$$I_{IP} = C_{FI} / C_{FE} + C_T \tag{7}$$

where:

- C_{FE}, total outsourced procurement costs
- C_T, total transport costs
- C_{FI}, internal manufacturing costs
- I_{IP}, has sub-unit value, the manufacturing process is sustainable, low costs, low emissions;
- I_{IP}, has super-unit value, the manufacturing process is not sustainable, high costs.

B. Case study

Many research papers that characterize a sustainable process place minimal emphasis on the consumption of electricity in the manufacture of the product. In this regard, a case study was conducted at the company SC SOPMET SA. This is a capital company, with over 15 years of experience in the field of underground activities and equipment, currently specializing in road and railway underpasses, using concrete pipes in the range of small and medium diameters.

The research conducted in this company, on an existing expense component in the annual budget, will lead to making an important decision related to the sustainability strategy of the classic manufacturing process. The exchange rate published by the National Bank of Romania of 5.0937 RON for one euro on 09.04.2026 will be used [18]. At the same time, the hypothesis that a conventional manufacturing process, with modifications to certain process components, will lead to sustainability is tested using the I_{ES} energy sustainability indicator. This manufacturing process will result in a net benefit to the environment, lower costs per product, and advantages for the company. Fig. 5 shows the product (reinforced concrete pipe) manufactured within the company. The production volume is 60 pipes per year. The production rate is 2 pipes in 8 h (one shift), in batches of 30 pieces. The equipment used for welding the metal reinforcement is an inverter welder (welding with consumable electrodes, with a diameter of 4 mm, model ARC 270ST Stahlwerk) [19].

The case study analyzes the changes that will occur as a result of the decision to change the following process components: pipes are no longer purchased from a specialized company; instead, the company uses its existing equipment, and the electricity used is renewable. Manufacturing is carried out as follows: reinforcement is done in the workshop and the pipe is manufactured in the yard.

(a) (b) (c)

Fig. 5. Product made by sustainable manufacturing process: (a) pipe frame, (b) vibration casting device, (c) manufactured product

The electricity requirement is produced by a photovoltaic system. It consists of monocrystalline solar panels. The panels are characterized by a conversion efficiency of 19.2% and an estimated operating life of 25 years [20]. The photovoltaic system is located on the roof of the metal fabrication workshop, with an inclination angle of 30°, south orientation. The installed power of the system is 30 kW. It was purchased with assembly, through a bank loan.

The excess energy produced will be directed as follows: primarily to a pneumatic energy storage system (which generates compressed air for equipment used in the pipe manufacturing process, such as grinders, angle grinders, etc.); the remainder is fed into the grid.

The welding machine has an electricity consumption of 5 − 6 kWh. Two welding machines are used. Welding time ≈ 5 hours per metal structure.

The case study analyzes whether the use of electricity generated by the photovoltaic system can be profitable, along with other process components. The following information is known about global solar radiation: it reaches relevant values in the hourly interval 10 − 14, (maximum in the period March − October). The company's electricity consumption, for the period: August − December 2025 was 45,620 kWh, presented monthly in Table. 2. For the analysis, the consumptions for the 2 (two) welding equipment were established, at a total value of 60 kW/ per shift (30 kWh/pipe). In this context, the amount of renewable energy used in the manufacturing process is useful for the study, because it generates the possibility of measuring the process, in order to provide that significant sustainability index.

The following information is known:

- 1 kWh of purchased electricity = 0.547 kg CO_2.
- 1 l of diesel = 2.6533 kg CO_2 [21].
- Supplier, PPC company, purchased electricity.
- 1 kWh = 1.51 lei (0.2964 Euro) [22, 23].
- Produced electricity (prosumer), 1kWh=0.7190 ei (0.1411 Euro) [18, 23].

Table 2. Consumption / Product − Solar Panels, Electricity of the Analyzed Company

No.	Month	Consumption [kWh]	Production [kWh]
1.	August	7.023	6.234
2.	September	9.124	5.905
3.	October	9.956	3.410
4.	November	10.134	1922
5.	December	8.300	1536
	Total	45.620	19.007

To calculate the energy sustainability indicator − I_{ES}, the total energy consumption profile is required. The electricity consumption for the period August − December 2025 is 45,620 kWh, equivalent to 24,954.14kg of CO_2 emissions. Table 3 presents details of the total energy consumption by different consumer subgroups and the corresponding carbon footprint.

Table 3. Details on Energy Consumption and Carbon Footprint: A Case Study

Total Electricity Consumed	**45.620 (kWh)**	**Carbon Footprint kg CO_2**
Sectors	Percentages	Amounts
Iluminat Lighting	10%	2.495,414
Pumps and Fans	25%	6.238,535
Motors	30%	7.396,2
Air Compressors	15%	3.743,121
Chiller	20%	4.990,828
Total	100%	24.954,14

Table 4. Carbon Footprint and Transportation Cost

Truck engine	**Cost per transported**	**Fuel quantity** [l]	**Number of races**	**Carbon footprint** (kg CO_2)
Diesel	478lei /4 tubes	12	15	477,594

This analysis shows that prioritizing the consumption of renewable energy for motors, compressors, and pumps can have a more positive impact on the I_{ES} energy sustainability index and the carbon footprint [24]. Future research on the storage of renewable electricity at the air compressor station will yield a better sustainability index.

At the same time, the manufacture of the pipe in the workshop will have a good impact on the cost and carbon footprint, by eliminating transportation, Table 4.

Table 2 enables the formation of a coherent basis for decision-making by analyzing all budgetary information (input/output data). Part of the renewable energy, highlighted in Table 2, will be used for welding equipment, concrete pipe forming, and compressed air finishing equipment. Using mathematical Eqs. (4−6), we can define the sustainability of a manufacturing process using the energy sustainability indicator for a pipe as follows:

$$I_{Mn} = 30 \text{ kWh} \times 1.51 \text{lei /kWh/} = 45.3 \text{ (RON)}$$
$$I_{Mr} = 30 \text{ kWh} \times 0.7190 \text{lei/kWh} = 21.57 \text{(RON)}$$
$$I_{Me} = 45.3 \text{ (lei)} / 21.57 \text{(lei)} = 2.1 \Rightarrow \text{ sustainable process}$$

To calculate the integration indicator of the I_{IP} product, the value of a purchased reinforced concrete pipe is taken into account, namely the amount of 11,250 RON excluding VAT (not including transport and loading/unloading operations) and from the company's accounting, the value of the internally manufactured pipe, 9,564 lei, excluding TVA.

Using the mathematical formulation (8), the integration indicator of the product is determined:

$$I_{IP} = 9{,}564 \text{ (RON)} / 11{,}250 \text{ (RON)} = 0.8501$$
$$\Rightarrow \text{ sustainable process } (I_{IP} < 1)$$

Mathematical Eq. (7) highlights the sustainability of the manufacturing process, given the use of renewable energy and the absence of transportation operations (which generates pollutant emissions). To provide a detailed analysis of the amounts spent and budgeted, the aforementioned indicators are analyzed. The resulting values are presented in Table 5. The analysis is performed by comparing the costs with the ones recorded in the second half of 2025.

A new variant of establishing the budget for 2026 is analyzed, using indicators presented in this paper. The data presented in Table 5 highlights the fact that the use of these indicators is effective in preparing the budget for 2026.

Table 5. Valorization of Data on Budget Expenditures for Pipe Manufacturing

No.	Expenditure groups	Budget based on history 2025	Budget based on indicators 2026	Rezultat RON	Percentage %	Cost Justification
1	Tube expenses	11,250	9,564	1.686	15%	Efficient use of resources
2	Tube transportation expenses	119.5	33.83	85,67	71.68%	Internal material transport costs
3	Electricity expenses Tube	/	21.57	21,57	100%	Use of renewable electricity
	Total	11,369.5	9,619.4	1.750,1	/	-------------

(Note:- The National Bank of Romania published a reference exchange rate of 5.0937 RON for one Euro on 09.04.2026) [18]

A new approach to setting the 2026 budget is analyzed, using the indicators presented in this paper. The data presented in Table 5 demonstrate that the use of these indicators is effective in developing the 2026 budget.

The cost of manufacturing a concrete pipe in the 2026 budget is 15% lower, with a reduced carbon footprint (transport), and 100% renewable energy used in the manufacturing process. Improving the cost analysis system by means of the indicators I_{Me}, I_{IP} will eliminate unjustified manufacturing costs and generate profit for the company.

IV. Conclusion

The research study analyzed a conventional manufacturing process, during which the factors influencing the manufacturing process were identified. To determine how to make a traditional manufacturing process sustainable in a competent manner, it is important to establish meaningful sustainability indicators that allow for the comparison of similar processes and the measurement of internal improvements. This research paper developed a working model by selecting significant factors and integrating them into the manufacturing process. The analytical model developed was validated using various mathematical relationships which reflect realistic approaches in production plants for small and medium-sized companies. The mathematical formulations and the manufacturing process analysis highlight the role of renewable energy and the importance of studying the carbon footprint. This information can help the company SC SOPMET SA to improve the sustainability of the work process.

The novelty is represented by the methodology and the new determined indicators: I_{IP}, I_{ES}, minimal indicators that can characterize a sustainable economic activity.

Research into some parameters and the type of electrical energy used shows that prioritizing the factor with the poorest performance leads to the fastest improvement in sustainability. The results obtained indicate that this methodology is an optimal solution regarding the path to sustainability of a manufacturing process while maintaining profit and market share. This methodology can be applied to the budgeting process for small and medium-sized companies.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

C.I. Păunescu: content analysis, data provision, conducted the research, first draft, revision and editing, correspondence; M. Hagiescu: formal analysis, methodology, and proofreading support; A. Velicu: analysis, modeling update, revision; all authors have read and agree with the presented version of the paper.

References

[1] S. G. Maza, S. R. Flores, and Á. D. G. Delgado, "Assessment of a mass and energy-integrated gas oil hydrocracking process via water–energy–product technical indicators," *Sci*., vol. 7, no. 4, 2025.

[2] H. Zhou, J. Lu, Z. Cao, J. Shi, M. Pan, W. Li, and Q. Jiang, "Modeling and optimization of an industrial hydrocracking unit to improve the yield of diesel or kerosene," *Fuel*, vol. 90, no. 12, 2011.
[3] A. T. Gorski, "Redesigning the performance management system to ensure organizational sustainability," Ph.D. dissertation, Universitatea Lucian Blaga, Sibiu, Romania, 2025.
[4] C. R. Weiser, T. Fletcher, D. Dornfeld, and S. Horne, "Development of supply chain optimization and planning tool for environmental purposes (application field) – Applied to solar energy," in *Proc. IEEE International Symposium on Electronics and Environment*, 2008, pp. 1−6.
[5] ONU, "Sustainable development indicators: Guidelines and methodologies," 3rd ed. New York, NY, USA: Națiunile Unite, 2006.
[6] EPA, "Sustenabilitate," Washington, DC, USA: Agenția pentru Protecția Mediului din SUA, 2008.
[7] M. M. E. Halwagi, "Sustainable design through process integration: Fundamentals and applications to industrial pollution prevention, resource conservation, and profitability enhancement," Amsterdam, The Netherlands: Elsevier, 2025.
[8] S. Moll, S. Bringezu, and H. Schütz, "Resource use in European countries: An estimate of materials and waste streams in the community, including imports and exports using the instrument of material flow analysis," Wuppertal Report, 2005.
[9] J. Jeswiet and S. Kara, "Carbon emissions and CES^{Tm} in the manufacturing industry," *CIRP Annals*, vol. 57, pp. 17–20, 2008.
[10] P. Bran, Rector − ASE, Value Economy, ASE Publishing House, 2002, Bucharest.
[11] BNR, "Climate risk monitoring dashboard for the Romanian banking sector," Bucharest, Romania, 2025, http://www.bnr.ro>uploads>2026.
[12] A. Ghira, "Top sustainable development trends in 2024," Build Green, Economica.Net, 2024, Bucharest Real Estate Club.
[13] E. Yakovleva and A. Miller, "Technological sustainability of industrial enterprises in intellectual infrastructure theory framework," in P*roc. E3S Web of Conferences*, 2021, vol. 258.
[14] M. T. Ballestar, E. Camiña, Á. D. Chao, and J. T. Sellens, "Productivity and employment effects of digital complementarities," *Journal of Innovation and Knowledge*, pp. 177–190, 2020.
[15] A. Horobet, C. D. Tudor, Z. Dinca, D. G. Dumitrescu, and E.A. Stoica, "Artificial intelligence and smart manufacturing: An analysis of strategic and performance narratives," *Amfiteatru Economic*, vol. 26, no. 66, pp. 440–457, 2024.
[16] J. Pang, Y. Zhang, and F. Jiao, "The impact of the digital economy on transformation and upgrading of industrial structure: A perspective based on the poverty trap," *Sustainability*, vol. 15, no. 20, 15125, 2023.
[17] A. A. Vărzaru, C. G. Bocean, D. Simion, D. Berceanu, and M. G. Mangra, "Digital revolution, sustainability, and government revenues: A transversal analysis of how digital transformation and sustainable practices impact sustainable government revenues," *Systems*, vol. 11, no. 11, p. 546, 2023.
[18] 90% Profit Split In Pro+ & 50%. [Online]. Available: https://www.cursbnr.ro/arhiva-curs-bnr
[19] Welding Machine. [Online]. Available: https://construct.md/ro/pages/product/aparat_sudura2-in-1stahlwerkarc 270 st/
[20] Recycling solar panels and their lifespan. [Online]. Available: https://solarcenter.ro/reciclarea-panourilor-solare-si-durata-de-viata-a-acestora
[21] Document display. [Online]. Available: https://www.uoradea.ro/wp-content/uploads/2024/documente/display30623
[22] PPC electricity PPC simple. [Online]. Available: https://www.ppcenergy.ro/energie-electrica/ppc-simplu-online/
[23] [Prosumer association. [Online]. Available: https://asociatiaprosumatorilor.ro/preturi-orientative-pentru-prosumat
[24] C. Fortea, "Analytical framework for assessing sustainable economic development in Romania and sustainable development solutions," Ph.D. dissertation, Universitatea Dunărea de Jos, Galați, Romania, 2024.