MULTIDISCIPLINARY DIMENSIONS AND ELEMENTS OF GREEN LOGISTICS AS A BASIS FOR THE DEVELOPMENT OF A REGIONAL SUSTAINABILITY INDICATOR

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ABSTRACT

The analysis of logistics related to the core business of any company is an important task to improve corporate sustainability. More precisely, the concept of green logistics is related to corporate sustainability. In general, green logistics involves the sustainable management of tangible and intangible resources as a key activity of the products or services offered. Nevertheless, improving a company's green logistics is an extremely complicated task without adequate tools to assess the baseline and initiate the continuous improvement process. In the same sense, even if there were evaluation tools for green logistics, unidisciplinary design would imply a superficial analysis of other disciplines involved in the problem. After the literature review, no studies were found that addressed the analysis and design of public tools for evaluating green logistics in a multidisciplinary way in companies as an important element for the creation of a regional sustainability indicator. In this way, this research proposes multidisciplinary dimensions and elements of green logistics that can be applied to companies in different economic sectors. In addition, an analysis of the political, social, environmental, and managerial implications of these dimensions and elements in the design of a public instrument for the evaluation of green logistics in companies is presented. Quantitative results of the internal and external validation of the proposed dimensions and elements are also presented. Finally, these results are important for the further development of the green logistics assessment tool in the industrial sector, as well as for contributing to the body of knowledge on green logistics from a multidisciplinary perspective.

Keywords: multidisciplinary analysis, green logistics, sustainability, regional indicator, freight transport.

1 INTRODUCTION

Today, both environmentally conscious customers and government policies in various countries are putting increasing pressure on companies to adopt more sustainable and environmentally friendly practices in all aspects and dimensions related to their business models, such as logistics [1]. The above implies revolutionizing the notion of conventional logistics and leading it to the concept of sustainable or green logistics, a concept closely related to Logistics 5.0 [2], [3]. Roughly speaking, green logistics is a way to minimize the environmental impact and carbon footprint of the internal and external logistics activities (transportation, packaging, recycling, storage, etc.) of a company that offers a product or service in the local, national, and international areas.

In particular, the carbon footprint of green logistics is part of the corporate carbon footprint [4]. Considering the above, a company must develop an inventory of greenhouse gas (GHG) emissions (carbon dioxide, CO_2, being the main gas) as a first activity to calculate the carbon footprint of its logistics, for which it can rely on the ISO 14064-1 standard. In general, there are three types of CO_2 emissions at the corporate level: Scope 1 emissions, Scope 2 emissions, and Scope 3 emissions. Scope 1 emissions, or direct emissions, are those generated directly by the company, primarily using fossil fuels in machinery or vehicles,

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losses of refrigerant gases, or chemical reactions during production. Scope 2 emissions, or indirect emissions, are due to the electricity consumed and purchased from a supplier in the electricity sector and will be higher or lower depending on the amount of energy required by the company and the types of energy used, i.e., conventional energy sources (oil, natural gas, coal, etc.) or renewable energy sources (solar, geothermal, wind, etc.). Finally, Scope 3 emissions or other indirect emissions are those generated in the processes of manufacturing the products and services acquired by the company, which are the property of the company but under the control of an external agent. In this way, the traditional internal and external logistics of a company can have emissions of the three scopes mentioned above [5].

Globally, freight transportation has been estimated to be responsible for 10% of global CO2 emissions [3]. In Mexico, the National Inventory of Emissions of Greenhouse Gases and Compounds (INEGyCEI, by its acronym in Spanish) 2020 mentions that in terms of CO_2 generation, the electricity generation sector contributes 21%, the transportation sector 23%, and the industrial process sector 8% [6]. In the particular case of the state of Baja California, in Mexico, the transportation sector is responsible for 59% of greenhouse gas emissions, a very logical result due to the economic and business dynamics of the state and the lack of legal control [7]. In the specific case of corporate carbon footprints, depending on the sector and core business, transportation and logistics are responsible for a large proportion of greenhouse gases, ranging from 10% to 39%. [8]–[10]. According to the Logistics Performance Index (LPI) 2023, Mexico ranks 66th out of 139 countries analyzed worldwide, with a score of 2.9, the highest possible quality being 5. The highest score in the LPI is 4.3 for Singapore [11]. In a longitudinal analysis, Mexico has lowered its rating in the LPI, for example, in 2018, it was 51st, in 2016, it was 54th and in 2014, it was 40th. In general, according to the LPI methodology, 6 components (dimensions) of logistics are analyzed, such as customs, infrastructure, international shipping, competence and quality of logistics, tracking and tracing, and punctuality. In the context of green logistics, the LPI 2023 presents some findings, e.g., that 75% of transport companies look for environmentally friendly options when exporting to high-income countries [11]. Considering the above, it is clear that Mexico must improve the performance of its logistics processes as an important element to increase its global competitiveness. In this way, companies must contextualize themselves with the requirements and trends of innovative logistics. It is important to clarify that the LPI methodology is based on the opinion of other countries about the particular country under study; therefore, it is a report of the global perception of logistics of countries. This prevents a strict analysis of the logistics performance within a company.

This paper is structured as follows. Section 2 provides a review of the literature and details of the problem and the different approaches to it. Next, Section 3 describes the multidisciplinary elements of the proposed approach. Section 4 then presents the main results. Finally, Section 5 presents the conclusions, implications, limitations, and constraints.

2 LITERATURE REVIEW

Internationally, several studies on green logistics have been presented. In Thailand, for example, a study was conducted on the management potential of green logistics and the readiness of the auto parts industry. In general, the statistical analysis carried out consisted of the identification of factors with confirmatory factor analysis. In addition, analysis of variance (ANOVA) was used to define the relative factors affecting the development of green logistics in the auto parts industry. Eventually, the study suggested that the factors affecting the green logistics management potential and readiness of auto parts industries in Thailand are environmental operations, and internal and external green supply chain management [12]. Also in Sweden, an analysis was conducted to explore green logistics practices in freight transport and logistics. One of the findings was that customers are increasingly demanding green freight transport and generally accept moderately higher prices for green freight. The development of green logistics services is mainly driven by company stakeholders and internal initiatives, while public regulation seems to have a weak influence [13].

In addition, green logistics studies have been carried out in Spain. These studies covered several aspects, among which the introduction of various changes in the management of the fleet and the implementation of a methodology to solve vehicle routing problems while minimizing environmental criteria stand out [14]. Investigations have also been conducted in the automotive industry [15]. One of the initiatives taken to reduce the need for transportation is the introduction of third-party logistics providers (3PLs), which has not only reduced the costs but also provided other intangible benefits. This initiative has resulted in a significant reduction in environmental impact. Fortunately, there is a wide range of actions that can be taken to benefit the environment through green logistics. Some are changes that can be made quite efficiently and effectively, while others require more time and research.

Other efforts to promote green logistics include the use of environmentally friendly packaging materials. In particular, it is estimated that a single package contains up to seven types of packaging materials, such as tape, cardboard boxes, foam padding, and bubble wrap, which are common ways to protect goods during transportation. To make matters worse, much of it is plastic [16]. In fact, according to a joint report by the World Economic Forum and the Ellen MacArthur Foundation, packaging accounts for nearly one-third of all plastic production, but only 14% is recycled [17]. Therefore, packaging is a major contributor to the catastrophic global plastic waste problem, and with the promotion of e-commerce, this contribution will increase. Hence the importance of green packaging, which is increasingly being adopted by major companies. For example, UK-based Woolcool has developed a sustainable, insulated packaging option made from sheep's wool that can keep products at room temperature, chilled and frozen, and can be reused four times. Huidu Huanbao, a Chinese company, has also developed an eco-friendly recyclable packaging box that can be reused up to 14 times. In addition, Noissue Company creates personalized packaging made to order, and each product is 100% reusable, recyclable, or compostable, which is related to reverse logistics, which seeks the recycling and return of materials from the customer to the producers or suppliers [18].

Efforts have also been made to use smarter packaging to save space. For example, to combat over-packaging caused by space in individual packages, some international shipping companies have worked with design firms to create a cartoning system that selects the right size boxes for each shipment. This ensures that more boxes can be packed into each shipment, which in turn reduces the total number of shipments required, thereby reducing environmental impacts and costs. Specialized smart shipment and packaging software can also be applied to ensure that all container is fully utilized [19]–[21]. In the same sense, green supply chain planning can be promoted. Waste within a supply chain has a major impact not only on its emissions, but also on its bottom line, whether it is lost employee time due to poor warehouse layout, wasted warehouse space, or wasted inventory due to poor inventory planning [22], [23]. Current smart technologies can help reduce this type of waste and improve business logistics. However, the most obvious obstacle to a green supply chain is transportation. Considering the above, a way to reduce its impact is through route optimization. Thus, using route optimization tools can reduce the time and distance to the destination without adding excess miles, thereby reducing fuel consumption and lowering both emissions and associated costs. Furthermore, using cleaner fuels is a better way to reduce transportation emissions. In addition, many companies have been using electric vehicles for many years, some of which have about 20% of their fleets as zero-emission vehicles, intending to electrify 60% of their land fleets by 2030 [24]–[26].

Another emerging option for supporting green logistics is carbon offsetting and insertion. In its most basic form, carbon offsetting is when a company commits to a customer to plant a certain number of trees to offset the CO_2 emissions associated with their purchase. In other words, carbon offsetting involves companies contributing to external carbon offset projects to offset their carbon emissions. On the other hand, carbon insertion is a relatively new idea. It was developed as a way to address a company's carbon footprint within its supply chain. Rather than contributing to external projects that are completely outside a company's control, carbon insertion projects aim to avoid or reduce emissions that are directly related to the company. Therefore, an organization will work with others (e.g., its suppliers) in the same supply chain to implement greener and more sustainable policies and practices [27]–[29]. While it is also true that a carbon insertion plan may take longer to implement and require collaboration with other companies in the supply chain, it is undoubtedly a better alternative in the long term.

In general, green logistics is all about getting a product from one place to another with the least amount of CO_2 emissions. Nevertheless, it can also include more sustainable storage. For example, thermally insulated warehouses can save energy on heating (using the ISO-50001 standard), which reduces greenhouse gas emissions. It is also possible to consider reducing water waste, perhaps even installing a rainwater harvesting system or using the ISO-46001 standard. Undoubtedly, low-consumption LED lighting is essential as it reduces the company's carbon footprint. In addition, more efficient warehouse layout and planning (internal logistics) would save time, energy, space, and money, as well as GHG emissions. It is also worth considering the location of storage, as locating them closer to customers will reduce emissions from last-mile deliveries. If the main storage is too far from the customer, a quick solution is to introduce pop-up storage for the most popular products. There are many other ways to make storage more sustainable [30]–[32]. There are undoubtedly many more options that support green logistics, such as reducing failed deliveries, reducing and sustainably managing returns, reducing paper processes, and nearshoring, among others.

It also seeks to integrate green marketing and sustainable management in the supply chain to meet the needs of green customers by applying the 6Ps, which correspond to product, promotion, price, process, people, and presentation. By integrating green marketing and sustainable management, better performance can be achieved in companies [33]. In addition, there is research focused on analysing the impact generated when implementing green marketing strategies, measuring the level of consumer purchase intention. The purchase intention of ecological products based on eco-friendly materials and processes has been evaluated on the research framework, concluding that consumers intend to buy a green product regardless of the cost [34].

Given the above, although there are a large number of options to promote green logistics, the first step has not been considered, that is, the initial diagnosis as a starting point and baseline. In fact, after reviewing the literature, no results were found from research and development projects based on public instruments to promote and increase the green logistics level in companies. Rather, private tools and processes are used, with the understanding that this is an element of competitiveness. Furthermore, no documents were found that explicitly show and describe the dimensions of green logistics from a multidisciplinary point of view; rather, the contributions are isolated. Therefore, this literature review aims to establish a framework regarding the multidisciplinary dimensions related to green logistics, both directly and indirectly.

3 DIMENSIONS, SUB-DIMENSIONS AND MULTIDISCIPLINARY ELEMENTS

This research addresses the approach of two dimensions (D) of green logistics, which are internal (D1) and external (D2) logistics. Then, each dimension is defined considering five sub-dimensions (SD), such as infrastructure (SD1), equipment (SD2), processes (SD3), human resources (SD4), standards, norms, and certifications (SD5). In the same sense, each SD consists of several elements. Fig. 1 shows the organization of the terms mentioned as a design element of the green logistics measurement tool in companies.

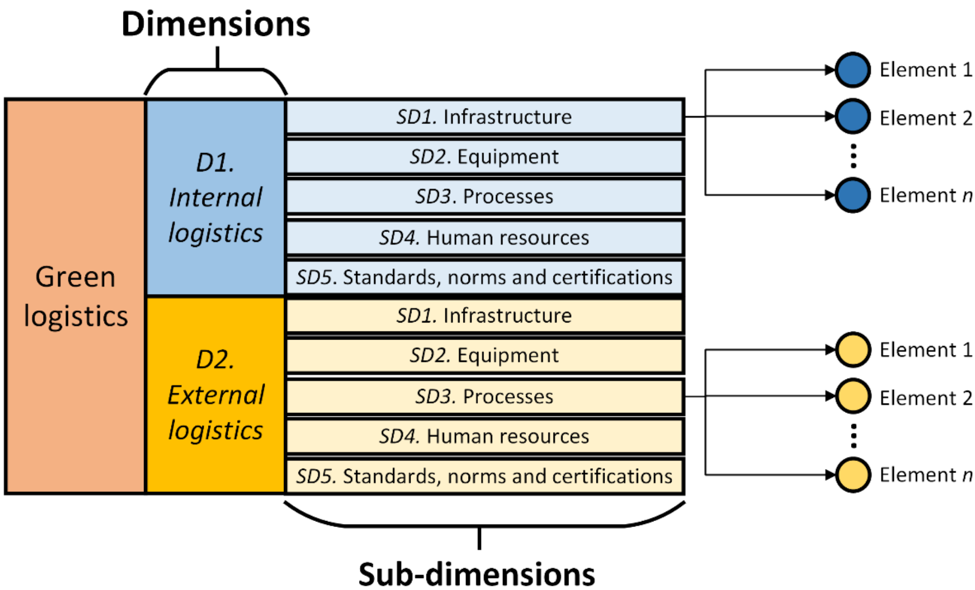

Figure 1: The structure of the instrument, from the general to the specific.

3.1 Dimension 1 (D1): Internal logistics

- ✓ Infrastructure (D1-SD1): The first sub-dimension of internal logistics is infrastructure (D1-SD1). It is important to clarify that this sub-dimension includes the set of architectural works and resources used by the company. Considering the above, the elements of this sub-dimension are Construction Materials (D1-SD1-E1), Electrical System (D1-SD1-E2), Hydraulic System (D1-SD1-E3), and Optimized Industrial Layout (D1-SD1-E4). In particular, building materials are materials used for the construction of all primary infrastructure (i.e., industrial warehouse structure) and secondary infrastructure (internal separation of industrial warehouses and production cells) where internal logistics are developed. Next, electrical and hydraulic systems refer to the design and development of those systems that serve as primary and secondary support for the logistic activities within the company. Finally, the optimized industrial layout refers to the appropriate arrangement of machines, tools, departments, and work areas to minimize the time of productive and administrative processes.
- ✓ Equipment (D1-SD2): This sub-dimension considers all the equipment and machinery related to the activities of internal logistics. In this way, the elements of this sub-dimension are, 1) the equipment related to production (D1-SD2-E1) (e.g., racks, sorters,

conveyors, and robots), 2) those related to internal mobility in industrial facilities (D1-SD2-E2) (e.g., hydraulic and electric skates, electric, LP gas and diesel forklift), 3) equipment related to administrative activities (D1-SD2-E3) (e.g., desktop, laptop, and smartphone) and, 4) those equipment and machinery related to services within the industry (D1-SD2-E4), (e.g., forklift maintenance equipment).

- ✓ Processes (D1-SD3): In general, this dimension considers the administrative, production, and information flow processes related to internal logistics. In particular, the elements of this sub-dimension are 1) input and output processes (D1-SD3-E1) of raw materials, products, and by-products, 2) interdepartmental processes (D1-SD3-E2) (e.g., the way things and information are exchanged), 3) warehouse management and internal stocks (D1-SD3-E3), 4) recycling, reduction, and waste management (D1-SD3-E4) derived from production and administrative processes, 5) internal packaging (D1-SD3-E5) (i.e., packaging of by-products or products during their stay in the warehouse), 6) internal green logistics Key performance indicators (KPIs) (D1-SD3-E6) (i.e., the existence of quantitative information organized into parameters specific to green logistics), and 7) Life Cycle Analysis (LCA) of products, processes, and services (D1-SD3-E7).
- ✓ Human Resources (D1-SD4): This sub-dimension analyses human resources as a key element for internal green logistics. In particular, the first element (D1-SD4-E1) considers the organizational structure of the company, which must be coherent and validate the corporate responsibility in this regard. The second (D1-SD4-E2) and third (D1-SD4-E3) elements are formal and informal training, respectively, in the techniques, tools, and good practices of internal green logistics. Finally, the fourth element (D1-SD4-E4), is related to D1-SD4-E1 and analyses the number of direct and indirect support personnel for the continuous improvement of green internal logistics.
- ✓ Standards, norms, and certifications (D1-SD5): This sub-dimension considers the external and internal formal processes (i.e., standards, norms, and certifications) that the company follows to support internal green logistics. Considering the above, the elements of this sub-dimension are energy management (D1-SD5-E1) (e.g., related to ISO 50001 standard), water management (D1-SD5-E2) (e.g., related to ISO 46001 standard), waste management (D1-SD5-E3) (e.g., related to ISO 14001 standard), quality management (D1-SD5-E4) (e.g., related to ISO 9001 standard), environmental management (D1-SD5-E5) (e.g., related to ISO 14000) and greenhouse gas calculation (D1-SD5-E6) (e.g., related to ISO 14064). All of the above is applied within the company.

3.2 Dimension 2 (D2): External logistics

- ✓ Infrastructure (D2-SD1): This sub-dimension analyses the same elements as D2-SD1 but in the context of external logistics. Thus, the elements such as Construction Materials (D2-SD1-E1), Electrical System (D2-SD1-E2), Hydraulic System (D2-SD1-E3), and Optimized Industrial Layout (D2-SD1-E4) are analyzed for warehouses and external administrative areas.
- ✓ Equipment (D2-SD2): This sub-dimension consists of material resources related to external mobility (D2-SD2-E1) (i.e., internal combustion and electric vehicles, contracted logistics services, ships, airplanes, etc.), administrative activities (D2-SD2-E2) (e.g., desktop and laptop computers, office equipment, and smartphones), and services (D2-SD2-E3).
- ✓ Processes (D2-SD3): This sub-dimension considers all production and service processes related to external logistics. Thus, the elements that make up this sub-dimension are local, regional, national, and international distribution processes (D2-SD3-E1), freight

transport strategies and policy (D2-SD3-E2) (e.g., backhaul return of loaded transport, that is, preventing the truck from returning empty), external packaging and packing (D2-SD3-E3), transport route management (D2-SD3-E4), reverse logistics and circular economy aspects (D2-SD3-E5), nearshoring aspects (D2-SD3-E6), warehouse management and external inventories (D2-SD3-E7), recycling, reduction and waste Management (D2-SD3-E8), external green logistics KPIs (D2-SD3-E9), and LCA of products, processes and services (D2-SD3-E10).

- ✓ Human Resources (D2-SD4): The elements of this sub-dimension are similar to those of D1-SD4 but in the context of external logistics.
- ✓ Standards, norms, and certifications (D2-SD5): The elements of this sub-dimension are similar to those of D1-SD5 but in the context of external logistics.

4 RESULTS AND DISCUSSIONS

To ensure the reliability and quality of the design process of the aforementioned instrument, internal and external validation tests have been carried out. The internal validation takes into account the participation of professors and researchers belonging to CETYS University, while the external validation takes into account the participation of members of civil society, businessmen, and logistics specialists from other institutions. As far as the profile of the participants is concerned, all of them have a formal education in logistics. In particular, 63.2% of the participants have more than 10 years of professional experience in logistics and 94.7% have multidisciplinary professional experience in logistics. The validation process took 4 weeks to complete. For both validation processes, the Likert scale was used, which makes it possible to measure the opinion of experts on the topic and to code it quantitatively for subsequent analysis. The Likert scale was categorized and quantified as follows, 1 point = Strongly disagree, 2 points = Disagree, 3 points = Neutral, 4 points = Agree and 5 points = Strongly agree. In this way, the desirability of the dimensions and sub-dimensions mentioned was assessed using 12 statements (S). It is important to clarify that aspects such as feasibility and viability were not evaluated, since these are technological, process, and financial aspects that may vary from company to company. Table 1 shows the statistical results of the internal and external validation. In particular, each statement (*S*) evaluates a particular parameter, e.g., D1-SD1. In this way, the mean (μ), standard deviation (σ), and coefficient of variation (CV = (σ/μ) × 100) of each S are presented.

Table 1: Statistical results of internal and external validation.

Statement	Parameter	Internal validation			External validation		
		μ	σ	CV	μ	σ	CV
1	D1	4.67	0.52	11.07	4.70	0.67	14.36
2	D1-SD1	4.17	0.75	18.07	4.60	0.52	11.23
3	D1-SD2	4.83	0.41	8.45	4.50	0.71	15.71
4	D1-SD3	4.17	0.98	23.60	4.60	0.97	21.00
5	D1-SD4	3.67	1.21	33.03	4.20	1.48	35.14
6	D1-SD5	4.67	0.52	11.07	4.80	0.42	8.78
7	D2	4.83	0.41	8.45	4.10	1.10	26.84
8	D2-SD1	4.33	0.82	18.84	3.90	1.10	28.22
9	D2-SD2	4.50	0.84	18.59	4.20	1.14	27.03
10	D2-SD3	4.33	0.82	18.84	4.50	0.97	21.60
11	D2-SD4	3.83	0.98	25.65	4.00	1.41	35.36
12	D2-SD5	5.00	0.00	0.00	4.50	0.97	21.60

In general, six logistics experts participated in the internal validation process of the dimensions and sub-dimensions mentioned, while for the external validation process, ten professional experts participated. Then, the statistical results were analysed for each dimension and sub-dimension, resulting in the following research findings regarding internal validation:

Finding 1: Regarding D1, the sub-dimension D1-SD4 was the worst rated, with a mean (μ) of 3.67. In addition, this sub-dimension also had the highest variability of responses (CV), 33.03%.
Finding 2: Concerning D1, the D1-SD2 sub-dimension was the best scored, with $\mu = 4.83$, and had the lowest response variability, with CV = 8.45%.
Finding 3: About D2, the sub-dimension D2-SD4 was the worst score, with an average score of 3.83. In addition, this sub-dimension also had the highest variability of responses (CV), 25.65%.
Finding 4: Concerning D2, the D2-SD5 sub-dimension was the best scored, with $\mu = 5$, and had the lowest response variability, with CV = 0%. There are other sub-dimensions with high scores but also have high variability.

In terms of external validation, the research findings are as follows:

Finding 5: Regarding D1, all sub-dimensions were well scored, with a μ greater than 4. Although D1-SD4 presents the highest variability of responses (CV), 35.14%.
Finding 6: Concerning D2, the sub-dimension D2-SD1 was the worst rated with a mean of 3.90. In addition, this sub-dimension has a relevant variability of responses, 28.22%.
Finding 7: About D2, the sub-dimensions D2-SD3 and D2-SD5 were the best scored, with a mean of 4.50. Such sub-dimensions also have high variability (CV) of responses, 21.60%.

Considering these results, it is possible to make approximations for the design of the instrument. For example, in the case of internal validation, the statistical results show that D1-SD4 and D2-SD4 are not sub-dimensions that are completely convenient to analyse.

5 CONCLUSIONS AND IMPLICATIONS

In this research, the dimensions and sub-dimensions have been evaluated as part of the process of designing an instrument that allows evaluation of the level of green logistics in a company. In particular, seven research findings have been presented that allow us to understand in depth the relevance of the analyzed sub-dimensions. The next step is to analyse the statistical results in depth and to correlate them with the professional experience of the respondents to make an intelligent decision regarding the development of the instrument. The results given in this research, and subsequently, the final instrument, have implications for the internal and external policies of companies since they can serve as a starting point for improving the regulation of internal and external logistics. These results also have social and environmental implications. This is because several sub-dimensions of internal and external logistics directly address the management of human resources and talent. While the environmental implications are addressed indirectly, for example, all dimensions and sub-dimensions have the goal of reducing the company's carbon footprint and thus supporting public health. On the other hand, the research findings also have managerial implications. For example, the sub-dimensions that evaluate internal and external processes can lead to organizational changes that facilitate increasing the level of green logistics in the company. It is also important to clarify the main limitations of this research, which lies in the wide variety of perspectives to evaluate green logistics, which may lead to disagreement among some companies or logistics professionals. Furthermore, although some international experts participated in the internal and external validation, there are still content issues that will be addressed in the formal design of the evaluation tool. Finally, regarding the main constraint, the proposed green logistics assessment tool is being designed to strengthen the regional industrial sector, i.e., other industrial sectors worldwide may have different views on the matter.

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