Challenges of Implementing Cleaner Production Strategies in the Food and Beverage Industry: Literature Review

Rodrigo Valle Espinosa, Maria Soto, Marcelo V. Garcia, and Jose E. Naranjo

Abstract Cleaner production (CP) represents a set of strategies in favor of the environment, productivity, and the optimization of manufacturing processes from a holistic point of view that includes the whole life cycle of the product, proactive, preventive, and environmentally friendly strategies through which water consumption is reduced, emissions, waste and the sustainability of the production chain is achieved. In general terms, the implementation of cleaner production strategies in the food and beverage industry represents a saving of 35 % of total costs; the accelerated growth of environmentally conscious markets has forced the industry to implement CP strategies in accordance with the particular line of business, with the aim of remaining competitive in markets where actions on environmental care are becoming increasingly important. This paper presents a qualitative systematic review of the literature (SRL) on the implementation of CP strategies in food and beverage industries and the challenges in applying them, analyzing scientific articles from the last five years, from relevant bibliographic databases (Scopus, ScienceDirect, IEEE Xplore, SpringerLink) synthesized particularly in five proposed topics. From the results obtained, it is concluded that the implementation of cleaner production strategies in the food industry represents an opportunity factor for the sector, not only by combining its actions with the sustainable development objectives for 2030, but also by reducing operating costs and optimizing production lines.

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1 Introduction

The productive model developed in the twentieth century operated under the criterion that natural resources were unlimited, for years factories managed productive systems that today are ecologically unsustainable. Man used natural resources without any kind of supervision because it was believed that nature was capable of absorbing waste and regenerating itself without affecting the biosphere [28]. Today's fiercely globalized and competitive twenty-first-century markets demand not only a greater variety of products at a reduced cost, shorter delivery time, and perfect quality, but they prefer these products to be ecologically sustainable. This changing scenario requires a new manufacturing paradigm [4].

The main environmental problems presented by industries are energy consumption and the generation of liquid and solid waste and emissions [22, 38]. To minimize environmental impact and increase competitiveness and business economy, industries use strategies of cleaner production (CP) that through technological innovation allows the reduction of manufacturing costs [21, 23].

CP allows energy to be saved, resources to be reused, the quantity of waste and unwanted emissions to be reduced and the consumption of raw materials to be reduced, and is understood as a model of industrial development based on the principle of reasonable use of resources. CP achieves the reduction of post-operational costs of waste management [38]. There are several strategies used by the CP to achieve its industrial innovation process. Among the strategies used are good operating practices, input substitution, improved process control, modification of equipment and machinery, technological changes, product restructuring, internal recycling, generation of products from waste [8, 23]. One of the productive sectors benefiting from these strategies is the agro-industrial sector. The relationship between the agricultural sector and the industrial sector favors the application of CP since it allows the closure of production cycles through the reuse of by-products [9, 38].

Agro-industry is an important part of the economy of South American countries, using as its main resources (inputs) raw materials from the exploitation of land, water, and energy to obtain products and waste (outputs). Due to the inadequate use and/or dumping of the waste generated, negative impacts are caused to the environment and, therefore, to human health [19]. Beverage and liquor companies are part of the agro-industrial sector and also play a key role in the consumption of non-renewable resources, mainly water and energy [34]. The proportion of energy used differs in each country, yet a pattern is observed where the energy consumed by agro-industry in developing countries is generally very high. For example, in African countries, energy consumed by the agro-food chain can contribute up to 55% of national consumption, a high value compared to 15.7% in the United States [1].

In this context, many governments and trade companies recognize the importance of energy-saving practices [34]. CP drives energy savings through well-distributed lighting design [17] and the use of alternative energy such as biomass which is a type of energy produced from plant and animal waste [10]. Another energy alternative is the use of heat pumps that allow the use of waste heat from thermal processes, including drying, cooking, evaporation, among others [1].

Additionally, the implementation of CP in the beverage industry allows for the reduction of the water footprint, benefiting the conservation of the biosphere especially considering that freshwater has become a scarce and overexploited natural resource in many parts of the world, threatening widespread irreversible environmental change and harmful impacts on human well-being [11]. In short, the CP has a practical approach that allows environmental and economic benefits to be balanced in an integrated manner. Replacing production and waste management processes with environmentally friendly operations is a challenge for beverage and liquor companies [20]. Countries such as Canada and Nigeria, the world's leading malt beverage producers, have joined the challenge of a CP [7, 20].

In order to preserve the environment, it is necessary that more companies join this initiative, the following is a bibliographical review that summarizes the results obtained and the main problems presented in the beverage industries when adapting to a cleaner production system, in addition the obtained results will serve to motivate to the agro-industrial companies to optimize the use of raw materials, water, and power resources, focusing the benefits not only from the environmental point of view but also the economic one.

This document is made up of five sections. Following the introduction, section two presents the methodology applied for the selection of articles and for the analysis of the data obtained. In section three is the bibliographic review, the research works analyzed are of implementation, therefore, in this section the results obtained in different companies when adapting to a CP system are presented. Section four contains a critical analysis of the articles analysed, emphasizing energy saving and water reuse, and finally concludes in section five.

1.1 Methodology

For this bibliographic article, we use the methodology of qualitative systematic review, proposed in [31, 32]. Based on this method, a strict review process was carried out to compile scientific publications that were later evaluated under a qualitative approach. In order to answer the questions raised in this research, the first one was What are the problems presented in the food industry when applying CP strategies? and the second one was What are the results obtained by the beverage and liquor industries when changing their processes to CP operations?. In Fig. 1 an outline of the protocol used to obtain relevant data is presented.

Within the databases, the most relevant key terms were generated: cleaner production, renewable energy, food industry, and ecologically sustainable production

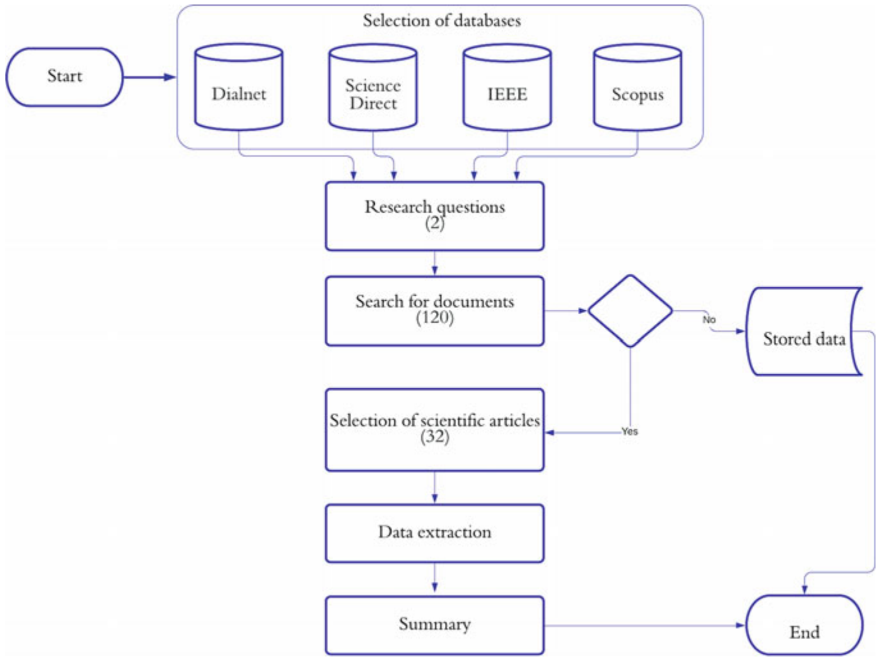


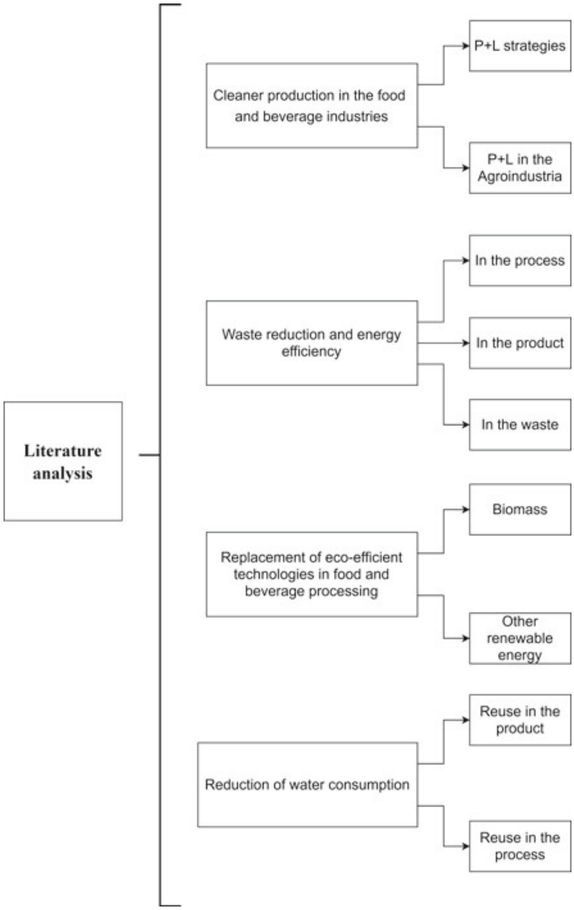
Fig. 1 Scheme of systematic qualitative bibliographic review

(see Fig. 2). Search criteria were applied prioritizing articles on cleaner production implementation in food industries, publications that have the endorsement of academic peers and papers published in the last five years in English language were chosen. A total of 120 articles were reviewed, of which 49 belonged to Science Direct, 37 to Scopus, 31 to IEEE, and 3 to Dialnet.

For the selection of articles and/or publications, the title was reviewed, followed by the abstract of the publication, to determine the degree of connection they presented with the questions posed in this literature review. When the relationship was high, the conclusions were read and then the introduction was added to the selection of publications that were subsequently analyzed. The 32 articles selected were summarized by answering the questions posed. The bibliographic manager Zotero was used to organize the information collected and the presentation format chosen was Springer.

Based on the data presented in the bibliographic review, a discussion was held consisting of a critical analysis of the progress made, recommendations for future research, and the author's own criteria were issued. The analysis was prioritized in terms of the CP strategies proposed to reduce energy consumption, and the strategies proposed to minimize the water footprint generated by agro-industrial companies dedicated to the production of beverages and liquors.

Fig. 2 Literature search relevant topics



2 Literature Analysis

In the case of the food industry, cleaner production (CP) opportunities can be applied by minimizing the loss of raw materials, improving energy efficiency, reducing water consumption, improving cleaning and maintenance practices, improving packaging processes, and properly separating waste; a review of the literature on some strategies applied in the industry is presented below.

2.1 Cleaner Production in the Food and Beverage Industries

Cleaner production represents a proactive and preventive industrial approach to the environment by seeking integrated process and/or product solutions that are both environmentally and economically efficient ("eco-efficiency"). The pioneers in this field were the large process industries in the United States of America (from the late 1970s), but until the early 1990s, cleaner production was generally recognized as a valuable approach for large and medium-sized enterprises in all industrial sectors [6].

The definition of cleaner production adopted by the United Nations Environment Programme (UNEP) [29] is "The continuous application of a preventive environmental strategy integrated into processes, products and services to increase overall efficiency and reduce risks to humans and the environment".

ANFAB [3] presents in context that cleaner production strategies are the continuous application of integrated policies and preventive environmental methodologies applied to processes, products, and services to increase overall efficiency by 30% and business competitiveness, therefore, the application of these strategies is indispensable in the food and beverage processing industry.

For the food industry, cleaner production (CP) opportunities can be applied by minimizing the loss of raw materials, improving energy efficiency, increasing water consumption efficiency, better cleaning and maintenance practices, improvements in packaging processes and proper waste separation.

Guo et al. [13] argue that the food and beverage industry is potentially a green industry, and the waste is safe and bio-friendly. However, these wastes can pose serious environmental problems if not properly managed. Nooi-Loo [25] states that, worldwide, a large percentage of total wastewater effluent is released by food processing companies without any treatment.

In addition, they point out that, specifically the alcoholic beverage industry whose main process is alcoholic and acetic fermentation; in Malaysia, by 2018 they contributed 35% of total industrial wastewater effluents, representing the fifth most polluting industry in the country, so the implementation of environmental mitigation strategies is essential for the beverage industry, based on government initiatives and corporate environmental awareness. Currently, there is a great demand for research on factors influencing the adoption of environmentally friendly technologies in the food and beverage industry. This concept is supported by Bates et al. [5], who suggested that research within the food and beverage industry should be intensified to improve waste treatment efficiency, and to minimize waste in food processing and manufacturing operations. Fryer [12] considers that from the consumer's point of view the application of cleaner production strategies in the alcoholic and non-alcoholic beverage industry does not represent a focus compared to food safety strategies, however, the continued growth of green markets and environmentally conscious consumers represent an important starting point in the adoption of eco-friendly production strategies. Henningsson et al. [14] describe how waste minimization can be as successful in the alcoholic beverage industry as in other industries that are often considered more polluting. Thirteen companies made annual savings of 1.1 million in the Eastern Angola Beverage Industry Waste Minimisation Project. These alcoholic beverage production companies reduced annually: raw material use and solid waste production by 1,400 tons; carbon dioxide (CO2) emissions by 670 tons; and water use by 70,000 cubic meters.

Abidin et al. [2] state that there are common non-regulatory aspects around the world that are the main limitations when it comes to implementing cleaner production strategies in the food and beverage industry, which are characteristics of environmental technology, communication networks, and efficiency of eco-friendly technologies, which must be adapted to the national reality and the line of business of each company. On the other hand, the most influential factors when implementing cleaner production strategies are focused on socio-political environmental aspects, the demands of the interested parties, the regulatory pressure, and the external governmental and legislative international pressure. In Latin American countries, there are no clear policies of incentive for the adoption of cleaner production strategies, but in contrast isolated public-private initiatives that support their implementation, however, in several countries these initiatives are more consistent than in others, based on their relationship with technology and their adoption processes. These characteristics include the relative advantage it offers compared to implementation costs, its complexity and compatibility with production processes, and how the results of the innovation are presented [24].

According to ANFAB [3], in Ecuador, starting in 2017 the food and beverage industry has deployed several initiatives to implement cleaner production strategies that allow for the optimization of production processes and care for the environment. Hence, the need to continue searching for alternatives such as technology substitution in production processes, leveraging on tax exemptions, incentives and government certifications (green dot, do good, do better) and private credit lines with preferential interest rates for industries with ecological initiatives.

2.2 *Waste Reduction and Energy Efficiency*

Wu y Low [35] propose a cleaner production alternative for the alcohol production and fermentation industry by recycling distillery residues (stillage) and using ultrafiltration with a ceramic membrane, which increases the average yield of ethanol production by 8.8% thus eliminating the stillage treatment stages using conventional biological treatment processes, such as anaerobic digestion and activated sludge stages currently used in the industry, reducing waste in 92% of the production process.

Notarnicola et al. [26] emphasize that, in the agro-industrial production chain, significant amounts of food-grade material are rejected from the production line because of unsatisfactory quality or out of standard for visual, physical, microbiological, or compositional (chemical or biochemical) reasons.

Reducing the use of raw materials carries the greatest potential for financial savings because this source reduction approach exceeded by more than two orders of magnitude the corresponding savings in landfill costs in an analysis in the UK alcoholic beverage industry in 2015. This reinforces the importance of companies identifying source reduction opportunities, rather than end-of-pipe solutions and the relatively low cost of disposal to the beverage industry.

Currently, with the aim of maximizing waste reduction the food and beverage industries are applying the methodology of life cycle assessment (LCA), which provides the organizational framework to holistically assess the environmental impacts of products and production systems. According to Özbaya and Demirer [37], the use of LCA in the environmental management and sustainability of the food and beverage industries has grown rapidly in recent years, as shown by the growing number of published documents on LCA methodology and case studies, which amounted to more than 4,500 in 2019 in Europe alone, focusing on the reduction of energy consumption or energy efficiency in the LCA chain.

Ikemoto et al. [16] state that the food industry includes many energy-intensive operations such as sterilization/pasteurization, drying, and even refrigeration of products during distribution, storage, and retail. All of this dictates the need to minimize energy consumption as a key element, so it is not feasible to consider only processing operations in isolation from the entire supply chain.

2.3 Replacement of Eco-Efficient Technologies in Food and Beverage Processing

Hyde et al. [15], through analysis of their success case in the East Angolan alcoholic beverage industry, describe that changes in alcoholic beverage processing technology brought significant savings in labor, materials, and services. Procedural changes often focus on processes, material handling, and staff training, and with a low associated capital cost, these results represent the key to success in implementing cleaner production strategies.

Jones [18], through their analysis of the success story of the alcoholic beverage industry in Eastern Angola, describes how changes in alcohol processing technology brought significant savings in labor, materials, and services. Process changes often focus on processes, materials handling, and staff training, and with a low associated capital cost, these results represent a key to the successful implementation of cleaner production strategies.

Rahim y Raman [30] present a study in which the viability of the use of CP strategies in a fruit juice production plant was evaluated. The main objective was to reduce carbon dioxide (CO2) emissions taking into account economic, health, and safety aspects. The analysis showed that the total CO2 emission generated in this plant was 0.07 kg of CO2 per liter of fruit juice, of which 88% was contributed by the combustion of fossil fuel, generating CP options such as the replacement of pasteurization equipment with electric pulses, which after implementation reduced CO2 emission by about 20% through an economically viable investment with a recovery rate of 2 years.

Valle [33] demonstrated that the application of ozone to fruit wine must ensure the quality and safety of the final product, providing, in addition, ideal organoleptic characteristics perceptible by the consumer, replacing the need for fossil fuels for the traditional pasteurization process, demonstrating that the ozone injection process eliminates the microbial load present in the product more efficiently, in a conclusive manner.

2.4 Reduction of Water Consumption

The alcoholic beverage industry is one of the largest industrial users of water, despite significant technological improvements over the past 20 years; energy consumption, wastewater, solid waste and by-products, and air emissions remain the industry's main environmental challenges. Olajire [27] presents an analysis that examines the main challenges of the alcoholic beverages industry focusing on these key issues and best environmental management practices that do not compromise final product quality.

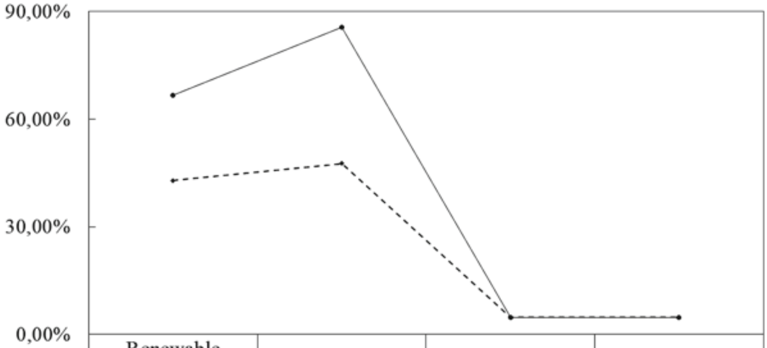
As a result of the work, it showed that technology substitutions in the production of alcoholic beverages significantly reduce process water consumption, air emissions, and solid waste, economically viable for the industries and encouraging environmental awareness through the application of this type of strategies, supporting the need for the development of alternatives such as the one in this paper.

Yi et al. [36], in their research work, carry out an analysis of the growth and competitiveness of eco-efficient food industries that maximize water consumption in their processes, in Heilongjiang province, showing that the general growth trend of the ecological food industry with lower water consumption in its processes and certified by the Chinese government, is likely to increase by 220% by the end of 2018, which makes it clear that the market is increasingly ecologically aware and forces food and beverage companies to be ecologically competitive.

3 Discussion and Analysis of Results

Most CP application articles, depending on the problem, are seeking to solve the use of appropriate techniques. In general, the resource that is sought to be optimized is energy consumption. Figure 3 shows the CP techniques applied in industry to minimize energy consumption. Of the 32 publications analyzed, 21 mention energy optimisation, and one of the most popular strategies is technological adaptation (47.62%), which involves changing machinery for more environmentally-friendly equipment, plants with better distributed lighting, or changes in fossil energy consumption for electrical energy, a high percentage (42.86%) of industries opt for the use of energy resources from biomass or energy sources generated from organic solid waste. Other alternative sources of energy are solar energy and product modifications, which are rare (4.76%).

100% of the articles analyzed with a focus on the reduction of the planet's water footprint agree that it is one of the resources that has been most exploited during the



	Renewable energy (solid waste)	Technological adaptations	Product modifications	Solar energy
Beverage Industry	23,81%	38,10%	0,00%	0,00%
Agroindustry	42,86%	47,62%	4,76%	4,76%

Fig. 3 CP energy alternatives in agroindustry

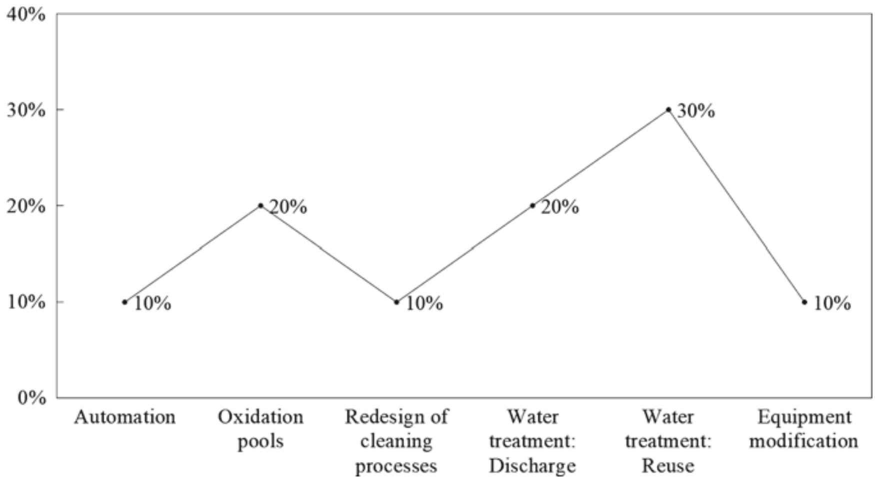


Fig. 4 Water footprint reduction techniques

twentieth century. Of the 32 publications analyzed, 10 apply techniques for reducing water consumption in the drinks and spirits industry. In Fig. 4, the strategies mentioned in the reviewed articles are observed, highlighting that the technique that has had the greatest impact is the treatment of wastewater. The treated water has two destinations, the first is direct discharge to sewers (20%) and the second is reuse in irrigation processes (30%). Other strategies mentioned are the automation of irrigation systems (10%) and the modification of equipment, especially pasteurizers (10%).

The analyzed articles concerning the reduction of the water footprint in food industries propose corrective actions, which seek to reduce the amount of contaminants present in this resource after its use, but few authors propose preventive actions for this resource. There is no talk of reducing consumption at source, nor of modifying the technology of the product; the processes used in the food industry have not changed over the years. Taking into account that in the twentieth century people still worked under the concept that natural resources were unlimited, one can understand the lack of process innovation at that time. With regard to energy consumption, the main problem that companies encounter is the lack of planning with which they start their industries. Most food companies start out as micro-enterprises, with minimal consistency in the installed capacity of the different machines that make up their production lines. As the industry grows, the capacity of these machines does not supply, and companies that generally do not have the resources to carry out re-engineering, make adaptations that, although it is true, are usually more economical in the short term, end up causing greater expenditure of money by consuming greater amounts of energy.

The main energy losses are produced by poor equipment design, lack of insulation materials. Considering the above, it is not surprising that most authors opt for technological modification, such as CP strategies. Many advances have been made in the twenty-first century in the field of CP, but there is still a long way to go.

4 Conclusions and Future Works

This study, through an SLR, analyzed previous work on the implementation of CP strategies in the food and beverage industry, and the challenges the industry confronts when implementing them, including government, legal, and market requirements; most of the works analyzed focused on their strategies on the reduction of water consumption through the reuse and recycling of water resources, in terms of waste reduction strategies focused on the adequate treatment of industrial effluents prior to discharge, however, this strategy is framed in the concept of control at the end of the pipe that does not combine with the objectives of CP, but as an environmental mitigation methodology.

On the other side, the investigation showed that the automation of processes is also a little exploited alternative within the food and beverage industry, compared to the replacement of more efficient equipment and the redesign of cleaning and disinfection processes that are less contaminating and that optimize water consumption, considering that due to health regulations it is one of the most important processes for ensuring the safety of products, taking into consideration that in industrialized countries 30% of all industrial effluents correspond to cleaning and disinfection processes in food and beverage production plants.

The implementation of new processing technologies, as well as the use of waste for energy generation, constituted the most used CP strategies by the food sector, marking a significant difference between the application of these strategies with respect to the beverage industry, putting in context the opportunity to strengthen the development of future research directed to the beverage industry specifically, in which the water resource is the main component of the final products, considering that of the whole industrial sector it is the least studied business line.

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