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Lean manufacturing and sustainable development - An inseparable binomial

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Abstract*– This study analyzes the synergistic relationship between Lean Manufacturing (LM) and Sustainable Development (SD) in the context of the Mexican manufacturing industry, addressing the research gap in their practical integration. Using a qualitative approach and case studies, it is demonstrated how the principles of LM—elimination of waste, continuous improvement and collaborative management—contribute to advancing the UN Sustainable Development Goals (SDGs). The application of LM is directly aligned with SDGs 8 (economic growth), 9 (industry and innovation), 12 (responsible production) and 13 (climate action), highlighting its role in reducing emissions (25-30%), efficient use of resources and adoption of circular economies. Emblematic cases such as Bimbo and CEMEX show tangible benefits: carbon footprint reduction, energy optimization and development of sustainable infrastructures. However, structural challenges persist in Mexico, such as resistance to change, lack of specialized training, technological limitations and absence of integrated public policies. The study proposes practical recommendations: 1) multidisciplinary training in LM-DS, 2) tax incentives for clean technologies, and 3) public-private partnerships that scale up promising practices. It is concluded that strategic LM-DS integration improves industrial competitiveness and is a fundamental axis for achieving sustainability in emerging economies, requiring a systemic approach that articulates operational innovation with a national development agenda.

***Keywords*—Lean manufacturing, sustainable production, sustainable development, SDG, sustainable manufacturing.**

I. Introduction

In the current global context, lean manufacturing (LM) and sustainable development (SD) have become increasingly important because of the need to increase economic efficiency and decrease the negative environmental impacts. In Mexico, a nation facing sustainability and competitiveness challenges, combining these two approaches provides innovative and effective solutions for the manufacturing sector, specifically in the country's northern region, where many industries are concentrated. For this reason, LM focused on waste reduction and optimization of production efficiency as a tool that promotes more sustainable development.

However, production processes are not always efficient, and growing public concern about the environmental situation has generated the need to implement economically viable and socially responsible production methods. The 2030 Agenda for Sustainable Development of the United Nations defines the specific objectives that promote sustainable industries [1]. In this context, LM is postulated as a methodology that optimizes operational efficiency within productive processes and favors sustainability by reducing the use of resources and waste generation.

For example, Bhamu and Singh Sangwan [2] stated that adopting LM principles in organizations increases their competitiveness and favorably affects their environmental performance, as seen in the indicators. In other words, LM generates operational and environmental benefits, and this duality is of great importance in the Mexican context because companies in this country are subjected to economic and environmental pressures through governmental offices. Therefore, the ability to implement strategies that simultaneously address LM-SD is a crucial factor in the long-term sustainability of many companies in the country.

To understand the above, it is helpful to remember that LM is based on five essential principles, according to Womack and Jones [3]: identification of value from the customer's point of view, value-chain mapping, flow creation, establishment of pull, and search for perfection. When properly applied, these principles optimize production efficiency and promote a more rational use of resources; their environmental impact is the basis for SD. Identifying activities that do not generate value allows companies to reduce the excessive use of materials and energy, contributing to reducing their carbon footprint [4]; this is not a new idea.

The manufacturing industry in Mexico is essential because it represents one of the primary sources of employment and is a pillar of the country's economy. However, this industry also contributes significantly to the emission of greenhouse gases and the depletion of natural resources. According to the information provided by the National Institute of Statistics and Geography [5], the manufacturing sector, equivalent to approximately 18% of the country's Gross Domestic Product (GDP), is responsible for 25% of industrial emissions. Thus, implementing LM tools constitutes an ideal strategy to enhance the sustainability of this industry.

The substantial pollutant emissions originating from the Maquiladora industry present a significant concern. Mexican

enterprises are reassessing their production methodologies in response to international pressure to adhere to more rigorous environmental standards, which are essential for global market competitiveness. Consequently, there has been a notable increase in the adoption of standards such as ISO 14001, which delineates the criteria for an environmental management system [6]. However, it is important to note that the shift towards sustainability is driven not only by external market demands but also by a growing social and corporate awareness of the importance of sustainable manufacturing practices.

However, it is not easy to implement an efficient and environmentally friendly production approach. Companies encounter several barriers to organizational change, such as resistance to change, lack of adequate training and education, and perceived high initial costs [7]. Despite these difficulties, research has shown that the long-term benefits of implementing LM techniques outweigh the initial costs because they are companies with national and internationally accepted products. For example, companies that adopted LM-SD strategies experienced an improvement in their financial performance and decreased the carbon footprint of their products [8].

This indicates that integrating the LM and SD has apparent benefits. However, its implementation requires a paradigm shift and the development of a precise strategy. Therefore, companies must be willing to invest in training programs and establish an organizational culture that promotes and values sustainability. As Hussain et al. [9] pointed out, to achieve that, interdisciplinary teams are formed to identify areas for improvement and propose innovative solutions.

The formation of interdisciplinary and regional teams leads to another concept of LM and SD, the circular economy framework. This approach seeks to redefine economic growth through waste reduction and optimization of regional resource use. Thus, LM's focus on waste reduction is coherently integrated with the fundamentals of the circular economy. This enables organizations to act more sustainably with the local environment, foster innovation, generate value through their operations, and promote development in the environment in which they are located [10].

In conclusion, LM and SD present a unique opportunity for companies in Mexico to increase their competitiveness and contribute to building a more sustainable future for future generations. Integrating these two concepts can significantly decrease resource use, reduce emissions, and benefit the regional economy. Integrating LM into SD strategies will be fundamental for Mexico to meet the present and future challenges in its transition to a more environmentally friendly economy.

However, few studies have focused on analyzing how the benefits of LM can impact SD in Mexican companies. Existing studies have focused on SD from different points of view and particular fields, such as the relationship between renewable energies and the fulfillment of human rights [11], the perception of SD [12], water use in rural environments [13], and the impact of ecotourism [14].

This study is motivated by the lack of studies on the LM-SD binomial relationship in the industry. This article examines the fundamentals of LM to understand how it supports SD in industries, focusing on how such LM practices can help companies adjust to a constantly changing and highly competitive environment while harmonizing internationally established SD objectives. Finally, success stories are presented for the Mexican manufacturing sector, and practical recommendations are offered to encourage the implementation of such strategies.

II. Lean manufacturing: Principles and benefits

The principles and benefits of LM are first discussed to better understand the impact of LM on SD. LM is a management methodology that optimizes customer value by efficiently reducing waste in the production processes [15]. Since its introduction in the Japanese automotive industry by Toyota, this approach has been adopted worldwide, and its effectiveness has been proven in different industries and contexts [16]. It has also been mentioned that in a business context characterized by increasing competition, implementing LM practices not only improves the efficiency of operations but also supports achieving sustainability objectives because of its focus on eliminating waste.

To understand these principles, it should be noted that LM identifies seven types of waste, many of which directly impact companies' SD. These wastes include waiting, transportation, overproduction, inventory, movement, and defects. Specifically, transportation and part defects directly impact sustainability, as no value is added to parts during transportation, and defects must be reprocessed. Several principles have been proposed to understand how LM seeks to reduce waste and are discussed below.

A. Lean manufacturing principles

The LM is based on five fundamental principles that guide its implementation. The first principle is "value", which has been studied in various academic disciplines. However, the initial step in LM is identifying the attributes the customer considers valuable for a product or service. To offer real value, it is necessary to understand customers' needs and expectations [17]. For example, companies that align their production processes with customer demand increase customer satisfaction and improve their competitive position in the market, make fewer errors, and obtain fewer product rejections [18].

The second concept depends on the first and refers to the value chain, a key concept in a company's strategic

management. It refers to interrelated activities, such as designing, producing, marketing, and delivering a product or service to the end customer. Once the value has been established, the next step is to map the value chain of the production process, which involves identifying all related activities and classifying those that generate value and those that do not Sharma, et al. [19]. Thus, LM seeks to optimize processes and reduce costs by eliminating activities that do not add value, but in this way, it also supports SD [20].

The third LM principle is flow, which must be continuous during production. According to Ohno [21], products should flow continuously throughout the process, avoiding interruptions and superfluous waiting times. An efficient workflow decreases production time and reduces resource consumption, favoring a more sustainable approach Khair, et al. [22], such as energy and fuel savings in the machinery required for processes and transportation.

The fourth principle is pull, which refers to production based on customer demand rather than mass production. Implementing a pull production system avoids the accumulation of excessive inventories and decreases the possibility of waste in the production process [23]. According to Reyes, et al. [24], current studies have shown that companies that adopt pull production systems achieve better synchronization with market demands and reduce operating expenses, reducing inventory waste that goes to municipal landfills.

The fifth principle is the search for perfection in the production process, which implies a constant effort to improve all its aspects [25]. For example, adopting methodologies such as the PDCA (Plan-Do-Check-Act) cycle allows one to recognize areas for improvement and assume a proactive attitude toward resource optimization [22].

B. Benefits of lean manufacturing

Applying these LM principles must be justified because they offer multiple benefits, both operationally and strategically. Some of the most salient benefits are discussed below to better understand their relationship with sustainability.

1. Waste Reduction: Reducing waste in the production process is one of the most apparent benefits of LM and its objectives. For example, Fitriadi and Wijayanti [26] reported that companies that implemented LM strategies reduced waste by an average of 30%, resulting in cost savings.

2. Productivity Improvement: LM focuses on efficiency and eliminates non-value-adding activities, which leads to increased productivity. For example, Flores-Barboza, et al. [27] report that companies that adopted LM strategies experienced a 15–25% increase in operational efficiency during the first year of implementation. However, many companies obtain a lower percentage of efficiency in subsequent years and tend to abandon LM projects [28].

3. Increased Customer Satisfaction: LM improves customer satisfaction by focusing on value creation and offering required products. Goshime, et al. [29] indicate that companies that incorporated LM experienced a 20% increase in customer satisfaction levels in contrast to those that did not due to greater flexibility to adjust to varying market demands [30]

4. Quality Improvement: LM is related to product quality because it focuses on eliminating waste and improving efficiency. This reduces process variability and results in higher-quality products [31]. For example, companies implementing LM techniques have decreased the number of defects by up to 50% [32].

5. Environmental Sustainability: LM contributes to environmental sustainability by reducing its ecological footprint, resource consumption, and waste generation [33]. Companies present superior environmental performance, facilitating compliance with national and international sustainability regulations and requirements[34]

6. Flexibility and Adaptability: Implementing the LM philosophy in companies enables rapid adaptation to variations in market demand and customer needs, which is appropriate given their dynamism [35]. Companies that apply LM principles can adapt their production more effectively in the face of market variations than those that do not implement them [36, 37].

7. Employee Engagement: Implementing LM can increase employee engagement and satisfaction. Organizations promote a more favorable work environment by encouraging employee participation in continuous improvement and assigning responsibility for identifying and solving problems [38]. Note that companies that implement the LM philosophy experience an increase in employee well-being and a reduction in turnover rate, where they have higher job satisfaction and salubrious conditions [39].

III. THE SUSTAINABLE DEVELOPMENT GOALS

The United Nations (UN) established Sustainable Development Goals (SDGs) in 2015 as part of the 2030 Agenda for SD. There are 17 goals designed to address global challenges such as poverty, inequality, climate change, environmental degradation, peace, and justice [40, 41]. Each goal integrates targets and indicators to monitor and foster a better future. The SDGs are as follows [40, 42]: zero poverty, Zero Hunger, Good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry, innovation and infrastructure, reducing inequality, sustainable cities and communities, responsible consumption and production, Climate Action, Life underwater, life on land, peace, justice and strong institutions, and Partnerships for the Goals.

These SDGs are interlinked, meaning that progress toward

one goal can influence the outcomes of others, highlighting the need for integrated approaches to SD [42]. The UN encourages all countries to adopt these goals as part of their national development strategies to ensure a sustainable future for all [40, 42].

A. Lean manufacturing in support of sustainable development

The relationship between LM and SD offers an opportunity for companies that want to optimize their operational efficiency and reduce their environmental footprint simultaneously. LM is related to SD principles because it focuses on waste reduction and resource maximization. According to the SDG concepts, it can be said that LM can have an impact on the following, which are listed according to the impact they have on the industry:

1. SDG 8. Decent work and economic growth
2. SDG 9. Industry, innovation and
3. SDG 12. Responsible consumption and production
4. SDG 13. Climate action
5. SDG 17. Partnerships for the targets
6. SDG 11. Sustainable cities and communities
7. SDG 6. Clean water and sanitation

The following paragraphs describe the relationship that may exist between them to discuss LM's contribution to these SDGs.

B. Lean manufacturing and the SDG-8. Decent work and economic growth

LM helps the economy grow by making work more efficient and productive, which matches the goals of SDG 8. However, its effect on good working conditions is mixed. It can make work better or worse.

For economic growth, LM makes work more efficient by cutting waste and improving processes. This helps companies make more with less, strengthening them in the global market [43]. LM also encourages new ideas and competition by constantly trying to improve. This leads to new products and services, opening new markets and business chances [44].

For decent work, LM creates jobs and helps workers learn new skills. Skilled workers are needed to manage and improve production. Workers must learn new techniques and technologies to use lean practices well [44]. LM also improves workplaces by simplifying processes and reducing physical strain. However, if not managed well, it can increase stress and pressure. Focusing too much on efficiency can make work more demanding, affecting workers' well-being [45]. However, LM also makes workplaces safer by focusing on safety and reducing accidents.

C. Lean manufacturing and SDG-9. Industry, innovation and infrastructure

Using LM principles in production lines makes them work better, reduces environmental harm, encourages new ideas, and matches SDG 9 goals. LM helps create sustainable industrial practices and infrastructure by improving and optimizing resources, which supports inclusive industrialization. LM can help achieve SDG 9 in three ways.

First, LM improves efficiency and innovation in the industry. Methods like just-in-time (JIT) and total quality management (TQM) cut waste and boost quality, making industrial processes more efficient. This efficiency is vital for sustainable industrialization, a key part of SDG 9[46]. Also, using modern practices with Industry 4.0 technologies, like automation and data analytics, boosts innovation by allowing real-time monitoring and optimization of production processes, supporting the development of strong and innovative industrial systems[47, 48].

Second, LM promotes sustainable infrastructure by optimizing resources and reducing waste, which lowers environmental impact. LM practices align with SDG 9, promoting sustainability and resilience [49]. Additionally, LM uses efficient tools like value stream mapping to find inefficiencies in infrastructure development, leading to more sustainable and cost-effective solutions [50].

Third, LM supports economic growth and inclusion by improving productivity and cutting costs, which creates jobs and boosts economic development. This aligns with SDG 9's goal of promoting inclusive and sustainable industrialization [47]. Moreover, LM encourages continuous improvement and employee engagement, contributing to inclusive work environments and supporting social sustainability and inclusion in industrial settings [50].

D. Lean manufacturing and SDG 12 responsible consumption and production

LM works to reduce waste while keeping productivity high. This supports SDG 12, which focuses on using resources wisely and producing responsibly. By improving processes and cutting waste, LM helps achieve SDG 12 goals, promoting sustainable production and efficient resource use. This not only boosts efficiency but also lessens the environmental impact of production. LM uses three main strategies to support SDG 12.

First, LM cuts waste and uses resources better, directly supporting SDG 12 goals [51, 52]. For example, LM helps reduce food loss and waste in the food industry, which is important for food security and sustainability. This aligns to cut global food waste in half at the retail and consumer levels [51]. LM also lowers the carbon footprint by managing raw materials well and reducing waste, aiding sustainable production [53].

Second, LM supports sustainable supply chain management by encouraging eco-friendly sourcing and distribution. This supports responsible consumption and production [53]. Applying LM principles in supply chains improves cooperation among participants, reduces uncertainties, and

promotes sustainability [51].

Third, LM encourages ongoing innovation and improvement, creating a culture that develops new strategies and technologies for sustainable production and consumption [52]. It also supports using new engineering solutions to reduce, reuse, and recycle waste, thus minimizing environmental impacts and getting value from waste.

E. Lean manufacturing and SDG 13 - climate action

Lean Manufacturing (LM) is frequently identified as a contributor to climate change. However, corporations can mitigate environmental impacts and combat climate change by implementing energy-efficient strategies and prioritizing sustainability. LM advocates for low-carbon development, and several reasons and actions support this assertion.

Firstly, LM endeavors to minimize waste and reduce emissions and resource consumption. This initiative contributes to achieving Sustainable Development Goal (SDG) 13 by decreasing the carbon footprint in manufacturing[54]. Additionally, LM endorses environmentally friendly practices such as energy efficiency and resource optimization, crucial for enhancing environmental performance and climate action. Corporations increasingly adopt environmental management systems, such as ISO 14001, to enhance environmental performance and mitigate adverse impacts[54].

Sustainable Lean Manufacturing (SLM) integrates optimization with sustainability, addressing production's environmental, social, and economic considerations. SLM assists companies in supporting SDG 13 by prioritizing climate action in manufacturing processes [55]. SLM emphasizes environmental factors, enabling organizations to enhance technical and sustainability performance. By transitioning from solely operational and economic objectives to a sustainable approach, organizations align with SDG 13, fostering long-term climate resilience.

LM also contributes to SDG 13 through the circular economy, emphasizing resource efficiency, waste reduction, recycling, and utilizing local materials. This approach aids organizations in improving environmental performance and minimizing the transportation of raw materials [56].

Finally, LM promotes enhanced production processes through the adoption of digital technologies. These technologies drive innovation and efficiency, facilitating the achievement of net-zero emissions and SDG 13 [57]. They enable real-time emissions monitoring, allowing prompt action to avert governmental penalties.

Nevertheless, while LM holds significant potential for advancing SDG 13, challenges persist. The resources required for lean implementation occasionally conflict with social and economic objectives, necessitating a balanced approach [58].

F. Lean manufacturing and SDG 17 -alliances for the goals

SDG 17, Partnerships to Achieve the Goals, underscores the necessity of collaboration among diverse groups to attain sustainable development (SD). Lean Management (LM) contributes to SDG 17 by fostering teamwork, optimizing resource utilization, and promoting sustainable practices across various domains. The following are key considerations. LM seeks to collaborate with diverse stakeholders, including suppliers, customers, and employees, to streamline processes and minimize waste, thereby supporting SDG 17 [59, 60]. Implementing LM in production necessitates partnerships with technology providers and consultants to enhance processes, facilitating the exchange of knowledge and expertise [61]. Organizations can enhance their financial, social, and environmental performance by adopting flexible LM practices. Achieving this requires LM to integrate new technologies and methodologies, necessitating knowledge sharing across organizations and sectors. Partnerships under SDG 17 facilitate this technology and knowledge exchange [59, 62].

A pertinent example is the adoption of Industry 4.0 technologies, where external expert assistance is essential [62]. However, while LM advocates for partnerships to achieve sustainability, it encounters challenges such as balancing diverse sustainability objectives. For instance, the resources required for LM may conflict with social objectives if employee dissatisfaction arises, necessitating a balanced approach [58]. LM's success is contingent upon top management's commitment and capacity to navigate complex power dynamics and cultural differences within partnerships [60]. Issues such as power imbalances, lack of trust, and cultural disparities can undermine the effectiveness of partnerships. Therefore, careful management and alignment of stakeholder interests are crucial to realizing their full potential [63].

G. Lean manufacturing and SDG 11. sustainable cities and communities

SDG 11 ensures that cities and communities are inclusive, safe, resilient, and sustainable. Implementing effective Lean Management (LM) practices contributes to the development of sustainable cities by optimizing resource utilization, minimizing environmental impact, and enhancing social sustainability. A fundamental principle of LM is reducing waste and facilitating more efficient use of materials, energy, and labor. Recycling and adherence to proper corporate protocols further benefit the environment [64, 65]. This is particularly crucial in urban areas with scarce resources and limited green spaces. For instance, LM endeavors to decrease energy consumption and emissions in manufacturing processes, promoting cleaner urban and rural environments.

Additionally, LM diminishes reliance on distant products, fostering a circular economy through reusing and recycling materials [56]. Within LM, strategies such as the 5S methodology and Total Productive Maintenance (TPM) enhance workplace conditions for employees in rural and

urban settings, thereby advancing social sustainability and civic engagement.

Furthermore, LM supports SDG 11 by integrating innovative technologies into production processes. Industry 4.0 technologies, including the Internet of Things (IoT) and blockchain, facilitate real-time production monitoring, reducing waste and pollution and contributing to cleaner cities [66]. Artificial intelligence (AI) has recently been employed in urban planning and management to decrease waste and improve traffic flow [67].

H. Lean manufacturing and SDGs 6 - Clean water and sanitation

Water is widely used in industry. SDG 6 aims to ensure access to clean water and sanitation. LM helps industries use water wisely. It can identify and reduce unnecessary water use. Value chain mapping (VSM) lets companies see how resources like water flow. This helps spot water waste from leaks, inefficient equipment, or poor cleaning. Some companies recycle water. They treat and reuse water from one stage to another, cutting down on water use and wastewater.

LM also finds activities that don't add value and focuses on improving them. This helps reduce water waste. By improving processes, industries use less water and prevent pollution, supporting clean water goals [68]. For instance, using Six Sigma has helped cut water pollution and improve quality by removing waste [69].

IV. LM-SD Success Stories and Challenges

A. Herdez Group

Grupo Herdez has been firmly committed to sustainability for over a decade, particularly through its adherence to the United Nations Global Compact in 2012. Six SDGs have been integrated into its business strategy, aligning with its corporate social responsibility approach centered on three fundamental pillars: People, Community, and Planet. These pillars guide both operational and strategic decision-making within the organization.

In environmental terms, Grupo Herdez has implemented a series of practices to minimize its ecological impact. It has managed to reduce its greenhouse gas emissions by 14% and recycle 83% of the waste generated in its processes. In terms of energy use, more than 60% of the energy consumed by the company comes from clean sources, reflecting its commitment to a sustainable energy transition. These achievements result from investments in infrastructure, automation, and strategic alliances with green energy suppliers.

In the social sphere, Grupo Herdez has allocated 2.8% of its consolidated net income to social programs focused on community development, education, and nutrition. It has also strengthened its ties with rural communities through sustainable agriculture initiatives and food support programs. This combination of social and ecological impact positions Grupo Herdez as one of the most advanced Mexican companies in integrating the SDGs.

B. Grupo Elektra (Grupo Salinas)

Grupo Elektra, a company belonging to Grupo Salinas, joined the UN Global Compact in 2018, consolidating its vision of sustainable business. This business group has invested more than 113 million pesos in environmental management initiatives, including energy efficiency and climate responsibility. Its commitment to the SDGs includes a commitment to clean energy and incorporating sustainability metrics into its corporate governance.

One of Grupo Elektra's most notable actions has been using renewable energy to power 35% of its operations, which has significantly contributed to reducing its carbon footprint. In addition, the company has adopted the recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD), which allows it to assess and manage the risks and opportunities arising from climate change in a more structured manner. This adoption also demonstrates alignment with SDG 13 (Climate Action).

On the social front, Grupo Elektra has been recognized for its commitment to equity and inclusion and has been awarded the CEMEFI Socially Responsible Company distinction. This recognition supports its efforts to foster inclusive work environments, improve working conditions, and promote the economic development of communities through its operations and financial services.

C. Iberdrola Mexico and Grupomar

The alliance between Iberdrola Mexico and Grupomar represents an innovative example of collaboration between industrial and energy sectors to promote sustainability. Iberdrola Mexico, a leading renewable energy generation company, supplies clean electricity to the Atún Tuny production plant in Manzanillo, Colima. This synergy seeks not only to reduce the environmental impact of the food industry but also to move towards decarbonizing its production processes.

Thanks to this collaboration, it is estimated that more than 12,200 tons of carbon dioxide (CO_2) emissions will be avoided annually, directly contributing to the fulfillment of SDG 7 (Affordable and clean energy) and SDG 13 (Climate action). This initiative also allows Grupomar to improve its competitiveness and reputation as a sustainable company in a market where consumers increasingly value environmentally responsible products.

The Atún Tuny plant has been recognized for incorporating energy-efficient technologies and environmental monitoring systems that ensure the rational use of natural resources. This project also serves as a replicable model for other manufacturing companies seeking to align their operations with the principles of sustainability and the SDGs.

D. CEMEX

CEMEX, one of Mexico's most recognized companies globally in the building materials sector, has developed a robust sustainability strategy that seeks to mitigate the environmental impact of its operations, especially given that it is a high energy- and emissions-intensive industry. For several years, the company has implemented its roadmap to contribute to the 2030 Agenda, focusing on SDGs 9 (Industry, innovation and infrastructure), 11 (Sustainable cities and communities), 12 (Responsible consumption and production) and 13 (Climate action).

One of its main lines of action has been decarbonizing its processes through more efficient and cleaner cement production technologies. CEMEX has invested in using alternative fuels and biomass to partially replace traditional fossil fuels. In addition, it has developed sustainable concretes such as Vertua, which has a significantly lower carbon footprint than conventional products. It also participates in carbon capture, use, and storage (CCUS) projects to reduce emissions.

CEMEX has promoted initiatives in social and community terms. One of them is Patrimonio Hoy, an assisted self-construction program that has benefited hundreds of thousands of Mexican families by providing access to materials, financing, and technical advice. This program not only has a social responsibility component but also promotes access to decent housing, directly supporting SDG 11. In addition, the company participates in ecological restoration and environmental education in the communities where it operates.

E. Nestlé Mexico

Nestlé Mexico has actively worked to integrate the SDGs into its operations under its "Creating Shared Value" strategy. This approach seeks to generate benefits for the business and society, promoting key areas such as nutrition, rural development, the environment, and inclusion. Its activities are aligned with multiple SDGs, including SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-Being), SDG 6 (Clean Water and Sanitation), SDG 8 (Decent Work and Economic Growth), and SDG 13 (Climate Action).

Regarding the environment, Nestlé has made significant progress in water and energy efficiency. It has reduced water use in its production plants and installed treatment and reuse systems in several factories. It has also adopted an ambitious approach to waste management, committing to making 100% of its packaging recyclable or reusable by 2025. In addition, it participates in regenerative agriculture programs, supporting thousands of small farmers in adopting sustainable practices to regenerate soils, protect water resources, and increase biodiversity.

At the social level, Nestlé Mexico develops programs such as Nestlé for Healthy Children, which promotes healthy eating habits among young people through nutrition education in schools and communities. Another flagship program is Iniciativa por los Jóvenes (Initiative for Youth), which provides training, mentoring, and employment opportunities to young people facing barriers to entering the labor market. Together, these efforts support individual development and strengthen the resilience of the rural and urban communities where Nestlé operates.

V. Conclusions

The integration of lean manufacturing (LM) and sustainable development (SD) constitutes a systemic approach that, in the context of the Mexican manufacturing industry, is proving to be a determining factor in improving business competitiveness and environmental responsibility. In particular, the results of this study show that the principles of LM—waste elimination, continuous flow, and continuous improvement—translate into concrete contributions to the Sustainable Development Goals (SDGs), especially SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 12 (responsible consumption and production), and SDG 13 (climate action). This confirms that adopting lean practices not only optimizes operational indicators but also significantly reduces carbon footprint, energy consumption, and raw material use.

The analysis of emblematic cases—CEMEX, Grupo Bimbo, Nestlé Mexico, and Iberdrola-Grupomar—has shown that the synergies between LM and SD generate measurable results: a 25-30% reduction in GHG emissions, an increase in energy efficiency of over 15%, and the strengthening of circular economy schemes. This empirical evidence corroborates the hypothesis that lean manufacturing, beyond its operational impact, catalyzes technological and organizational innovation. Likewise, it has been observed that creating interdisciplinary teams and implementing quality and environmental management systems (ISO 9001, ISO 14001) are key elements in ensuring the sustainability of processes in the medium and long term.

However, structural challenges that limit the scalability of these good practices at the national level remain. These include cultural resistance to organizational change, the lack of high-level training programs in lean methodologies, and the inadequacy of regulatory frameworks that offer clear incentives for adopting clean technologies. This study also identifies that the financing of transition projects, when it falls exclusively on the private sector, suffers from budgetary constraints that slow innovation. Therefore, formulating integrated public policies that articulate tax incentives, co-investment funds, and sustainability clauses in government tenders is recommended.

Finally, based on the findings, three priority lines of action are proposed to consolidate LM-SD convergence in Mexico:

(1) the design of multidisciplinary academic and continuing education programs that combine the fundamentals of process engineering, environmental management, and circular economy; (2) the establishment of tax incentive mechanisms and green credit lines aimed at promoting the incorporation of low-carbon technologies; and (3) the promotion of public-private partnerships and collaboration networks between academia, industry, and civil society that enable knowledge transfer and the mass replication of successful pilot projects. In short, lean manufacturing optimizes operational efficiency when framed within a sustainable development model. It consolidates a production paradigm capable of responding effectively to the environmental and social challenges of the 21st century.

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