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Article

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Article

Lean and Green Product Development in SMEs: A Comparative Study between Small- and Medium-Sized Brazilian and Japanese Enterprises

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Abstract: Facing the new challenges in production processes, companies should adopt lean and green practices in product development. In SMEs, the application of these practices is more complex. This work explores the maturity of lean–green methodologies in the product development process in Brazilian and Japanese SMEs. The methodology used is multicriteria, combining the analytic hierarchy process (AHP) and TOPSIS 2-tuple method, applied to four Japanese SMEs and four Brazilian SMEs in the metalworking sector. The criteria for evaluating SMEs are company flexibility, difficulties with NPD, innovation, limited resources, and personnel authority high. The TOPSIS method alternatives refer to 18 lean–green enablers. In the AHP method, the prioritisation of criteria between Japanese and Brazilian specialists presented divergences. In the Japanese context, the incidence of innovation is predominant, while in the Brazilian context, the most important is the limited resources. In the TOPSIS 2-tuple method, the results showed a higher level of maturity in lean–green methodologies in Japanese companies than in Brazilian ones. Lean practices are more evolved compared to sustainable practices in both countries. The study also addressed how open innovation adoption may contribute to innovation and NPD practices. Policymakers need to understand the heterogeneity of innovators within SMEs and how they differently innovate, developing distinct internal and external activities.

Keywords: SMEs; lean product development; green product development; multicriteria analysis; AHP; TOPSIS; multinational comparative study; open innovation



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1. Introduction

With the consumer market becoming increasingly competitive, companies cannot survive if they are not effective in the development of new products [1]. It is important that restricted resources are used well to obtain maximum profit [2].

There are social, economic, and environmental pillars that guide new product development (NPD) in a sustainable way. It is important to understand that sustainability is an iterative process, which implies several perspectives and disciplines for its application and maintenance in the medium and long term [3]. Adopting green practices helps companies on a large scale due to the benefit they can bring, mainly in obtaining a competitive advantage. However, to incorporate these practices into daily life, top management may experience great challenges and resistance due to the complexity of this methodology [4].

In view of the limited natural resources, companies must ensure that all available assets are used avoiding all types of waste. Thus, to achieve the goal of higher revenue with less waste, companies started to adopt lean practices. Lean principles are widely disseminated as a means for waste disposal, value proposition, and continuous improvement in product development [5].

Product development is not restricted to technical functionality only, but also to the balance between sustainable and lean concepts to guarantee the growth and maintenance of organisations in the market [6]. Based on lean and green principles, NPD must reduce the amount of waste in companies, aiming at better use of productive resources to increase the competitiveness of companies in the market [7]. In addition, the waste of resources can compromise the financial aspects of companies [8].

Despite the synergy between lean and green, there is a gap in the literature where most of the previous studies concentrate on individual product development with a focus on green or lean [9]. Still, current literature presents few studies on NPD in SMEs, generating questions about the product development processes that were established and formalised for large companies, and if they can be transferred appropriately to SMEs [10]. Finally, open innovation (OI) practices in SMEs have been overlooked, and there are a few studies by scholars from and in the context of developing countries [11–13] and it is also pertinent to discuss the OI role as a synergic strategy for improving lean and green practices. Therefore, the research questions are:

- RQ1: What are the main evaluation criteria for SMEs and how can they be prioritized?
- RQ2: What are the main lean–green NPD practices in SMEs and how can they be ranked?
- RQ3: How open innovation adoption may contribute to lean–green NPD practices in SMEs?

A comparative analysis between a developed country (Japan) and a developing country (Brazil) seeks to enrich the discussion. The remaining of this paper is presented as follows: in Section 2, we discuss NPD and lean–green operations in SMEs and multicriteria methods pertinent to the enablers evaluation process; Section 3 describes the evaluation method adopted; in Section 4, we present and discuss the results; and finally, in Section 5, a conclusion and further research developments are presented.

2. Theoretical Framework

2.1. New Product Development and Lean–Green Operations in SMEs

New product development (NPD) consists of a set of activities from which it is possible to express the needs of the market and customers, making use of technologies and competitive strategies. It is involved with the entire product life cycle, from the conception of the project to its disposal [10,14]. Thus, NPD is subject to the uncertainties of its nature throughout this cycle, and these need to be mitigated throughout the process [15].

The introduction of new products into the market is pure innovation [16]. This innovation is vital for the economic growth of companies, as well as for the formation of new factories and for facing new challenges [17]. However, the search for innovation may require the adoption of complementary approaches to be successful in companies [18].

In the context of SMEs, Henriques et al. [19] highlight the need to tackle the problem of a lack of skills, a factor that has been often identified as one of the major hurdles to innovation. Managers should also reinforce the support of partnerships between SMEs and R&I institutions, particularly in less developed regions.

Different management concepts have been established in commercial practice to increase competitiveness and achieve improvement in terms of cost, quality and time [14]. Among these concepts are lean and green methodologies. Lean emphasises the elimination of waste in operations that do not add value to products, while green aims at selecting materials and maximising their use, such as good practices for reuse and recycling [20]. Although few studies conciliate the practical implementation of lean and green concepts

simultaneously in NPD, both have similar interests and can be more successful if applied together [21].

Lean also defines the means to improve the optimisation of the production system [22]. Lean principles are widely disseminated and applied to eliminate waste in the value proposition and continuous improvement in the NPD process [23]. This application of lean in NPD is known as lean product development (LPD). Companies that adopt LPD seek efficiency and effectiveness in their operations. Efficiency is sought by minimising internal and external variability and reducing all forms of waste in information and production flow. Effectiveness is achieved by increasing the quality and value of the product from the customer's perspective [24].

Some lean practices that enhance NPD are simultaneous engineering, modularisation, customer and supplier involvement and design for manufacturing capacity. These practices can improve the NPD process and assist in the management of the product portfolio [5]. Nowadays, companies need to achieve their goals in NPD not only to make their processes more efficient but also to reconcile productivity with sustainable operations. Sustainable implementation involves complex decision processes that permeate the design, planning and management and should be analysed at the hierarchical levels: strategic, tactical, and operational [25]. This search for sustainable operations arose motivated by the scarcity of resources, international pressure and national bodies adopting environmental regulations [26].

There is no clear integration for Lean-green strategies. While the green perspective is more associated with the value proposition and eco-efficiency, lean emphasises organisational strategies with a focus on efficiency, longevity, and cost reduction through reuse [21].

Thus, it is both an opportunity and a necessity for a company to be green, that is, to have sustainable product development [27]. The main objectives of sustainable product design are to reduce the use and emission of resources of a product to the environment, as well as to improve socioeconomic performance throughout the product's life cycle [28].

Therefore, green product development (GPD) must include approaches to innovation, with sustainable strategies and goals aiming at the formal incorporation of environmental requirements and finally implementing sustainable and personalised tools. It must also integrate environmental aspects in project management [29]. The orientation towards sustainability can be incorporated by SMEs through the knowledge associated with the level of experience and capacity in both the strategic and operational aspects [30]. This is because SMEs differ from large companies in important aspects, such as the experience acquired with foreign companies, the capacity to support increasing production demands and the level of resources available to manage much higher operations [31]. These companies have well-defined strengths in relation to large companies, such as business dynamics, flexibility, efficiency, and speed in decision-making. On the other hand, they also present difficulties, such as marketing and financial and technological resources [32].

SMEs represent a substantial part of economic activity in terms of the number of companies and gross domestic product (GDP) in practically all countries in the world [33]. In Japan, SMEs represent about 99.7% of all companies, making up 70.2% of jobs, and their employees constitute 80% of the country's voters [34]. In Brazil, SMEs are responsible for approximately 60% of the workforce and 42% of the wage bill [35].

2.2. Multicriteria Methods

Multicriteria methods can be used to classify alternatives efficiently or list limited numbers of options for subsequent evaluation [36]. In addition, a benefit offered by these methods is that they can be applied together to obtain results with greater precision. The analytic hierarchy process (AHP) method is considered a selection method and aims to choose the presented criteria as a hierarchy. The analysis of the criteria occurs in pairs, listing which is the best between two criteria and how much better one is than the other. This method is carried out by experts on the subject by building hierarchy through the

responses, defining priorities and verifying the logical consistency [37]. The consistency ratio (CR) is determined during the data collection process [38].

The AHP is probably the best recognised and most extensively used multicriteria method for tackling multi-attribute decision-making problems in real situations, and is also easy to understand [39,40]. Thus, it is well suited to be used in practical applications [39]. AHP is maybe the simplest method for composing priorities. It involves multiplying each priority of an item by the priority of its corresponding criterion and adding over all the criteria to get the general priority of that criterion [41]. While there are some critics of AHP, as its limitation when the number of criteria increases, various examples in the literature and the daily operations of numerous governmental agencies, corporations and consulting companies demonstrate how AHP is a viable, and useful decision-making strategy [42].

TOPSIS with a 2-tuple linguistic model is an important tool that can be applied to problems in different areas for a qualitative approach, such as information retrieval [43]. The concept of linguistic variable is useful for working with situations that have a high level of complexity or that are not well enough defined to be described as quantitative expressions [44]. It is easier for the decision-makers to evaluate complex issues through linguistic terms than through numbers [36].

The 2-tuple model expands the use of indexes by adjusting the representation of the fuzzy linguistic method, including a parameter in the basic linguistic representation improving the accuracy of linguistic calculations after the back-translation and the interpretation [45,46].

A linguistic variable is denoted by a quintuple $(L, H(L), U, G, M)$ where L is the variable name; $H(L)$ (or simply H) denotes the set of L terms, i.e., the set of names linguistic value of L , each value being a fuzzy variable denoted generically by X and ranging a universe of discourse U that is associated with the base variable u ; G is a syntactic rule (which usually takes the form of a grammar) for generating the names of the values of L ; and M is a semantic rule for associating its meaning with each $L, M(X)$, which is a fuzzy subset of U [47].

Ref. [45] established the 2-tuple linguistic representation model. In this model, linguistic information is characterized by a linguistic term and a number which is (s_i, a_i) , where s_i is a linguistic label from predefined linguistic term set S and $a_i \in [-0.5, 0.5]$ is the value of symbolic translation.

Definition 1. β results from an indices aggregation of a set of labels evaluated in a linguistic term set S . $\beta \in [0, g]$, where g is the cardinality of S . Then $i = \text{round}(\beta)$ and $\alpha = \beta - i$ are two values such that $i \in [0, g]$ and $\alpha \in [-0.5, 0.5]$, then α is named a Symbolic Translation [43].

Definition 2. $S = \{s_0, s_1, \dots, s_g\}$ is a linguistic term set and $\beta \in [0, g]$ is the result of a symbolic aggregation procedure. The 2-tuple expresses the corresponding information to β that is obtained from the function below [43]:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5] \tag{1}$$

$$\Delta(\beta) = (s_i, a_i), \text{ with } \begin{cases} s_i, i = \text{round}(\beta), \\ \alpha_i = \beta - i, \alpha_i \in [-0.5, 0.5]. \end{cases} \tag{2}$$

being $\text{round}(\cdot)$ the usual round procedure and s_i has the closest index label to β and a_i is the result of the Symbolic Translation.

Definition 3. [45]: $S = \{s_0, s_1, \dots, s_g\}$ is a linguistic term set and (s_i, a_i) is a 2-tuple. Then always exists a function Δ^{-1} that can be defined from a 2-tuple (s_i, a_i) that returns its equivalent numerical value (s_i, a_i) :

$$\Delta^{-1} : S \times [-0.5, 0.5] \rightarrow [0, g], \tag{3}$$

$$\Delta^{-1} (s_i, a_i) = i + a_i = \beta. \tag{4}$$

Definition 4. [45]: $a = (s_k, a_k)$ and $b = (s_i, a_i)$ are two 2-tuples, having the following properties:

- (1) If $k < i$, thus $a < b$.
- (2) If $k = i$, then
 - If $a_k = a_i$, thus $a = b$;
 - If $a_k < a_i$, thus $a < b$;
 - If $a_k > a_i$, thus $a > b$.
- (3) There exists a negative operator: $\text{Neg} (s_i, a) = \Delta(g - (\Delta^{-1}(s_i, a)))$, where (s_i, a_i) is an arbitrary 2-tuple, $g + 1$ is the cardinality of S , $S = \{s_0, s_1, \dots, s_g\}$.

3. Evaluation Method

3.1. Criteria and Alternatives

The criteria represent the fundamental characteristics of SMEs as identified in the literature [48–50] (Table 1). This table has several aspects of SMEs summarised in a few criteria (in this case, five). This was necessary because cognitive science suggests that an individual’s working memory capacity is in the order of 7 ± 2 which implies that 5–9 criteria should be the ideal [50,51].

Table 1. Criteria and description.

Criteria		Description
C1 (+)	Flexibility	<i>Flexibility</i> is a benefit criterion since the organisation is more adaptive. Fewer layers mean easy vertical integrations and encourage team teamworking. The organisation is more adaptive and welcome changes.
C2 (–)	NPD Disability	<i>NPD Disability</i> is a cost criterion since most of the NPD activities are performed by one worker in small companies. The documentation is considered unnecessary. Likewise, it limits the usage of tools and techniques that are potentially valuable to NPD practices.
C3 (+)	Innovativeness	<i>Innovativeness</i> is clearly a benefit criterion.
C4 (–)	Limited Resources	<i>Limited Resources</i> is a cost criterion because the occurrence of innovation requires a significant amount of resources.
C5 (–)	Personnel Authority High	<i>Personnel Authority High</i> is a cost criterion since it is normal in SMEs that the top management is not technically capable and regularly may be hesitant to new ideas.

The alternatives are the lean and green enablers identified in the literature: **A1–Continuous improvement** (the way improvements occur should not be abrupt and punctual, but longitudinal and gradual) [52–54], **A2–Knowledge transfer between projects** (teams can use the accumulated experience of the best practices from previous projects to design new products) [55–57], **A3–Define value and value flow** (In NPD, successive and coordinated iterations translate into value. Flow mapping of value is a successful method applied in small businesses) [4,20,52–54,56,58,59], **A4–Dynamic eco-design and capacity tools** (design for the environment, waste disposal, and green dynamic resources) [20,60–67], **A5–Knowledge and learning** (knowledge and learning are associated to the capacity of firms to hold implicit knowledge to use in their NPD operations) [52,54,55,59], **A6–Life cycle assessment** (associates environmental issues with the products effects, comprising manufacture to final disposal) [20,68,69], **A7–Selection of materials** (results of the materials influence recycling and disposal processes in the environment) [70,71], **A8–Standardization of processes** (consists of standardising all periodic activities) [53–55], **A9–Product variety management** (consists of the standardisation of parts, modules, and subsets) [54–56], **A10–Rapid prototyping**, evaluations and tests (used to validate both the geometric problems

and the failure modes) [55,57,59], **A11–Set-based control** (in controlling the scheduled activities structured on individual responsibility, managers outline the benchmarks, while the project team have autonomy to define their workflows, estimate time of activities and provide feedback to their managers about the viability of the proposed agendas) [55,57,72], **A12–Set-based engineering** (considering multiple aspects, considers sets of projects and solutions during the development, discarding those solutions that are less effective) [55–57,72], **A13–Simultaneous engineering** (the NPD steps are executed sequentially, and the next step starts before the end of the current one) [55,56,72,73], **A14–Engineering specialization and workload levelling** (the engineers on the project team must remain in their areas of specialization) [55,57], **A15–Integration of suppliers** (suppliers are linked to the project team) [20,55,56,74], **A16–Strong project manager** (the chief engineer is responsible for defining the value) [55,56,59,74], **A17–Waste reduction** (better use of resources) [20,70], **A18–Environmental impact analysis** (analyses the materials used in the development of the product, so that there is no environmental risk when discarded at the end of their useful life) [20,70].

3.2. AHP and TOPSIS 2-Tuple

Two combined multicriteria methods were applied: AHP (phase 1) and TOPSIS 2-tuple (phase 2). These methods serve to assist in decision-making. They have generic steps, which include the choice of evaluation criteria, the alternatives, analysis, and definition of the best alternative that is the closest to the ideal [75]. In practice, the end of the evaluation is a ranking that shows the most frequent practices in the investigated SMEs.

Figure 1 presents the multicriteria phase. The AHP method determines the weights of the SME evaluation criteria and the TOPSIS 2-tuple linguistic variable method establishes the ranking of the alternatives. The top management or the person responsible for the company’s NPD evaluates how many of the listed enablers are deployed in SMEs.

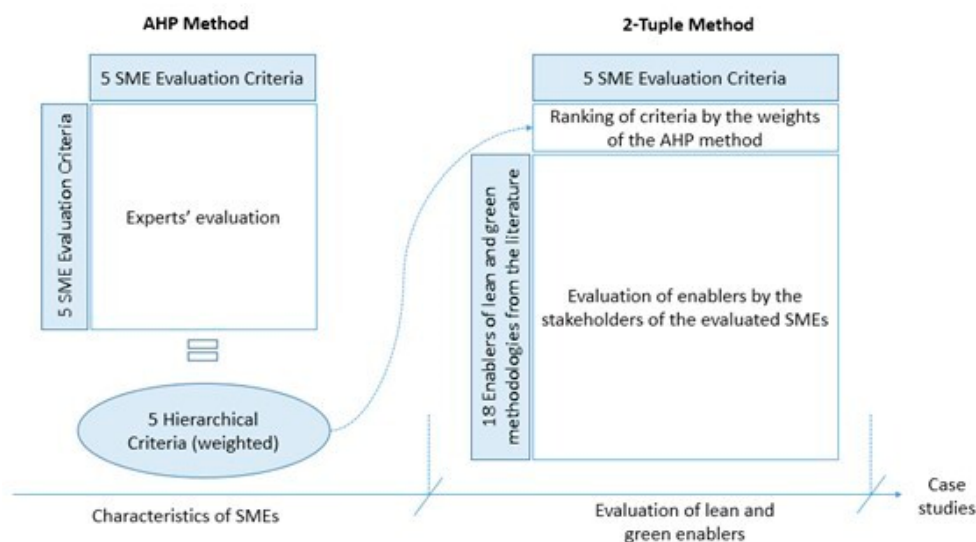


Figure 1. Evaluation model for NPD operations in SMEs.

3.2.1. AHP Method

Brazilian and Japanese experts carried out a priority analysis using the analytic hierarchy process (AHP) method. The steps for the development are presented below:

1. Decision matrix of the experts. The decision matrix in the AHP method is determined by a pairwise comparison of the n elements (criteria) based on an appropriate linguistic/numerical scale (Table 2). The decision makers (DM) assess the relative importance of any two criteria C_i and C_j by providing a comparison judgment a_{ij} , specifying by how much C_i is preferred/not preferred to C_j . If the criteria C_i is preferred to C_j then $a_{ij} > 1$, if the criteria are equally preferred, then $a_{ij} = 1$ and if C_j is preferred to C_i then a_{ij}

< 1. The a_{ij} , above the main diagonal of the decision matrix, is obtained by $n \cdot (n - 1) / 2$ comparisons. The elements of the main diagonal are equal to 1. The elements below the main diagonal are reciprocals of the values obtained above the main diagonal, i.e., $a_{ij} = 1/a_{ji}$

Table 2. Saaty’s fundamental scale.

Intensity of Importance	Value
Equal importance	1
Weak	2
Moderate importance	3
Moderate plus	4
Strong importance	5
Strong plus	6
Very strong or demonstrated importance	7
Very, very strong	8
Extreme importance	9

2. Prioritization method. The additive normalization (AN) method [76] is the procedure used in this paper to obtain the priority vector w of elements (criteria). Priority vector w is obtained by division of the elements of each column of decision matrix A by the sum of that column (i.e., to normalize the column). In the next step, then sum the resulting values in each row, and finally divide these sums by the number of elements in the row. Equations (5) and (6) describe this procedure;

$$a'_{ij} = a_{ij} / \sum_{i=j}^m a_{ij}, i, j = 1, 2, \dots, m \tag{5}$$

$$w_i = \left(\frac{1}{m}\right) \sum_{j=1}^m a_{ij}, i, j = 1, 2, \dots, m \tag{6}$$

where:

- a_{ij} = element of the decision matrix;
- a'_{ij} = normalized element of the decision matrix;
- w_i = normalized weight of criterion i .

3. Consistency of decision matrix. The consistency of the priority vector is calculated by the harmonic consistency index (HCI) proposed by Stein and Mizzi (2007). HCI is recommended as a consistency measure if the AN method is used. The HCI is calculated by Equation (7).

$$HCI = \frac{[(MH_s - n) \times (n + 1)]}{n \times (n + 1)} \tag{7}$$

where:

- HCI = harmonic consistency index;
 - $MH(s)$ = harmonic mean of the sum of the columns of the comparison matrix;
 - n = number of elements of the decision matrix.
- The division of HCI by the appropriate HRI (1061 for $n = 5$) results in the consistency ratio (CR) Equation (8).

$$CR = HCI/HRI \tag{8}$$

The rule-of-thumb generally used is that if a matrix has a CR of up to 0.10 (0.05 for $n = 3$ and 0.08 for $n = 4$) then the priority vector obtained is sufficiently close to the eigenvector matrix to be consistent [77];

4. Aggregation of the experts’ weights. The aggregation of the weights obtained by the experts from each country (Japan and Brazil) was determined by the geometric mean,

Equation (9). After the geometric mean was found, it was necessary to normalize the values, Equation (10);

$$\bar{w}_i = \sqrt[3]{w_1 \cdot w_2 \cdot w_3} \tag{9}$$

$$\bar{\bar{w}}_i = \left(\frac{1}{K}\right) \sum_{i=1}^K \bar{w}_i, i = 1, 2, \dots, K \tag{10}$$

where:

\bar{w}_i = aggregated weight of criterion I;

$\bar{\bar{w}}_i$ = aggregated and normalized weight of criterion *i*.

3.2.2. TOPSIS 2-Tuple Method

The TOPSIS 2-tuple method was used to inform the degree of applicability of each of the enablers in SMEs. The TOPSIS method proposed by Hwang and Yoon [78] was adapted by Wei [79] to use the 2-tuple model, which allows the use of linguistic variables as a way of obtaining information. This model has good results for modelling and managing uncertainty and involves carrying out the process using words [45]. It is an important tool that can be applied to problems in different areas for a qualitative approach, such as information retrieval (Herrera et al., 2008). According to dos Santos et al. [80], the appropriate language variables should be chosen to evaluate the alternatives' performance concerning the criteria. The linguistic variables and equivalent 2-tuple for the evaluation of the different alternatives are shown in Table 3.

Table 3. Linguistic variables for the ratings of alternatives.

Intensity of Importance	Value
None (N)	(S ₀ , 0)
Very low (VL)	(S ₁ , 0)
Low (L)	(S ₂ , 0)
Average (A)	(S ₃ , 0)
High (H)	(S ₄ , 0)
Very high (VH)	(S ₅ , 0)
Absolute (AB)	(S ₆ , 0)

Stakeholders (Brazil and Japan) were questioned through a structured interview based on the linguistic variables in Table 2. For the benefit criteria (C1 and C3), the questions are as follows: "Considering the current practices in your company: What is the importance of the enabler "A1" in the characteristic "C1" of the company?" For the cost criteria (C2, C4 and C5), the questions will be in the form: "Considering the current practices in your company: How important is the enabler "A1" in reducing the effects of the company's "C2" characteristic?"

A separate form was created for each of the five criteria. All forms present the criterion and description of it, as well as the enablers of lean and green methodologies and descriptions. Five forms were elaborated, comprising 18 questions in each of them. The questions were answered according to current practices within the companies.

The data collection was carried out by a researcher from the country, both in Japanese and Brazilian SMEs. In addition, the forms were developed in the language of the country in which it was applied to prevent misunderstanding of the questions.

The websites of several companies were searched. After a pre-selection, eight companies were evaluated in advance as an indication of the application of lean and green methodologies. This preliminary assessment was carried out informally before starting the questionnaires and case selection, by means of telephone and e-mail contact.

The TOPSIS 2-tuple method was adapted from Wei [79]. The steps for the development are presented below.

1. Preferences of the experts (criteria weights). After using the AHP method to assign weights to the criteria listed above, the TOPSIS 2-tuple was applied;
2. Transform the linguistic decision matrix of each of the decision makers $R_k = (r_{ij}^{(k)})_{m \times n}$, into a single decision matrix in the form of a 2-tuple linguistic variable aggregated using the Equation (11);

$$(r_{ij}, a_{ij}) = \Delta \left(\frac{1}{t} \sum_{k=1}^t \Delta^{-1} (r_{ij}^{(k)}, a_{ij}) \right), i = 1, 2, \dots, m, j = 1, 2, \dots, n. \quad (11)$$

where:

$(r_{ij}^{(k)}, a_{ij})$ = the performance of alternative (enabler) i concerning criterion j for decision maker k in the form of a 2-tuple linguistic variable;

(r_{ij}, a_{ij}) = performance of alternative (enabler) i concerning criterion j after aggregation in the form of a 2-tuple linguistic variable.

3. Check the ideal positive solution (A^*) and the ideal negative solution (A^-) and the distance between them. For this, we use Equations (12) and (13), which refer to the identification;

$$(r_j^+, a_j^+) = \max_i \{ (r_{ij}, a_{ij}) \}, j = 1, 2, \dots, n. \quad (12)$$

$$(r_j^-, a_j^-) = \min_i \{ (r_{ij}, a_{ij}) \}, j = 1, 2, \dots, n. \quad (13)$$

where:

(r_j^+, a_j^+) = ideal positive solution for criterion j in the form of a 2-tuple linguistic variable;

(r_j^-, a_j^-) = ideal negative solution for criterion j in the form of a 2-tuple linguistic variable.

4. In this stage, the distances of alternative (enabler) i are calculated concerning the ideal positive solution and the ideal negative solution of each of the criteria j , using Equations (14) and (15);

$$(\delta_i^+, n_i^+) = \Delta \left(\sum_{j=0}^n | \Delta^{-1} (r_{ij}, a_{ij}) - \Delta^{-1} (r_j^+, a_j^+) | w_j \right) \quad (14)$$

$$(\delta_i^-, n_i^-) = \Delta \left(\sum_{j=0}^n | \Delta^{-1} (r_{ij}, a_{ij}) - \Delta^{-1} (r_j^-, a_j^-) | w_j \right) \quad (15)$$

where:

(δ_i^+, n_i^+) = total distance of the alternative (enabler) i concerning the ideal positive solution of each of the criteria j in the form of linguistic variable 2-tuple;

(δ_i^-, n_i^-) = total distance of the alternative (enabler) i concerning the ideal negative solution of each of the criteria j in the form of linguistic variable 2-tuple.

5. Calculate the closeness index with the ideal solution of alternative (enabler) i using Equation (16).

$$CC_i = \frac{\Delta^{-1}(\delta_i^-, n_i^-)}{\Delta^{-1}(\delta_i^+, n_i^+) + \Delta^{-1}(\delta_i^-, n_i^-)}, i = 1, 2, \dots, m. \quad (16)$$

where:

CC_i = closeness index with the ideal solution of alternative (enabler) i in the form of a real number (0–1).

The higher the real number of the alternative (enabler) i , the better the classification of that alternative (enabler). Finally, all 18 lean and green enablers in SMEs are classified in order of closeness index.

3.3. Case Selection and Comparative Study

Comparative studies occupy a prominent place in scientific research, providing a structured analysis of the whole being evaluated. They assist in the diagnosis of social problems, in the performance of public policies, and at the same time serve as a reference parameter and source of legitimation. The starting point is to establish empirical relationships between two or more variables, keeping all the others constant. Even though in many cases it is more associated with the humanities, comparative studies are the basis for several studies, including statistical analyses with quantitative data [81].

Brazil and Japan, each of the countries represent different scenarios. Analysing adherence of lean–green methodologies in both allows the observation of improvement points and the degree of formalization of NPD in the SMEs of these countries. For a valid comparison, the selected companies meet the same requirements. All companies are classified as SMEs, operate in NPD of the metalworking sector, and use potentially lean and green methodologies in their processes. These companies were previously evaluated according to a list of companies belonging to the networking of the Brazilian and Japanese collaborators of this research.

Brazil is one of the BRICS members, which highlights its importance in the global scenario, as these countries are considered fundamental for future global economic development [82]. In addition, SMEs in BRICS are considered more likely to adhere to the development of sustainable and lean operations [83].

Japan is a country of prominence among developed countries. SMEs in Japan are known as a model of economic growth, as they present excellent results in that country's economy. Their production and management systems were regarded as highly efficient and are considered a reason for testing to be transferred to other regions in Asia as a model of success and productivity [84].

The comparison between the two scenarios reports both the differences and the similarities of the countries studied. To this end, the responses of the structured research were evaluated and compared on a case-by-case basis, with the aim of debating which enablers are most used in SMEs and which lessons learned from Japanese companies can help Brazilian SMEs to improve the NPD process and increase the level of application and maturity of lean and green methodologies. This is an important practical implication of this research.

We applied five main steps proposed by Walk [85]:

- Establishment of a referential frame, which means finding the context in which the scenarios are compared. In this study, the frame of reference established was the product development sector within the studied SMEs;
- List of the reasons for carrying out the comparison, justifying the scenarios. Brazil and Japan were selected due to the influence that both present in the world economy, Brazil representing the context of a developing country and Japan representing that of a developed country. This choice is supported by the partnership agreement existing between the two countries, which guarantees friendly concessions between SMEs and can be an essential factor for the research [86];
- Identification of a thesis before performing the comparison. There was an expectation that Japanese companies would show superior maturity in the application lean–green enablers;
- An organizational scheme, that is, the way in which the results should appear: point by point or text by text. In this study, the text-by-text schematic was used, where everything is discussed in one context and then discussed from the other perspective. Then, the context is discussed under the thesis initially elaborated, creating a link between them, which can be achieved in the presentation of the results.

4. Results and Discussion

Data collection with experts and companies’ managers occurred between October 2020 and March 2021.

4.1. Phase 1 Results—AHP Method

The qualifications of the experts can be seen in Table 4. Experts reside in different regions in their countries, and then evaluate the country as a whole and not based only on a specific region. According to their backgrounds, they assessed which characteristics are most important or determinant in the SMEs’ growth.

Table 4. Experts and the descriptions of their skills and qualifications.

Country	Experts	Skills and Qualifications
Japan	E1	Area director of a government institution (SME organization).
	E2	Banker with several years of experience with local SMEs, now CEO of a midsize construction company.
	E3	CEO of a small- to medium-sized manufacturer in Japan with several years of experience.
Brazil	E4	Technical analyst at SEBRAE (Brazilian Micro and Small Enterprises Support Service) working in programs and projects for SMEs.
	E5	Academic professor. Strategic management researcher on small- and medium-sized companies.
	E6	Works in companies and is a professor. Accountant focused on business administration and market competitiveness.

For Japanese specialists, the most relevant criterion for SMEs is *innovativeness* (C3) in production processes, where individual and collective creativity is encouraged by management. Secondly, comes *flexibility* (C1) of the companies to adapt to the changes imposed by the market, to the few levels of management, to the top management close to the employees and to the low resistance to environmental change. In third place, we have *personnel authority high* (C5), which states that the manager ends up performing functions of which he does not present the required knowledge. *Limited resources* (C4) comes in fourth, a topic that addresses resources regarding time, labour (people) and finance. As a developed country, it was not a surprise that the lowest-ranked criterium is *NPD difficulty* (C2), a characteristic related to the complexities faced by companies in developing new products and formalizing their NPD process.

The awareness about *innovativeness* (C3) is coherent with previous studies. Most countries in the Asia–Pacific Economic Cooperation (APEC region) as Japan have now adopted competition laws. The more competition, the better—especially for SMEs. Efficient competition laws, measured by a range of characteristics commonly associated with competition law and policy rankings, may actually hurt trade and growth [87]. Table 5 shows the Japanese specialists’ responses.

Table 5. Criteria weights (AHP method) from Japanese experts (Ei).

Criteria	E2	E2	E3	Aggregated Criteria Weights	Ranking
C1–Flexibility	0.446	0.079	0.148	0.196	2
C2–NPD Difficulty	0.091	0.041	0.068	0.072	5
C3–Innovativeness	0.219	0.514	0.515	0.438	1
C4–Limited Resources	0.091	0.248	0.047	0.115	4
C5–Personnel Authority High	0.153	0.118	0.221	0.179	3
Consistency Ratio (RC < 0.10)	0.008	0.038	0.028	-	-

The Brazilian perspective is more homogenous (Table 6). Although in first, *NPD difficulty* (C2) is slightly higher than *flexibility* (C1), *limited resources* (C4), and *innovativeness* (C3). In last, *personnel authority high* (C5) is clearly less significant. This is coherent with a developing country scenario, as companies in Brazil tend to be both less competitive and internationalised than in Japan. The World Trade Organisation (WTO) estimates that SMEs in developing countries are 70% less productive than large companies [88].

Table 6. Criteria weights (AHP method) from Brazilian experts (Ei).

Criteria	E2	E2	E3	Aggregated Criteria Weights	Ranking
C1–Flexibility	0.192	0.088	0.264	0.208	2
C2–NPD Difficulty	0.220	0.265	0.183	0.278	1
C3–Innovativeness	0.258	0.181	0.070	0.187	4
C4–Limited Resources	0.289	0.416	0.035	0.204	3
C5–Personnel Authority High	0.041	0.049	0.448	0.122	5
Consistency Ratio (RC < 0.10)	0.024	0.093	0.052	-	-

4.2. Phase 2 Results—TOPSIS 2-Tuple Method

General information about the eight investigated SMEs can be seen in Table 7.

Table 7. Selected Japanese and Brazilian SMEs.

Country	Enterprises	Business Area of Enterprise
Japan	SME1	Metal chain manufacturer
	SME2	Mechatronics equipment manufacturer
	SME3	Manufacturer of copper and metal materials
	SME4	Nanoscale turning enterprise with precision
Brazil	SME5	Manufacturer of agricultural implements and road equipment
	SME6	Manufacturer of office equipment and supplies, consolidated in the automation and manufacturing segments
	SME7	Manufacturer of industrial equipment, projects for feed factories, industrial maintenance, process engineering
	SME8	Metal structures development enterprise, focusing on metal and precast pavilions

From a general perspective, the application of lean and green methodologies is well balanced in Japanese companies, with good adherence rates. The mean of the responses (four SMEs) was from high to very high importance and adherence of the enablers in the daily activities. The executed TOPSIS 2-tuple method shows the rank of the most applied enablers (Table 8).

Table 8. TOPSIS 2-tuple closeness index from Japanese enterprises.

Alternatives	Lean and Green Enablersx	TOPSIS 2-Tuple Closeness Index	Ranking
A16	Strong project manager	0.941	1
A1	Continuous improvement	0.658	2
A10	Rapid prototyping, evaluations and tests	0.653	3
A5	Knowledge and learning	0.564	4
A9	Product variety management	0.536	5
A2	Knowledge transfer between projects	0.507	6
A3	Define value and value stream	0.447	7

Table 8. *Cont.*

Alternatives	Lean and Green Enablersx	TOPSIS 2-Tuple Closeness Index	Ranking
A11	Set-based control	0.345	8
A12	Set-based engineering	0.331	9
A15	Supplier integration	0.317	10
A13	Simultaneous engineering	0.302	11
A14	Engineering specialization and workload levelling	0.275	12
A4	Dynamic eco-design and capacity tools	0.250	13
A7	Material selection	0.159	14
A8	Standardization of processes	0.157	15
A18	Analysis of environmental impacts	0.032	16
A6	Life cycle assessment	0.029	17
A17	Waste reduction	0.000	18

In general, the top management and those responsible for NPD in Japan elected the strong project manager (A16) as the main enabler, which refers to the chief engineer responsible for defining the value and representing the voice of customers (VoC) at all stages of the development process. Second, we have continuous improvement (A1), which is one of the best-known enablers of the lean methodology that seeks gradual and constant improvements. It is worth mentioning that A16 and A1 refer directly to the Japanese roots of lean manufacturing, with the massive use of VoC-related tools such as QFD, as well as the adoption of total quality management. QFD is naturally highly disseminated in Japan by, for example, the Japan Standards Association, Central Japan Quality Control Organisation, and the Union of Japanese Scientists and Engineers [89].

Next is rapid prototyping, evaluations and tests (A10), which encourages the use of technologies to carry out tests on products before their launch, aiming to correct flaws and analyse their acceptance in the consumer market.

In contrast, there are three green enablers presenting the least adherence to daily practices: environmental impact analysis (A18), which concerns the analysis carried out during the product design phase so that the products do not negatively impact the environment, leading to early degradation; life cycle assessment (A6), which concerns the analysis of the product’s useful life, from its conception to disposal when it is no longer useful; waste reduction (A17), which refers to the use of less polluting materials and more sustainable projects which do not harm the environment. These three enablers have several shared characteristics. This includes analysing how the product will be manufactured, how it will be disposed of and how to produce it to generate less waste as possible.

The mean of the responses implies that Brazilian companies are in a medium to high level of adherence to lean–green practices. According to the input data and applying TOPSIS 2-tuple, the ranking of lean and green enablers can be analysed in Table 9.

The main enabler in Brazilian companies is knowledge transfer between projects (A2), which is linked to the lean methodology and involves using the accumulated experience of the best practices to design new products. Then comes waste reduction (A17), which consists of the best use of resources, aiming at the environmental preservation. Next, we see continuous improvement (A1), in the same position as in the Japanese context.

Table 9. TOPSIS 2-tuple closeness index from Brazilian enterprises.

Alternatives	Lean and Green Enablers	TOPSIS 2-Tuple Closeness Index	Ranking
A2	Knowledge transfer between projects	0.966	1
A17	Waste reduction	0.823	2
A1	Continuous improvement	0.804	3
A5	Knowledge and learning	0.753	4
A7	Material selection	0.739	5
A9	Product variety management	0.632	6
A10	Rapid prototyping, evaluations and tests	0.602	7
A8	Standardization of processes	0.598	8
A13	Simultaneous engineering	0.554	9
A16	Strong project manager	0.533	10
A14	Engineering specialization and workload levelling	0.508	11
A15	Supplier integration	0.446	12
A3	Define value and value stream	0.425	13
A12	Set-based engineering	0.416	14
A11	Set-based control	0.340	15
A18	Analysis of environmental impacts	0.140	16
A6	Life cycle assessment	0.130	17
A4	Dynamic eco-design and capacity tools	0.048	18

Also aligned with the Japanese context, the low-ranked enablers in Brazilian companies are those related to the green perspective: environmental impact analysis (A18), which refers to the required analysis during the conception of the product to verify that it does not present any harm to the environment, both during its useful life and after being discarded; life cycle assessment (A6), which meets the needs of enabler A18; and dynamic eco-design and capacity tools (A4), which refers to the use of eco-design tools that facilitate the integration of environmental needs in the NPD process.

4.3. Comparative Analysis and Open Innovation Contribution for NPD in SMEs

Brazilian specialists attributed similar weights among the established criteria related to the characteristics of SMEs (AHP step), while Japanese experts showed a greater emphasis on criterion innovativeness (C3) (Figure 2).

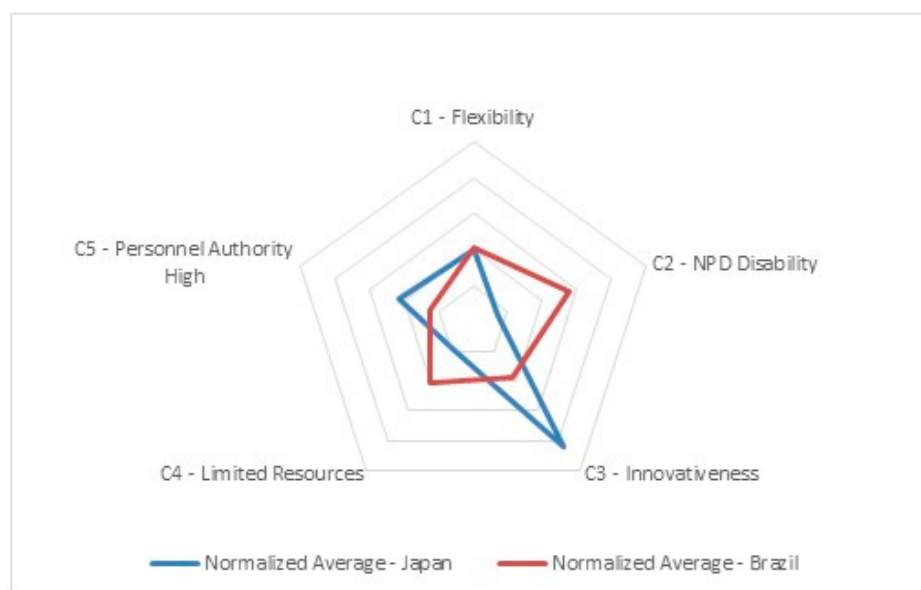


Figure 2. Comparison of the weights assigned to the criteria in the AHP method.

In general, Brazilian SMEs have a lower level of adherence to the lean–green enablers than Japanese companies. During the evaluations, enablers were found as “low”, “very low”, or in specific cases, “no” importance of the enabler in the company’s daily practices. It is also possible to verify that the lean enablers have more applicability than the green enablers in both contexts, with responses “none” or “very low”.

Therefore, the sustainable perspective is a point with high potential for improvement. Although the Japanese context studied is more mature, there is still a lot of opportunity for progress. This stems from the fact that Japanese companies, despite having more evolved R&D sectors than SMEs in developing countries, still find a gap in the innovations proposed for NPD [90]. In addition, Japanese SMEs also face financial problems with banks that make it difficult to release loans, in addition to the fact that taxes for these types of companies are high [33,34].

The role of an SME is to act as a key driver for economic growth, an agent of change, and a pioneer in saving the environment. Sustainability in SMEs is oriented towards business governance, capital support, improving human resource capacity, competitiveness and the marketing of business products in a sustainable way [91]. SMEs are more effective when they use open innovation practices to introduce new products on the market and open innovation models (OIM) favour the innovativeness in SMEs [92,93]. OI may benefit SMEs by sharing innovation-related risks, but implementing an OI strategy can present numerous challenges [94]. To be more involved with other companies for technology or NPD, SMEs should understand the potential disadvantages of OI, such as expensive and slow, long-lasting processes. Some authors claim that SMEs depend more on OI than large businesses. This occurs particularly in the commercialisation function. Considering SMEs frequently suffer of limited resources and time for networking, they have to retain their existent networks manageable [12,95].

Companies in an OI context can exchange ideas using channels external of their existing businesses to create value for the organisations. The OI model presents the limit within a company and its nearby environment that is more permeable, enabling innovation to occur easily within the two [96]. SMEs have to create a well-balanced level of openness. An excess might result in superfluous costs, while underemphasis can drive to losing opportunities. In SMEs, market sourcing is more desirable than science sourcing, because SMEs highlight OI commercialisation over product or technology development. OI has become more suitable for radical product development, whereas closed innovation has been more effective for incremental innovations [12].

There is a trend towards increased popularity and dissemination of OI and innovation in SMEs is becoming more open. This is coherent with the increasingly important role SMEs play in innovation. These firms often lack resources to develop and commercialise new products in-house and consequently, are more often motivated or forced to collaborate with other organisations [11,97]. The development of relations with universities and research institutions is recommended for enhancing the innovation process for manufacturing SMEs [98].

The effects of OI practices in SMEs often differ from those in large companies. SMEs are more efficient in using varied OI practices simultaneously when they introduce new products on the market, whereas this is less the case for large companies. Revenues from new products in SMEs are driven by intellectual property protection mechanisms, while large firms are benefited more from their search strategies [92]. Collaboration with customers and purchasing intellectual property rights are among the main inbound practices for SMEs' performance [99]. There is a wide variety of perspectives to measure OI activities in SMEs: external knowledge sources, internal knowledge, and collaboration; technology exploitation and technology exploration; inbound, outbound, and couple; and openness [100].

The managers' behaviour facing risks and the formalisation of an innovation approach are the most significant parameters for promoting OI in SMEs. This formalisation increases the impact of human capital and commitment to adopting OI. Open Innovation practices encourage product and process innovation, while this outcome is more prominent for outbound activities [101]. Practices such as selling out by-products contribute to firms' performance [99]. Partnership with clients and purchasing intellectual property rights are among the main inbound activities for SMEs' performance. Inbound OI activity such as trade show participation supports NPD operations [99].

In the manufacturing industry, recent studies suggest more frequency of inbound practices and strong supplier role in product design. An organisational culture that favours Open Innovation and the implementation of new PDP practices could drive more openness into design [102]. Based on their demands, high-tech firms in developing countries choose to implement OI into NPD at several stages with many partners. To keep their know-how, they are more closed at the experimentation stage. In the ideation phase, SMEs adopt inbound practices for basic research as well as for customer knowledge. These companies use both inbound and outbound OI during the manufacturing and commercialisation [103].

Policymakers should understand the heterogeneity of innovators among SMEs and how they promote innovation, developing different activities. Product and process innovation requires different initiatives. The specific internal and external activities, that may be effectively adopted have crucial value for policymakers. General policies for SME towards innovation do not consider the variety of innovation typologies and their associated activities. R&D vouchers may stimulate product-oriented innovators, funding the creation of R&D departments and activities for business intelligence. On the other hand, process-oriented innovation demands equipment renewal, whereas scientific-based incentives are useless due to the low inner innovation skills [104].

5. Conclusions

A practical result of this research is identifying lean-green enablers that have the best adhesion in a binational context. The research also reports the weaknesses of the companies and where more attention is needed to raise the level of awareness regarding efficiency and sustainability. In addition, it enables the selection of the best practices adopted to replicate them in other companies in the same sector that seek to evolve their NPD processes. Finally, the study also discusses the potentialities of open innovation for sustainable NPD practices in SMEs.

Japanese companies presented a higher level of maturity than Brazilian companies. Belonging to the country where the lean methodology emerged, they should have it well applied in their activities. As lean is a catalyst for green, this would also have greater

adherence. Brazilian SMEs need to build project management more solidly and advance with the available technology towards prototyping, investing more in the design phase, and reducing costs in the production processes.

Practitioners can boost the NPD of their organisations, using the assessment results to establish a roadmap to evolve their daily practices. The proposed model may be implemented into digital platforms specific for SMEs, as these companies often demand scalable and personalised solutions.

This paper contributes to NPD management theory by offering an evaluation model based on a robust two-step MCDM approach. Although designed for NPD practices, the method may be applied in different contexts since its backbone is generic. Therefore, with the establishment of criteria and alternatives, the proposed evaluation process can provide insights into varied management and engineering topics. Furthermore, replicating this model in its core (lean–green NPD practices) in other national contexts is welcome, capturing socio-political differences in a multinational study. We strongly recommend this further investigation to improve the external validity of these findings.

The context of just eight SMEs evaluated in two countries, even using multicriterial tools, presents a limited scenario. Further research should explore these lean–green enablers through longitudinal studies, as well as surveys to analyse the relationships among the 18 alternatives. These studies should include open innovation potentialities and current OI practices in the evaluations and data collection.

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