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Cleaner Production Techniques in the Beverage Industry: A Review of Strategies and Practices for Sustainable Manufacturing

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ABSTRACT. –

The beverage industry is highly resource-intensive, requiring vast amounts of water, energy, and raw materials while generating considerable waste. Cleaner production (CP) techniques are vital for reducing the environmental impact of beverage manufacturing by improving resource efficiency, minimizing waste, and implementing sustainable technologies. This review provides an overview of key CP methods utilized in the beverage industry, including water conservation, energy optimization, waste recycling, and eco-friendly packaging solutions. Case studies demonstrate CP implementation's economic and environmental benefits, such as cost reductions, improved sustainability, and regulatory compliance. The paper also identifies challenges and future opportunities, emphasizing the importance of industry-wide adoption of CP techniques to ensure long-term sustainability.

Keywords: - Cleaner Production, Beverage industry, Water conservation, Sustainability, Waste management

1 Introduction :

The beverage industry represents a major segment of the global food sector, contributing significantly to economic development and environmental degradation [3]. Beverage production relies on vast quantities of water, energy, and agricultural resources, making it one of the most resource-intensive industries. The environmental footprint of beverage production is marked by high water consumption, large amounts of organic and inorganic waste, extensive use of packaging materials, and significant energy use for heating, cooling, and transportation [29].

The main tools for implementing sustainable development are cleaner production (CP), the 7Rs Golden Rule, industrial ecology (IE), and environmental impact assessment (EIA)[13]. Cleaner production (CP), a concept introduced by the United Nations Environment Programme (UNEP) in 1989, offers a preventive environmental approach to minimize waste and pollution at the source. It encourages companies to rethink their production processes, adopt efficient technologies, and reduce their reliance on non-renewable resources [26]. CP techniques have become especially important in the beverage industry, as consumer expectations for sustainability grow and regulatory pressures increase. This paper reviews the various cleaner production techniques applied in the beverage industry and examines their economic and environmental impact. Cleaner production is a product of the "end-of-pipe" vision. Still, it has a preventive approach to environmental management and aims to produce goods and services in a way that minimizes their impact on the environment within the current economic and technological constraints that companies face [28].

2 Cleaner Production Technology :

Cleaner production technologies provide a more basic approach to dealing with environmental degradation from economic activities. Clean technologies also allow developing countries to "leapfrog" over the older, more polluting growth path historically followed by the more industrialized countries [11].

Companies can achieve clean production by [29]: -

- Knowing all the chemicals used, and in what quantities, in their production system by doing a comprehensive materials audit.
- Assessing the hazard of each chemical and material and ensuring that the information on all releases of hazardous substances is publicly available for free.
- Prioritizing all hazardous chemicals for elimination through substituting safer chemicals in processes or product redesign.
- Establishing reduction targets and timelines for the complete elimination of current hazardous chemicals use through toxic use reduction and elimination plans.

Cleaner productions about beverage manufacturing emphasize greatly the following [5]:

- Use of materials
- Energy consumption

- Minimization of waste
- Minimization of emissions
- Reduced risk to humans

Various steps are involved in the assessment of cleaner production which are shown in the following Fig 1.

Fig 1: - Steps addressed in the study of cleaner production methodology [5]

Table 1: - Cleaner production stages [22]

Phase	*Stages*
I: Planning and organization	1. Obtain management commitment 2. Establish a project team 3. Develop policy, objectives and targets 4. Plan the Cleaner Production assessment
II: Pre-assessment (qualitative review)	1. Company description and flow chart 2. Walk-through inspection 3. Establish a focus
III: Assessment (quantitative review)	1. Collection of quantitative data 2. Material balance 3. Identify Cleaner Production opportunities 4. Record and sort options

3 Literature Study :

- **(Frondel et al., 2007): -**The paper compares two types of environmental innovations: cleaner production and end-of-pipe technologies, highlighting that cleaner production is generally considered superior for environmental and economic reasons. It identifies barriers to adopting cleaner technologies, such as high investment costs and lack of organizational support. The study utilizes a unique dataset from seven OECD countries to analyze the factors influencing firms' choices between these technologies. The research reveals that most facilities prefer cleaner production technologies, with notable differences among countries, particularly lower adoption rates in Germany compared to Japan. It concludes that while end-of-pipe technologies have historically dominated, there is a growing trend toward cleaner production, especially in response to changing regulations and market conditions [7].

- **Ignatio Madanhire, and Charles Mbohwa(2014):-**The study focuses on improving resource efficiency, reducing wastewater, and minimizing raw material losses in the beverage manufacturing sector. It proposes several cleaner production technologies to achieve these goals. Cleaner production technologies are beneficial not only for environmental sustainability but also for economic efficiency. The assessment of current practices reveals that the company generates significant solid waste, primarily from packaging materials like cardboard and plastic containers. Approximately 1420 kg of solid waste is produced monthly, with 1200 containers lost as waste. The study suggests that implementing advanced cleaner production options can lead to better resource management and waste reduction. For instance, one proposed option includes a buy-back method for plastic containers, which requires further investigation. Overall, the findings indicate that adopting cleaner production practices can lead to both environmental benefits and improved economic performance for companies in the beverage industry [9].

- **Samuel, F. Oyawale1 and O.S.I Fayomi(2019):-** This study explores the challenges and strategies related to waste management in beverage industries. It emphasizes efforts to minimize waste through improved packaging, redesigning operational processes, and recycling practices. The study identifies various sources of waste, including production excess, packaging defects, and inefficiencies in the production line. It also discusses the importance of adopting lean manufacturing tools like Value Stream Mapping (VSM), Just-In-Time (JIT), and Six Sigma to optimize processes and reduce waste. Implementing effective waste management strategies is highlighted as a key approach to enhancing profitability and sustainability in the beverage industry [24].

- **Hannah de Oliveira Santos et al., (2019): -**The study suggests that adopting CP involves not just technical adjustments but a shift in organizational behaviour, requiring commitment from both management and employees. This approach enables service providers to improve their use of resources, minimize waste, and contribute to sustainable development. The paper highlights that successful CP implementation can lead to financial gains through better resource use, improved market positioning, and a positive impact on the quality of life for local and

global communities. Key findings demonstrate that targeted investments in resource-efficient technologies, such as flow reducers in hotel showers and energy-saving appliances, can yield substantial savings and rapid payback periods. For example, the hotel case studies showed water savings of over 2,000 m³/year and annual financial savings exceeding $4,000, with investments recouped in as little as 2 to 5 months [25].

- **Kumbi Mugwindiri, Ignatio Madanhire, Tapiwa Masiiwa(2013):-** The study proposed an integrated system that combines various advanced cleaner production technologies to enhance resource efficiency, reduce wastewater, and minimize raw material losses during manufacturing. This approach aims to create a more sustainable production process for DrinkCo Beverages. For instance, recovering steam condensate or switching to more energy-efficient equipment can yield savings in energy and water consumption, reducing the overall production costs. It concludes that the successful implementation of cleaner production measures depends on a strong commitment from management and staff training. If done properly, these initiatives can enhance both the environmental performance and economic viability of companies like DrinkCo, promoting long-term sustainability [9].

- **Adriana S. Silva, Carla F. Medeiros, Raimundo Kennedy Vieira (2017): -** It focuses on using the PDCA (Plan-Do-Check-Act) methodology to reduce waste in the production process of a beverage company. The main target was to decrease the Cans Loss Index (CLI), which represents the percentage of cans lost during production. Key results include the Implementation of actions like training, revising maintenance plans, and improving operational processes. The CLI decreased from 0.97% to 0.78% by the end of the year, resulting in a cost reduction of over 35% in the second half of the year compared to the first half. In the following year, the CLI further decreased to 0.60%, achieving a 28.91% reduction in costs within the first four months. Overall, the study demonstrated that integrating cleaner production practices with the PDCA cycle can lead to substantial reductions in waste and cost while improving productivity and operational efficiency [26].

- **Doris T. Hicks et al., (2009): -** This paper examines consumer knowledge, attitudes, and willingness to pay (WTP) for foods treated with high-pressure processing (HPP). The study surveyed 1,204 adults in the U.S., revealing that only 8% of participants were aware of HPP. When provided with information about HPP's benefits, 39% of respondents expressed a willingness to pay more for products treated with this method, while 15% were not willing to pay extra, and 45% were unsure. Most willing consumers indicated they would pay an additional $0.25 to $0.50 per item for improved safety and quality. Higher education and income levels were associated with a greater likelihood of willingness to pay [4].

- **Ioana A. Negroir et al., (2017): -**This paper focuses on sustainable waste management practices in a natural juice production company. It emphasizes cleaner production (CP) strategies, such as using the best available techniques (BAT) like High-Pressure Processing (HPP) to reduce waste and improve product quality. The study highlights the importance of reusing and recycling waste materials, like pulp from fruit pressing, for other products, such as animal feed or energy bars. It also discusses the integration of industrial ecology principles to create a closed-loop system where waste from one stage serves as input for another [18].

- **Abidin, Rahimi, Abdullah, Che Sobry and Osman, Wan Nadzri(2010):-** The study Clean Production Strategies Adoption: A Survey on Food and Beverage Manufacturing Sector examines factors influencing the adoption of clean production strategies in Malaysia's food and beverage industry. It identifies three key factors: technology characteristics (ease of integration, benefits), technology performance (manufacturing and environmental benefits), and communication networks (information sharing within industry groups). The study found that all three significantly impact adoption, especially environmental performance and communication networks. Firms adopt these strategies to comply with regulations and improve their environmental image, enhancing sustainability efforts [1].

- **Manoel Gonçales Filho et al., (2018):-** The paper explores how sugarcane processing plants can use Cleaner Production (CP) methods to minimize water use. Key opportunities identified include implementing dry cleaning systems, recycling wastewater, and concentrating vinasse (a byproduct). These strategies can help reduce water consumption while improving sustainability. Challenges involve the high costs of CP technologies and the need for better environmental management systems. Case studies showed potential water savings, highlighting CP's role in balancing economic and environmental goals [6].

- **Letícia do Couto Pereira1 and Éverton Hansen (2020): -**The paper discusses the implementation of wastewater reuse in the Clean in Place (CIP) process within a beverage industry, focusing on improving water efficiency and reducing environmental impact. The study achieved a significant reduction of 32.75% in water consumption and effluents generated by reusing water from the final rinse stage. This resulted in a decrease of 8.62 tons of water consumed annually, which also means that the same amount of effluent is no longer discharged. There was a notable reduction in detergent usage, decreasing from 320 kg to 200 kg per CIP cycle, which represents a 37.5% reduction. This was achieved through adjustments in detergent concentration and process timing. The improvements led to a 34% reduction in CIP time, enhancing the overall efficiency of the production lines. Shorter downtime translates to increased productivity for the industry. The financial impact of these improvements was substantial, with annual savings of approximately US$ 141,491.19, equating to a 36.4% reduction in costs associated with water and detergent consumption. The study also included microbiological analyses to ensure that the quality of equipment decontamination was maintained after implementing the changes. Samples from the final rinse and recovered water were tested to meet the company's microbiological standards [11].

- **Hengky K. Salim, Rory Padfield (2017):-** The paper examines the adoption of environmental management systems (EMS), specifically ISO 14001, in the Malaysian food and beverage (F&B) sector. It highlights the challenges faced by companies, including high certification costs, lack of in-house knowledge, and insufficient government support, which hinder the adoption of these standards. Despite a general awareness of environmental impacts among companies, only a small percentage are certified, particularly among small and medium-sized

enterprises (SMEs). The study suggests that without increased government incentives and support, the adoption rates of ISO 14001 will remain low, potentially excluding uncertified SMEs from competitive markets [23].

- **Thomas B. Long, Arnold Looijen, Vincent Blok (2018):-** The paper examines critical success factors for transitioning to sustainable business models in the Dutch food and beverage industry, focusing on small and medium-sized enterprises. It involves in-depth interviews with companies in the proactive phase of sustainability, emphasizing the need for models that balance economic profit with social and environmental benefits. The paper emphasizes the importance of creating business models for sustainability (BMfS) that not only aim for economic profit but also prioritize social and environmental benefits. This includes encouraging sufficiency and developing scalable solutions. Overall, the paper highlights the critical success factors and barriers that influence the transition to sustainable business practices in the food and beverage industry, providing valuable insights for practitioners [27].

- **Genett Isabel Jiménez-Delgado (2024): -**The paper examines the implementation of Lean Manufacturing in a non-alcoholic beverage company, focusing on achieving quick wins in productivity and cost efficiency. The non-alcoholic beverage sector faces competition, regulatory pressures, and evolving consumer preferences, necessitating effective strategies for quality and cost management. The study followed a four-phase process: diagnosing the production line, identifying waste, implementing Lean techniques, and evaluating the impact on performance metrics. Focused on a leading Latin American beverage company, the research revealed significant time losses during flavor changes, prompting targeted Lean interventions. The application of Lean techniques reduced flavour change time from 234 minutes to 170 minutes, leading to substantial cost savings and fostering a culture of quality and continuous improvement within the organization. Overall, the study highlights the effectiveness of Lean Manufacturing in enhancing operational efficiency and addressing industry-specific challenges in the non-alcoholic beverage sector [12].

- **Indra Budaya, Anggil Novra Lova, Elex Sarmigi(2024):-** The study aims to explain how green customer integration affects economic performance, particularly through the mediation of green product innovation. Green product innovation has a significant direct effect on economic performance, with a critical ratio (CR) value of 4.993, indicating a strong relationship. Green customer integration also directly influences economic performance, with a CR value of 4.973, suggesting that better customer relationships positively impact profits. The research concludes that green customer integration has a partial mediating effect on economic performance through green product innovation, with an indirect influence of -0.003. The findings highlight that effective integration of environmentally friendly practices with consumers can enhance product innovation and, consequently, improve economic performance. This research underscores the importance of green practices in enhancing both customer relationships and economic outcomes in the agro-food and beverage sector [2].

- **Rafael Mora-Contreras et al., (2023): -** The paper investigates the impact of environmental management systems (EMS) and cleaner production (CP) practices on circular and sustainability performance in Colombian manufacturing firms. It highlights the need for clarity in the relationship between these practices and sustainability outcomes, as previous research has shown mixed results, including some negative effects. Key findings indicate that while companies adopting EMS and CP practices can benefit from improved organizational performance, such as waste sales and water reuse, these practices do not necessarily lead to waste circularity. It also emphasizes limited sustainable value creation in social terms and suggests that strategic implementation of circular economy practices and eco-innovations is essential for enhancing sustainability performance. The paper concludes by acknowledging limitations, such as the focus on manufacturing firms in an emerging economy and the restricted selection of variables based on available data. It calls for future research to explore these relationships in other sectors and countries [16].

- **Lopes, R.B., Freitas, F., Sousa, I.(2015):-**The research aims to explore how LM tools can improve processes in the food and beverage industries, addressing increased costs due to regulations and the need for process innovations. Two case studies were conducted, focusing on Company A, a medium-sized beverage producer, and Company B, part of a larger food industry group. Both companies faced challenges related to production efficiency and changeover times. The study specifically highlights the application of 5S (a workplace organization method) and SMED (Single-Minute Exchange of Die), which aims to reduce changeover times to single-digit minutes. This is crucial for minimizing non-value-adding activities during production. The implementation of LM tools led to significant gains in production flexibility, reduced lead times, and fostered a culture of continuous improvement within the organizations. This shift not only improved operational performance but also enhanced customer satisfaction The findings suggest that LM principles are underutilized in the food industry, and their effective application can lead to substantial improvements in efficiency and competitiveness [14].
- **Khusaini, N.S., Jaffar, A., Yusoff, N (2014): -**The study presents a preliminary study focused on the implementation of Lean Tools (LT) within the Malaysian food and beverages sector. A survey was conducted involving 300 organizations selected from a total of 1309, aiming to identify the most implemented Lean Tools in the industry. The analysis revealed that only six out of eighteen Lean Tools are actively applied by the organizations surveyed. Notably, Kaizen emerged as the most preferred tool, while Single Minute Exchange of Die (SMED) was identified as the least favourable. The results were analysed using the Rasch Model, which provided insights into the extent of Lean Tool implementation in the Malaysian food and beverages industry. This approach is significant as it may be one of the first attempts to assess Lean Tool usage in this specific context. The literature suggests that while Lean Manufacturing can lead to significant improvements, organizations often face challenges in changing existing management systems, which can lead to confusion and disturbances during the implementation process [13].

4 Conclusion :

Implementing Cleaner Production (CP) techniques in the beverage industry presents a viable pathway toward achieving both environmental sustainability and economic efficiency. This review has explored the application of CP strategies across diverse industrial contexts. Thus, the

implementation of cleaner production programs in service companies can provide financial gains through better use of raw materials, energy, and water, and minimization of waste generation [9]. It is possible that through this practice there will be an increase in competitiveness, reducing production costs and improving the quality of life of the local and global community. Adopting cleaner production means innovating for organizations, as it is a process that requires behavioral change, including all actors involved in the process [11]. Therefore, the commitment of all managers and employees is necessary to achieve an efficient performance regarding sustainability development. While sum up, it is heartening to note that cleaner production technologies exercises are not only desirable from the environmental point of view as a pre-emptive strategy but also make good economic sense [8]. As has been seen in many cases, such exercises have added to the bottom line by conserving resources like energy, raw materials, and manpower, improving yield, and reducing treatment/disposal costs is important to highlight that each company must understand its role in society and contribute, even with small actions, to the sustainable development of organizational processes [22].

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