Chapter X. Synergies at Industry: Integrating Sustainability principles in Lean Manufacturing

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Abstract: This chapter explores integrating sustainability principles into lean manufacturing, emphasizing the key factors contributing to sustainability adoption. Focusing on automotive manufacturing plants in Northeast Mexico, this study underscores the role of factors such as the implementation of energy management systems, promotion of gender equality in the workforce, human development through training initiatives, improvement, including utilization of clean renewable energy, reduction of carbon dioxide emissions, enhancement of worker productivity, and reduction of solid waste materials. The analysis delves into the relationship between these factors and lean manufacturing principles, outlining their combined impacts on sustainability adoption. By bridging economic, environmental, and social considerations, the insights generated provide a pathway for organizations to achieve long-term economic prosperity while fostering overall well-being within the business and broader community.

X.1 Concept of sustainability adoption tool in the automotive industry

Sustainability adoption encompasses three classical dimensions: economic, social, and environmental (Artaraz 2002). When these three dimensions coexist, sustainable development can be achieved. This study, in line with the findings of other authors (Pourvaziry et al. 2020), defines sustainable development as the generation

of long-term economic wealth, production with low environmental impact, and the socially responsible treatment of employees, communities, and customers. It is worth mentioning that previous studies conducted in the automotive context have highlighted that sustainable development serves as a strategic tool for competitiveness (Wellbrock et al. 2020) and can contribute to the success of organizations in the present and long term.

X.2 The origin of sustainable development and LM

Since the industrial revolution, humanity has significantly benefited from the era of industrialization (Horn et al. 2010). However, as we enter the 21st century, we have witnessed significant environmental degradation, economic inequality, and social stress on a global scale. In response to these intertwined challenges, sustainable development has emerged as an alternative approach that holistically addresses economic, environmental, and social issues. According to Brundtland, sustainable development refers to a development paradigm that aims to fulfill the needs of the present generation without compromising the ability of future generations to meet their own needs. This proposition was published by the United Nations Organization (UN 1987) and adopted by the Organization for Economic Cooperation and Development (OECD 2020) along with its member states, including Mexico. It is important to note that the concept of sustainable development continues to evolve under the guidance of the United Nations (UN).

Lean manufacturing is a systematic approach derived from the Toyota Production System (Toyota 2023), which aims to eliminate waste and enhance the efficiency of manufacturing and production processes. It focuses on delivering the maximum customer value while minimizing resource usage. Key principles include understanding value from the customer's perspective, optimizing workflows, implementing pull systems, standardizing work processes, and promoting continuous improvements. Lean manufacturing has been widely adopted in various industries to reduce costs, enhance product quality, and improve overall productivity.

Lean manufacturing and sustainability are closely related concepts in business and production. They share several common principles and objectives, and when implemented together, they can positively impact a business's environmental and economic aspects.

X.3 Driving sustainability in the industry

Worldwide, major automotive assemblers are actively working towards adopting sustainable practices (Forbes 2021). Recognizing the challenges at hand, these as-

semblers are striving to modify their operating and business models to align themselves with the principles of sustainable development. Automotive assemblers and other organizations economic and noneconomic disclosure standards in their sustainability efforts. The most widely used standard for reporting sustainability in organizations is the Global Reporting Initiative (GRI 2022), which provides guidelines and frameworks aligned with sustainability principles. These standards are a common framework for measuring, managing, and disclosing environmental, social, and governance (ESG) performance. By adhering to these disclosure standards, automotive assemblers and other organizations are committed to transparently communicating their sustainability practices and performance. This fosters accountability and helps stakeholders evaluate progress in achieving development goals.

The automotive industry in Mexico holds significant importance, with production reaching 2.9 million vehicles in 2021 (CI 2022). In Mexico, the northeastern region stands out because it is home to notable automotive industrial clusters, namely the Nuevo León Automotive Clusters (CLAUT 2023) and the Coahuila Automotive Industrial Cluster (CIAC 2023). These clusters serve as exemplary models for national industry, focusing on sustainability, energy management, human development, and social responsibility. Committees dedicated to sustainability, energy, human development, and social responsibility within these clusters actively promote initiatives related to sustainable development. They facilitate sharing best practices among partner organizations and strive to stay up-to-date with international advancements in the field. In 2022, both Nuevo León and Coahuila were among the states in Mexico that attracted the highest foreign investment in the automotive industry (CI 2022). This translated into a significant influx of $2,434 million investment for Nuevo León, creating almost 8,000 jobs. These investments and job opportunities further underline the significance and growth potential of the region’s automotive industry, reinforcing its position as a key player in Mexico's economic landscape.

X.4 Worldwide sustainability adoption studies

Study factors such as the implementation of energy management systems, promotion of gender equality in the workforce, human development through training initiatives, improvement of workers' well-being, utilization of clean renewable energy, reduction of carbon dioxide emissions, enhancement of worker productivity, and reduction of solid waste materials. These factors are developed below from empirical studies worldwide in different contexts.

X.4.1 Implementation of an energy management system

An EMS is an energy management system that improves energy efficiency and reduces associated costs. ISO 50001 is the certification most adopted in northeastern Mexico. A study conducted by Cahyono and Yudoko (2022) on sustainability in business in Indonesia found that integrating occupational safety, health, and environmental certifications can contribute to sustainability efforts. This study employed cause-and-effect analysis to examine the interrelationships between these factors and a qualitative analysis was conducted. Similarly, a study conducted in an automotive factory in Turkey by Yavas, Savran et al. (2022) aimed to understand the impact of energy management systems on sustainability. The findings of this study are consistent with those of a study conducted on the hotel industry in Serbia by Rajic et al. (2022). Both studies revealed that energy management systems such as ISO 50001 promote adopting sustainability practices. The study in Serbia included a sample size of 280 hotels and demonstrated significant results. These studies highlight the positive role of energy management systems such as ISO 50001 in driving sustainability efforts and their potential impact across different industries.

X.4.2 Promotion of gender equality in the workforce

This is an essential factor in this study. According to definitions from various authors such as the United Nations (DESA 2021), Subrahmanian (2005), and Oluwadamilola (2016), gender equality in this context refers to achieving equal representation of both genders in lower-level positions within industrial plants, particularly in the automotive industry, where floor manufacturing jobs make up a significant portion of the workforce. A study conducted in Nigeria by Adebosin et al. (2018) revealed a strong and positive correlation between gender equality and sustainable development indicators. Furthermore, research has shown that countries with higher women's participation in parliaments tend to have higher levels of sustainability adoption (Boer et al. 2023). These findings indicate that gender equality is crucial for promoting sustainable development and has positive implications for the sustainability efforts of the automotive industry. According to the regional automotive clusters in northeast Mexico, the stratification of personnel in industrial plants is 2% for high hierarchical level, 12% for medium hierarchical level, and 85% for low hierarchical level. This study focuses on the workforce at a low hierarchical level, where a greater social impact is encountered.

X.4.3 Human development through training initiatives and improvement of workers' well-being

Happiness, freedom, and human satisfaction are subjective characteristics of human development. In contrast, access to health, longevity, and education are objective components of human development, as measured by the Human Development Index (Oxford 1990). These objective components should be guaranteed to be human rights. In the context of this study, human development can be achieved by increasing the education level of the workforce and improving the well-being of workers Yumashev et al. (2020); Hickel (2020). We included two critical factors to assess in line with the previous concepts. First, human development through training initiatives refers to enhancing individuals' capacities and opportunities through appropriate training programs. Second, improving workers' well-being measures their quality of life in manufacturing plants. Otoo (2019) and Ma (2019) found that improving individual competencies enhances the competitiveness of organizations. While numerous studies have examined the relationship between compensation and performance, such as Nugroho's study (2022), limited research has directly explored the connection between worker well-being and the improvement of sustainability adoption.

X.4.4 Utilization of clean renewable energy

The definitions provided by the IEA (2020), Rozansky (2020), and et al. (2019) are used within the context of manufacturing plants in the automotive industry. The utilization of clean, renewable energy is defined as a type of energy technology that utilizes energy sources that are replenished at a rate faster than they are consumed and are characterized by low emissions. A study by Yumashev et al. (2020) compared data from OECD countries and found a positive correlation between the improvement of sustainable development and the use of renewable energy. The study revealed that a 1% increase in renewable energy usage contributed to a 0.31% improvement in the sustainable development indicator, with a significance level of 0.01. This indicates that adopting renewable energy sources positively impacts pollution reduction and greenhouse gas emissions, thereby influencing sustainability's social and environmental dimensions Egli et al. (2018) and Cîrstea et al. (2018).

X.4.5 Reduction of carbon dioxide emissions

The combustion of fuels generates this greenhouse gas, which consists of one carbon atom and two oxygen atoms. Reducing carbon dioxide emissions from combustion is essential for automotive industry plants to align with international sustainability objectives. Scientific consensus exists that global temperature is correlated with the carbon dioxide emissions generated by human activities, according to NASA (2019), NOAA (2023), and Berkeley Earth (2020). According to the International Energy Agency (IEA), the automotive industry is responsible for approximately 23% of direct carbon dioxide emissions. However, when considering the entire supply chain of the industry, including indirect emissions from the transport sector, buildings, and other factors, the overall contribution to CO_2 emissions is even greater (IEA 2022). Yumashev et al. (2020), in their study using data from OECD countries, found a negative correlation between CO_2 emissions per capita and the sustainable development indicator, indicating that higher emissions have a negative impact on sustainable development.

X.4.6 Enhancement of workers' productivity

Their output can define the enhancement of worker productivity. Some of these outputs (Feldstein 2017) are efficient in terms of time and quality(Clements-Croome and Kaluarachchi 2000). However, this performance is strongly related to other factors, such as skills, knowledge, motivations, work environment, absenteeism, and long work hours (Durdyeva et al. 2017). Pang et al. (2018) found that employee performance positively affects the organization's financial performance. A strong positive relationship was also found in a study on productivity as an independent variable and economic growth as a dependent variable (Prasetyo 2019).

The reduction of solid waste materials in the plants of the automotive industry is the action of recycling, reusing, reducing materials, surplus resources, or remnants of the production process of the plant (Minh et al. 2019), using strategies such as waste management (Filatov et al. 2019), circular economics (Vinante et al. 2020), or processes such as the life cycle assessment of products and processes or LCA or by its acronym in English (Ghosh et al. 2019). In his study on sustainability in world-class manufacturing for the Iranian automotive industry, Pourvaziry found within the indicators of the environmental dimension of sustainability that its resource conservation variable weights 0.212, the strongest among the five environmental criteria, which gives it the most significant importance within the environmental dimension in our study (Pourvaziry et al. 2020).

X.5 General benefits of the sustainability adoption aligned with LM

Based on general knowledge and synthesis of concepts related to sustainability and lean manufacturing. Adopting sustainability principles within the context of lean manufacturing can serve as a powerful tool offering various benefits that align with the goals of sustainability and lean practices. The benefits of incorporating sustainability as a tool in lean manufacturing are as follows:

1. Waste reduction.
2. Energy efficiency.
3. Cost savings.
4. Continuous improvement.
5. Employee engagement.
6. Enhanced reputation.
7. Regulatory compliance
8. Supply chain optimization.
9. Risk mitigation.
10. Long-term viability.
11. Innovation.

X.6 Key factors for the improvement of the sustainability adoption

The critical factors presented here were tested and selected in an empirical study.

1. Improvement of sustainability adoption
2. Implementation of an energy management system
3. Promotion of gender equality in the workforce
4. Human development through training initiatives
5. Improving workers' well-being
6. Utilization of clean renewable energy
7. Reduction of carbon dioxide emissions
8. Enhancement of workers productivity

In summary, adopting sustainability as a tool for lean manufacturing offers a range of synergistic benefits. Combining lean and sustainability principles creates a robust framework for organizations to optimize operations, reduce waste, enhance efficiency, and contribute to a more sustainable and socially responsible business model.

X.7 Implementation barriers for the sustainability adoption as a lean manufacturing tool

Conflicting priorities between lean manufacturing and sustainability: Lean manufacturing traditionally prioritizes operational efficiency and waste reduction. Introducing sustainability may conflict with the primary focus on cost reduction and efficiency. Lean manufacturing focuses on efficiency, whereas sustainability may focus on efficiency.

Immediate financial goals can be an issue. Lean manufacturing often emphasizes short-term financial gains. Organizations may prioritize projects with quick returns over long-term sustainability initiatives.

The lack of awareness and education on sustainability topics may be a barrier to sustainability adoption as a tool for lean manufacturing. The complexity of the topics covered by sustainability and lean manufacturing versus the complexity of the manufacturing process could be overwhelming. Therefore, innovation and research are required.

Utilizing sustainability adoption in a lean manufacturing tool without the proper implementation process can result in resistance to change from the existing lean process and employees.

X.8 Implementation process for the sustainability adoption

The following are the implementation processes of the critical factors for the adoption of sustainability as a lean manufacturing tool:

X.8.1 Implementation of an energy management system

Implementing an energy management system such as ISO 50001 has a statistically significant positive impact on improving sustainability adoption. This certification

is typically implemented in manufacturing plants that face pressure from customers to address energy and sustainability issues. However, compared to other traditional certifications (ISO 9001, ISO 140001, and ISO 45001), ISO 50001 is not as prevalent in most industrial plants, and its adoption is becoming more popular (ISO 2023).

ISO 50001 indicates a positive correlation between ISO 50001 certification and improvement of sustainability adoption in the automotive industry. Several studies support this finding, including those by da Silva et al. (2019), Trianni et al. (2019), Yavas et al. (2022) and Rajic et al. (2022) confirmed that ISO 50001 certification enhances the degree of sustainability adoption.

The adoption of energy management systems (such as ISO 50001) is highly recommended because of their positive impact on improving sustainability adoption. This type of certification brings benefits across the three sustainability dimensions. Economically, adopting ISO 50001 makes industrial operations more efficient, leading to lower energy costs and improved economic competitiveness for organizations. In terms of the environment, ISO 50001 promotes the use of renewable energy and encourages decarbonization efforts, contributing to reducing greenhouse gas emissions and conserving natural resources. From a social perspective, certification creates new employment opportunities in energy-management-related fields and supports the promotion of clean and non-polluting manufacturing practices.

ISO 50001 certification complements traditional ISO certifications, working together to enhance standardization and continuous improvement in industrial plants, but with a specific focus on sustainability from a technical standpoint. By encouraging the use of renewable energy and the reduction of carbon dioxide emissions in industrial plants, ISO 50001 not only helps achieve sustainability goals but also fosters a broader awareness of sustainability issues.

In conclusion, the implementation of an energy management system is a valuable step for organizations aiming to improve their sustainability performance. It offers comprehensive economic, environmental, and social benefits, making it a powerful tool in the journey towards more sustainable and responsible industrial practices. Bellow listed the relationship between lean manufacturing principles and ISO 50001.

1. Energy efficiency and waste reduction: Lean manufacturing principles align with the objectives of ISO 50001 by emphasizing the reduction of energy waste in production processes. Identifying and eliminating energy-related wastes, such as excessive machine idling or inefficient heating and cooling, can contribute to improved energy efficiency.
2. Continuous improvement: Both ISO 50001 and lean manufacturing promote a continuous improvement culture. Lean methodologies, such as the Plan-Do-Check-Act cycle, are compatible with the iterative energy-management process advocated by ISO 50001. The pursuit of ISO 50001 certification often requires organizations to commit to ongoing improvements in energy performance.
3. Standardization and documentation: ISO 50001 emphasizes the establishment of an energy management system that includes processes for setting energy performance objectives and targets. Lean practices can help organizations

streamline and standardize these processes while maintaining the necessary documentation and records efficiently.

4. Waste heat recovery: Lean manufacturing involves identifying and utilizing waste heat in production processes. ISO 50001 encourages energy efficiency measures, such as waste heat recovery, aligning with lean principles to maximize available resources.
5. Energy performance indicators: ISO 50001 encourages the use of energy performance indicators to monitor and measure energy performance. Lean practices can help organizations identify key performance indicators that are relevant to energy management, enabling them to track progress more effectively.
6. Resource optimization: Lean manufacturing focuses on optimizing resources, including energy. By reducing energy waste and consumption, organizations can align with ISO 50001 and lean objectives for resource efficiency.
7. Cost reduction: ISO 50001 and lean manufacturing can reduce costs. ISO 50001 can help organizations reduce energy costs, whereas lean practices can save operational costs through waste reduction. These cost savings can be reinvested in energy-management initiatives.
8. Environmental impact: ISO 50001 strongly emphasizes reducing the environmental impact of an organization's energy use. Lean practices that reduce energy waste and emissions can help organizations meet the ISO 50001 criteria for minimizing adverse environmental impacts.

X.8.2 Promotion of gender equality in the workforce

The promotion of gender equality in the workforce shows statistical significance with improvement in response to sustainability adoption. This finding is consistent with that of Morais (2017) Adebosin et al. (2018), Yildirim et al. (2017) y Looze (2018). It is important to note that this factor represents most of the plant population (86% of the population), as it was directed at lower hierarchical level workers.

The deficit in women's participation in the automotive industry could be attributed to their gender preferences for working in this sector, as suggested by Falk et al. (2018). Incorporating more women into the industry under suitable conditions is crucial, as it can lead to increased productivity by integrating underutilized human resources. However, the lack of proper social conditions could be another factor that hinders gender equality. Addressing barriers that prevent women from actively participating in the automotive industry is essential.

Professionals of both genders covered the middle and high hierarchical positions. However, more empowered professional women may prefer to work in sectors other than the automotive industry. In some countries, incentives for women to study STEM careers (science, technology, engineering, and mathematics) have shown an increase in female enrollment; however, this trend might decrease once the incentives are no longer in place, according to Amon (2017) and Piani et al.

(2017). Empowered women may have more opportunities to choose where they want to work.

Promoting gender equality in low hierarchical-level positions positively impacts the adoption of sustainability in the automotive industry, and efforts to incorporate more women into the industry should be accompanied by understanding and addressing the factors influencing their career choices. Promoting gender equality in the automotive industry is crucial because it brings several benefits, including integrating a larger population into production chains and harnessing both genders' diverse perspectives and talents. However, achieving gender equality requires addressing various aspects that differentiate men and women.

One of the primary challenges is the existing societal norms and education systems that can lead girls, boys, women, and men to develop predefined career choices. To tackle this issue, education systems must be reformed and made aware of the importance of providing equal opportunities for both genders. By offering diverse activities and perspectives, individuals can make choices that align with their true passions and potential, leading to fulfilling and satisfying career paths.

The second aspect to consider is women's lack of academic and business development opportunities. Encouraging the integration of women into industrial organizations should not be based on the belief that one gender is superior or inferior to the other, but rather on the recognition that both genders bring unique strengths and perspectives to the table when men and women work together in equal proportions, problem-solving benefits from a greater variety of viewpoints and holistic approaches.

Addressing these challenges and promoting gender equality in the automotive industry are not simple tasks and cannot be achieved quickly. It requires concerted efforts from educational institutions, businesses, and society to break down barriers and create an inclusive and supportive environment for all individuals.

In conclusion, striving for gender equality in the automotive industry is essential to fostering a diverse and innovative workforce. By challenging existing norms and providing equal opportunities for both genders, we can create a more inclusive and successful industry that benefits from the unique contributions of all individuals regardless of gender. Future studies need to be performed to understand the barriers that limit more women's participation in the automotive industry's low hierarchical levels. Bellow listed the relationship between lean manufacturing principles and gender equality.

1. Inclusivity in process improvement: Lean principles encourage the involvement of employees at all levels in process improvement. This inclusivity can help ensure that women and other under-represented groups have a voice in shaping the work environment.
2. Skill-based roles: lean manufacturing emphasizes cross-training and skill development among workers. This approach can help break down gender stereotypes and enable individuals to acquire skills traditionally associated with a specific gender.
3. Flexibility in work arrangements: Lean manufacturing's emphasis on flexible work arrangements can support gender equality by accommodating diverse needs, such as those of working parents, and help reduce barriers for women who wish to participate in the workforce.

4. Elimination of gender bias: lean processes aim to eliminate waste, including any form of workplace bias or discrimination. This commitment to fairness and equity supports gender equality by creating an inclusive and respectful work culture.
5. Performance-based evaluation: Lean manufacturing often employs performance-based evaluations, rather than relying on subjective criteria. This can reduce gender bias in performance assessments and promotions, thus making opportunities more equitable.
6. Work-life balance: Lean manufacturing can help organizations better manage workloads and schedules, allowing employees, including women, to achieve a healthier work-life balance, which is essential for career progression and retention.
7. Equal opportunity for leadership: Lean principles encourage employees to assume leadership roles in continuous improvement projects. By providing equal opportunities for women to lead these initiatives, organizations can promote gender diversity in leadership positions.
8. Equal pay for equal work: Lean manufacturing principles can help identify and rectify compensation disparities, ensuring that women are paid equally to perform the same work as their male counterparts.
9. Workforce engagement: Engaging all employees, including women, in lean initiatives can improve overall job satisfaction and retention. Gender equality is closely tied to the workforce's overall well-being and engagement.
10. Talent development: Lean manufacturing encourages companies to invest in employee development and management. This can help women access training, mentorship, and career progression opportunities, breaking down the barriers to advancement.

X.8.3 Human development through training initiatives and Improving workers' well-being

The two factors related to human development involve training initiatives and improving workers' well-being. Both have a positive impact on sustainability adoption. This finding is consistent with the works of Otoo (2019) and Ma et al. (2019), who found a correlation between education and training factors and the improvement of sustainability. Hickel's study (2020) also supports this correlation, showing a strong link between the level of human development in general and sustainability.

Improving employees' standard of living at all hierarchical levels is indeed a relevant and beneficial activity for enhancing the degree of sustainability adoption within industrial plants. This approach can result in a win-win situation for both companies and employees. Companies can increase their economic perceptions by developing training programs that enable employees to enhance their skills and knowledge. This can lead to improved productivity, which can compensate for the

increased costs associated with higher salaries, ultimately resulting in an improved standard of living for employees.

On a broader scale, raising the standard of living for most societies, especially those at the bottom of the economic pyramid, can positively affect the overall economy. People with higher purchasing power contribute more to economic growth and development.

Human development in industrial plants should encompass improving living standards, training opportunities, and occupational safety. Although this study did not perceive occupational safety, it should still be promoted as a crucial aspect that enhances working conditions and ensures employees' well-being and life expectancy.

Raj Sisodia's concept of "Firms of Endearment" (FoE) highlights the positive economic outcomes of companies that treat their employees more humanely and provide better benefits. FoE companies prioritize the well-being of all stakeholders, including customers, employees, investors, suppliers, and communities. These companies build stronger relationships and contribute to their success by fostering emotional ties with stakeholders.

In conclusion, improving the standard of living and investing in human development, including training, is an essential strategy for companies aiming to enhance their adoption of sustainability. These initiatives benefit employees and contribute to the organization's economic growth and success, fostering a more inclusive and sustainable business environment. The relationship between lean manufacturing principles and human development is described as follows.

1. Skill development: Lean manufacturing emphasizes cross-training and skill development among the workers. This can contribute to human development by equipping employees with a broader range of skills and making their roles more versatile. As individuals acquire new skills, they become more valuable in the organization and the broader job market.
2. Empowerment and engagement: Lean principles encourage employee involvement in process improvement. Empowering employees to identify and solve problems enhances the organization's efficiency and fosters a sense of ownership and engagement. This engagement contributes to personal and professional development.
3. Teamwork and communication: Lean manufacturing often involves collaborative teamwork. Effective teamwork fosters better communication, interpersonal skills, and cooperation, essential for personal development and can translate into improved performance in various life situations.
4. Eliminating waste: Lean principles focus on eliminating process waste. This often leads to removing non-value-added tasks and activities, which can reduce unnecessary stress and workloads for employees. A healthier work environment can positively impact the mental and physical well-being of the workforce.
5. Efficiency and time management: Lean practices aim to streamline operations and reduce inefficiency. This can result in more manageable workloads, better time management, and a healthier work-life balance, contributing to personal development by allowing employees to allocate time to personal and family activities.

6. Problem-solving skills: lean manufacturing requires employees to identify and solve problems. Developing problem-solving skills is valuable in the workplace and everyday life, promoting continuous learning and personal growth.
7. Continuous improvement: Lean principles promote a culture of continuous improvement. This mindset encourages individuals to continually seek personal growth and development, which aligns with human development principles.
8. Respect for individuals: Lean manufacturing emphasizes respect for individuals and their contributions. This can contribute to a positive workplace culture that values each individual's growth and well-being.
9. Health and safety: Lean practices often address health and safety concerns in the workplace, contributing to employees' physical well-being. This supports human development by ensuring a safe and healthy working environment.
10. Job satisfaction and quality of life: Lean practices can increase job satisfaction by reducing stress and frustration. Job satisfaction is closely linked to overall quality of life and well-being, contributing to human development.

X.8.4 Enhancement of workers' productivity

Enhancement of workers' productivity has demonstrated acceptable significance and, as a result, has a positive impact on the dependent variable. Palvalin's (2019) findings (2019) support this, indicating that enhancing the work environment and individuals' attitudes and skills can improve productivity. This theory aligns with the findings of Czyżewski et al. (2018), Pang et al. (2018), Busu (2019), Prasetyo (2019) and Baharin (2020); all of whom have shown that improving factors such as the work environment or individuals' characteristics contribute to improving productivity and, consequently, the adoption of sustainability.

Therefore, the hypothesis is that the enhancement of worker productivity positively impacts the incidence of sustainability adoption. This suggests that efforts to enhance personnel's productive performance can positively influence the adoption of sustainability in the automotive industry in the northeastern region of Mexico. By focusing on factors contributing to improving productivity, companies can be better equipped to embrace sustainable practices and achieve higher sustainability performance.

Indeed, improving productive staff performance is crucial for enhancing sustainability adoption in the automotive industry. Companies can focus on several key areas to achieve this.

1. Reduce absenteeism: Implement measures to promote employee well-being and work-life balance, which can help reduce absenteeism and improve overall productivity.
2. Minimize overtime: address the root causes of excessive overtime and streamline processes to ensure a more efficient use of labor resources.

3. Improve skills and Competencies: Invest in training and development programs to enhance employees' skills and competencies, making them more capable of contributing to sustainable practices.
4. Motivate employees: Implementing motivational strategies and recognition programs to keep employees engaged and committed to the company's sustainability goals.
5. Foster a positive work environment: Cultivate a positive and inclusive environment that fosters collaboration and encourages employees to participate actively in sustainability initiatives.

Additionally, initiatives to improve the standard of living, such as increasing salaries and offering training opportunities, can significantly enhance employee satisfaction and overall well-being. Employees who feel valued and supported are more likely to be motivated and productive, ultimately contributing to the success of sustainability efforts within the organization. The relationship between lean manufacturing principles and enhancing worker productivity:

1. Elimination of waste: A core principle of lean manufacturing is eliminating all forms of waste, including overproduction, excess inventory, defects, and non-value-added activities. This process streamlining ensures that employees spend more time on productive tasks, leading to increased productivity.
2. Standardization and consistency: Lean manufacturing often involves the development of standardized work procedures and processes. Employees with clear, standardized instructions and workflows can work more efficiently and consistently, leading to higher productivity.
3. Continuous improvement: Leans promote a culture of continuous improvement, where employees are encouraged to identify and solve problems in their work processes. Employees' engagement and empowerment lead to process enhancements and increased productivity over time.
4. Reduced downtime: Lean principles emphasize reducing downtime and delays in the production processes. By addressing bottlenecks and inefficiencies, employees spend less time waiting for materials, machinery, or information, which results in improved productivity.
5. Quality improvement: Lean practices focus on reducing defects and errors. When employees produce higher-quality work with fewer errors, less rework or correction is required, which, in turn, enhances productivity.
6. Workplace organization: Lean manufacturing often includes the concept of 5S (sorting, setting in order, shining, standardizing, and sustaining) for workplace organizations. An organized workspace reduces the time and effort required to find tools, materials, and information, thereby improving productivity.
7. Visual management: Leans often employ visual management tools, such as Kanban boards and visual cues, to help employees understand the status of their work and make better decisions. This visual clarity aids in task prioritization and decision-making, leading to increased productivity.
8. Reduced WIP Inventory: Lean manufacturing encourages limiting work-in-progress (WIP) inventory. This minimizes multitasking and allows employees to focus on completing one task before moving to another, which can improve concentration and productivity.

9. Employee involvement: Lean practices promote employee involvement in process improvements. Engaged employees are often more motivated and productive as they take ownership of their work processes and strive for better outcomes.
10. Time and motion studies: Lean techniques such as time and motion studies can help to identify and reduce unnecessary movements or activities in a process, leading to time savings and increased productivity.
11. Reduced overburden and uneven workloads: Lean manufacturing aims to balance workloads and eliminate overburdens on employees. This prevents burnout and fatigue, which can negatively impact productivity.
12. Employee training and development: Lean principles emphasize employee training and development, which can enhance employees' skills and capabilities and contribute to improved productivity.

X.8.5 Reduction of solid waste materials

The factor reduction of solid waste materials significantly impacts the response to sustainability adoption, as it has achieved a statistical significance of less than 5%. As a result, the hypothesis that the reduction of solid waste materials positively impacts sustainability adoption was accepted. The findings from the literature review were validated, and this agreement was observed in studies conducted by Yildimir et al. (2017) and Pourvaziry et al. (2020).

Additionally, Woolley et al. (2018) emphasized the economic benefits of waste recovery, particularly in terms of energy generation in the form of heat. Considering the global scarcity of resources, as highlighted by the Food and Agriculture Organization (FAO 2019), it is essential to use resources efficiently to minimize strain on the planet, as indicated by the World Wide Fund for Nature (WWF 2020). Efficient resource utilization is vital not only for environmental sustainability but also for meeting the needs of humanity, as people depend on products and services derived from these inputs.

Reducing the waste of solid material resources is crucial for improving the adoption of sustainability in the automotive industry. It aligns with environmental concerns related to resource scarcity and planet preservation and offers economic benefits through waste recovery and efficient resource utilization. Emphasizing sustainable practices that minimize waste generation and resource consumption can significantly contribute to an industry's overall sustainability performance.

Optimizing resource usage has several benefits to reducing the waste of solid material resources.

1. Lower car prices: Reducing waste can lead to cost savings in production, which can potentially translate into lower car prices for consumers, thus making sustainable products more accessible.

2. Addressing global resource Scarcity: By using resources efficiently, companies can mitigate the global scarcity of essential resources, thereby promoting sustainability at a broader level.
3. Circular economy: Developing awareness through training can lead to the adoption of circular economy principles such as reuse, recycling, and waste reduction. These activities can help minimize environmental impacts and promote a more sustainable approach to resource management.
4. focusing on employee performance and resource optimization are essential strategies for automotive industry players to improve their sustainability practices. By incorporating these measures, companies can enhance their environmental responsibility and contribute to a more sustainable and resilient future for society.

The relationship between lean manufacturing and waste reduction in the context of solid materials is similar to the general principles of lean manufacturing; however, it focuses explicitly on the management of materials and solid waste in production processes. Solid materials, including raw materials, work-in-progress, and finished goods, are a significant source of waste in manufacturing. The relationship between lean manufacturing principles and waste reduction is as follows:

1. Inventory reduction: One of the fundamental principles of lean manufacturing is the minimization of excess inventory. These include raw materials, components, and finished products made from solid materials. By reducing inventory levels and implementing just-in-time (JIT) practices, companies can significantly reduce waste associated with storage, handling, and obsolescence.
2. Material flow: Lean manufacturing emphasizes optimizing the flow of materials during the production process. Efficient material flow reduces waste associated with material handling, transportation, and waiting times.
3. Value stream mapping: Value stream mapping is a lean tool used to analyze and improve the flow of materials and information through the production process. It helps to identify areas of waste and inefficiency related to solid materials and their movement within the manufacturing process.
4. Defect reduction: Lean principles aim to reduce defects and errors during the production process. Reducing the defects in products made from solid materials can minimize the waste of raw materials and rework.
5. Standardization: Standardized work procedures and processes in lean manufacturing help ensure consistency and quality, thereby reducing the risk of using solid materials inefficiently or producing defective products.
6. 5S: The 5S methodology focuses on organizing the workplace for efficiency and cleanliness. It can be applied to storing and handling solid materials, reducing the waste caused by disorganization and inefficiency.
7. Waste types: Lean manufacturing identifies and targets specific waste types, including waste related to solid materials, such as overproduction (producing more solid materials than needed) and excess inventory of solid materials.
8. Continuous improvement: Leans' commitment to continuous improvement means that organizations regularly assess and optimize their processes, including those related to the use of solid materials. This ongoing effort reduces waste and improves the efficiency over time.

9. Supplier collaboration: Lean principles often involve collaborating closely with suppliers to minimize waste in the supply chain, including waste related to the sourcing and transportation of solid materials.

X.8.6 Climate change actions

In this study, there was no substantial evidence to support the notion that using renewable energy and reducing carbon dioxide emissions significantly enhances sustainability adoption. The discrepancies with other studies may reflect variations in the specific contexts and participants involved and differences in the level of understanding and awareness regarding sustainability issues. Further research and analysis are required to gain a deeper understanding of the relationship between these environmental factors and sustainability adoption in the automotive industry in the northeastern region of Mexico.

This phenomenon may be attributed to a lack of technical knowledge and education concerning sustainability. The perceptions of those surveyed suggest that using renewable energy and reducing carbon dioxide emissions do not significantly contribute to increasing the adoption of sustainability. This is in contrast to other studies, such as that conducted by Yumashev et al. (2020), who found that renewable energy and the reduction of carbon dioxide emissions positively impact the sustainability index.

Increasing awareness among respondents about the positive impact of using renewable energy and reducing carbon dioxide emissions is crucial, despite their current perception indicating no statistical significance in improving the adoption of sustainability. It is essential to educate individuals on the scientific and technical evidence that supports the effectiveness of these measures in combating climate change and enhancing the environmental dimension of sustainability.

Both rejected hypotheses are related to the environmental dimension of sustainability and are part of the solutions for climate change. This could be a problem of perception (Smith 2005), and perception does not always match reality (Reddy et al. 2016). On the one hand, this opens this topic for further investigation to confirm the relationship between the factors. We also investigate how to encourage the use of renewable energy and efforts to reduce carbon emissions in the industry. In the field and practice, it is also perceived that companies from outside the region, such as the USA and Europe, have a better promotion and understanding of this topic. They are more committed to actions aimed at fighting climate change.

Carbon dioxide emissions are a significant driver of global warming as they contribute to the greenhouse effect. Therefore, reducing these emissions is crucial for mitigating the impact of climate change. On the other hand, renewable energy offers a cleaner and more sustainable alternative to conventional fossil fuels. Not only do they not produce carbon dioxide but are also abundant and have become increasingly cost-competitive.

The relationship between climate change (focusing on the use of renewable energy and carbon dioxide reduction in the automotive industry) and lean manufacturing is complex. Lean manufacturing, which focuses on reducing waste, improving operational efficiency, and optimizing processes, can directly and indirectly affect climate change. Relationship between lean manufacturing principles and climate change

1. Reduced carbon footprint: Lean manufacturing aims to minimize waste, which often includes reducing energy consumption and emissions. By improving process efficiency and minimizing resource use, lean practices can directly contribute to a reduction in an organization's carbon footprint, which is essential for mitigating climate change.
2. Energy efficiency: Lean principles can lead to energy-efficient processes, equipment, and operation. Enhanced energy efficiency can reduce greenhouse gas emissions, significantly contributing to climate change.
3. Resource conservation: Lean practices often result in the more efficient use of resources, such as raw materials and water. The conservation of resources is vital for sustainability and can indirectly help mitigate the environmental impacts of climate change.
4. Environmental impact reduction: Lean manufacturing principles include reducing environmental impacts such as air and water pollution. This aligns with climate change mitigation efforts because many pollutants released into the environment are also contributors to climate change.
5. Supply chain optimization: Lean practices can be extended to supply chain optimization, which can reduce the carbon footprint associated with the transportation of goods. Optimized logistics and reduced transportation distances can lead to lower emissions from the transportation sector.
6. Life cycle thinking: Lean manufacturing encourages focus on the entire life cycle of a product. This can lead to a more sustainable product design and material selection, which can reduce emissions throughout a product's life cycle.
7. Waste reduction: Lean's core principle of waste reduction, including the reduction in materials and energy waste, aligns with the need to reduce resource consumption and greenhouse gas emissions, as excessive waste contributes to climate change.
8. Cost savings for sustainability initiatives: Cost savings from lean manufacturing can be reinvested in sustainability initiatives, such as transitioning to renewable energy sources or implementing carbon offset programs that can directly address climate change.
9. Adaptation to climate risks: Climate change can bring about new business challenges and risks, such as extreme weather events and supply chain disruptions. Lean principles, with their focus on agility and responsiveness, can help organizations adapt to these new risks more effectively.
10. Employee engagement Lean manufacturing often involves employee involvement and empowerment. Engaged employees are more likely to support an organization's sustainability and climate change initiatives.

Reinforcing training programs in the industry to raise awareness about their environmental impact and the measures that can be taken to address them is vital.

Such measures should include adopting renewable energy sources and implementing projects aimed at reducing carbon dioxide emissions. The implementation process can be streamlined and facilitated by integrating these initiatives with the energy management system through the ISO 50001 certification.

X.9 Sustainability adoption utility model

The investigation is a quantitative analysis, specifically an exploratory one, as the topic of the study is not well developed in the local context.

Table X.1 Key factors for sustainability adoption

No.	Key factor (Independent variable)
Y	Improvement of sustainability adoption
X_1	Implementation of an energy management system
X_2	Promotion of gender equality in the workforce
X_3	Human development through training initiatives
X_4	Improving workers' well-being
X_5	Utilization of clean renewable energy
X_6	Reduction of carbon dioxide emissions
X_7	Enhancement of workers productivity
X_8	Reduction of solid waste materials

The main aim of this study was to describe the phenomenon and explore the correlations between the selected key factors. For data collection, a questionnaire was designed and distributed to the study subjects selected from the sample representing the population. The research design was non-experimental, meaning that no modifications were made to the existing facts or conditions. Quantitative data analysis was conducted. It is worth noting that this study was cross-sectional and focused on one point in time (Hernandez, Fernandez and Baptista 2014).

The study was conducted in automotive manufacturing industrial plants, and the sample was randomly selected. The object of the study comprises a population of 101 manufacturing plants belonging to two regional industrial clusters: the Nuevo Leon Automotive Cluster (CLAUT) and the Coahuila Automotive Cluster (CIAC). The sample of 80 industrial plants was stratified proportionally, with 18 plants belonging to the CIAC and 62 plants belonging to the CLAUT. This study focuses on professionals employed in these industrial plants, particularly those in the areas of sustainability, operations, and energy. These professionals hold the highest hierarchical positions within their respective plants and possess substantial knowledge of relevant sustainability topics.

This study employed multivariate linear regression using successive steps (forward). This algorithm is one of the most widely used in scientific research. A vari-

able was added or subtracted at each step, and the SPSS Software generated several models as outputs. The regression was tested using F and t-tests, with a less than 5% significance level. Six models were identified in this study. Table X.2 displays the models found, with Models 1 to 5 discarded, while Model 6 was further investigated.

Where the final linear regression model is as follows:

$$Y = \beta_0 + \beta_1 * X_1 + \beta_2 * X_2 + \beta_3 * X_3 + \beta_4 * X_4 + \beta_7 * X_7 + \beta_8 * X_8 + \varepsilon \quad \text{(X.1)}$$

Table X.2. Coefficient from model

Coefficient / Variable	Variable	Beta unstd. Coef.	Beta std. Coef.
β_0	NA	1.115	
β_3 / X_3	Human development through training initiatives	0.154	0.215
β_7 / X_7	Enhancement of workers productivity	0.222	0.287
β_2 / X_2	Promotion of gender equality in the workforce	0.188	0.342
β_8 / X_8	Reduction of solid waste materials	0.109	0.185
β_4 / X_4	Improving workers' well-being	0.175	0.225
β_1 / X_1	Implementation of an energy management system	0.079	0.169

Where non-standardized β coefficients were used to make predictions using the model. Standardized coefficients were used to determine the relative predictive weight of each coefficient on the response variable.

Analyzing the standardized coefficients in Table X.3, it becomes evident that the variable X_2: Promotion of gender equality in the workforce positively impacts the adoption of sustainability.

Table X.3. TABLE Standardized coefficients

Coefficient / Variable	Variable	Std. Beta
β_2 / X_2	Promotion of gender equality in the workforce	0.342
β_7 / X_7	Enhancement of workers productivity	0.287
β_4 / X_4	Improving workers' well-being	0.225
β_3 / X_3	Human development through training initiatives	0.215
β_8 / X_8	Reduction of solid waste materials	0.185
β_1 / X_1	Implementation of an energy management system	0.169

Table X.4 presents the significance of the excluded variables—(X_5) Utilization of clean, renewable energy and (X_6) Reduction of carbon dioxide emissions.

Table X.4 Excluded variables

Coefficient/Variable	Beta In	t	Sig.
β_5 / X_5	0.035	0.375	0.709
β_6 / X_6	0.111	1.262	0.211

X.10 Use case

In this section, we explore some of the companies that participated in the study and reached a high sustainability adoption level. All companies (A, B, and C) have sustainability reports under GRI standards. All of these companies participate in the automotive industry, such as OEM, Tier 1, Tier 2, or service providers.

X.10.1 Case 1: Company A

Company A is a Tier 1 automotive system manufacturer with a long-standing reputation for providing innovative solutions for OEMs and the aftermarket. It is a transnational company with headquarters in Europe, leading the world in designing and producing high-performance systems and components. In 2022, they will participate globally in 15 countries, over 12000 employees and eight research centers. They have strong economic growth and profits. They won 22 renowned awards on sustainability. This company is an example of the adoption of sustainability in the automotive sector.

The following Table X.5 highlights the key factors that improve sustainability adoption.

Table X.5 Achievements

Key factors	Reported efforts
Implementation of an energy management system	30% of the plants are certified ISO 50001.
Promotion of gender equality in the workforce	Gender equality Policy on non-discrimination and diversity.
	17% women in 2022 compared with 13% in 2021.
Human development through training initiatives	Over 400k training hours.

	Training activities concerning organizational behavior.
Improving workers' well-being	Employee retention programs and talent attraction.
Utilization of clean renewable energy	Around 69% of renewable energy usage in their plants is for electrical energy usage.
	100% is planned for 2030.
Reduction of carbon dioxide emissions	It is included in the A list for climate change actions by CPD.
Enhancement of workers productivity	100% of the plants are certified ISO IATF.
Reduction of solid waste materials	100% of the plants are certified ISO 14001.

X.10.2 Case 2: Company B

Company A is a tier 2 power and automation system manufacturer known for focusing on sustainability around its product and service offerings. It is a transnational company with headquarters based in the United States of America, leading the North American region in the design and production of high-performance power and automation systems. It also has a growing presence in Asia and Europe. The company performs much better than the average S&P 500 Index. By 2022, they sold 7,800 MUSD. They had over 26000 employees. They won seven renowned awards for sustainability. This company provides an example of sustainability adoption in the automation sector. ISO 26000 for scorecard performance of sustainability indicators.

Table X.6 highlights the key factors that improve sustainability adoption.

Table X.6 Achievements

Key factors	Reported efforts
Implementation of an energy management system	Development of their energy management system software.
Promotion of gender equality in the workforce	Gender equality Policy on non-discrimination and diversity.
	32% of women in 2022.
Human development through training initiatives	The approach is to understand the gaps in the workforce and upskill and reskill employees.
Improving workers' well-being	Listed in the 2022 world's most ethical companies and best place to work.
Utilization of clean renewable energy	100% is planned for 2030. Carbon neutral on scopes 1 and 2.
Reduction of carbon dioxide emissions	100% is planned for 2030. Carbon neutral on scopes 1 and 2.
Enhancement of workers productivity	100% of the plants are certified ISO 90001.
Reduction of solid waste materials	Nineteen plants are certified ISO 14001.

X.10.3 Case 3: Company C

Company C is an OEM manufacturer of agricultural automotive systems, leading the sector worldwide in innovation and high-quality products and systems. It is a transnational company with headquarters in the United States. In 2022, they will have global participation and over 80,000 employees. They have strong economic growth and profits, with USD 52,000 million in sales. They won twelve renowned awards related to sustainability.

Table X.7 highlights the key factors that improve the adoption of sustainability.

Table X.7 Achievements.

Key factors	Reported efforts
Implementation of an energy management system	They have an internal energy management system focused on sustainable energy usage and efficiency excellence.
Promotion of gender equality in the workforce	Gender equality Policy on non-discrimination and diversity.
	21% of women in 2022.
Human development through training initiatives	Over 400k training hours.
	Robust training and innovative development
	opportunities so every employee can build a rewarding career.
Improving workers' well-being	Listed in the 2022 world's most ethical companies and best place to work.
Utilization of clean renewable energy	Around 59% of renewable energy usage in their plants is for electrical energy usage.
Reduction of carbon dioxide emissions	Focus on reduction on emission on their customer. By implementing technologies with reduced CO_2 emission.
Enhancement of workers productivity	100% of the plants are certified ISO 9001.
Reduction of solid waste materials	Fifty-two plants are certified ISO 14001.

X.11 Conclusions

From the use cases, it is easy to see how companies that invest in sustainability adoption have been the company that delivers good results. These companies reduce environmental impact, meet customer demands for eco-friendly products and services, improve operational efficiency, comply with regulations, and enhance long-term resilience by mitigating the risks associated with climate change and resource scarcity. In addition, sustainability initiatives contribute to a positive brand image and attract socially responsible investors.

Sustainability adoption can be used as a tool for LM initiatives, which can work together with mutual synergy. The key factors that help improve sustainability adoption are related to the social dimension of sustainability in this study. This indicates that employee actions are perceived more in the adoption of sustainability. The social dimension is the most neglected of the three dimensions of sustainability in the automotive industry and other types of industries in Mexico. This makes sense when comparing indicators such as minimum wages, vacations, or salary perceptions with those of other countries that have better sustainability adoption.

Humanity probably never imagined the type of problem it was generating: problems related to the sustainability of humans as a species. It unconsciously originated over a long period, mainly during the industrialization epoch. With a significant problem at hand and limited time, conscious efforts must be made to implement appropriate solutions to reverse the adverse consequences of not adopting sustainable development. Lean manufacturing and sustainable development are part of this solution. To paraphrase Albert Einstein, "No problem can be solved at the same level of consciousness that created it".

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