SELLO EDITORIAL
UNIVERSIDAD DE PAMPLONA



SPIRITS INDUSTRY TRENDS

ECONOMIC, ENVIRONMENTAL IMPACTS AND SUSTAINABLE STRATEGIES

Juan Manuel Madrid Solorzano
Jorge Luis García Alcaraz
Maribel Mendoza Solís
Luis Asunción Pérez Domínguez
Francisco Raúl Arencibia Pardo

Spirits Industry Trends

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AND SUSTAINABLE STRATEGIES

Spirits Industry Trends. Economic, environmental impacts and sustainable strategies / Juan Manuel Madrid Solorzano, Jorge Luis García Alcaraz, Maribel Mendoza Solís, Luis Asunción Pérez Domínguez, Francisco Raúl Arencibia Pardo— Pamplona: Universidad de Pamplona. 2026.

209 p. 17 cm x 24 cm
ISBN (Digital): 978-628-7937-18-5

© Universidad de Pamplona
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Sede Principal Pamplona, Km 1 Vía Bucaramanga-
Ciudad Universitaria. Norte de Santander, Colombia.
www.unipamplona.edu.co
Teléfono: 6075685303

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ISBN (Digital): 978-628-7937-18-5
First edition, July 2026
Science and Innovation Collection
© Sello Editorial Unipamplona

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Formando nuevas generaciones con sello de excelencia comprometidos con la transformación social de las regiones y un país en paz

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PROLOGUE

The alcoholic beverage industry is central to the world economy, and the gross domestic product (GDP) of some countries is closely related to the production of alcoholic beverages, as is the case in Scotland, where the distilled beverage industry represented approximately 3% of the country's total GDP in 2019. The book comprises five chapters discussing different topics related to the spirit industry.

Chapter 1 is entitled 'The Economic and Environmental Contribution of the Production of Alcoholic Beverages' and describes the economic importance of the alcoholic beverage industry sector globally, particularly beer, distilled spirits, and wine. It shows economic and demographic figures that support the conjecture that the alcoholic beverage industry will continue to grow economically, not at the expected rate of years before the COVID-19 pandemic but at a slow and steady pace. In addition, it mentions factors that influence the growth of alcoholic beverage consumption, such as new buying patterns due to the Internet.

Likewise, this chapter discusses the alcoholic beverage sector in general; however, since there is little literature on the environmental impact of distilled beverages and their decarbonization strategies, the current state of research on the environmental impact of this industrial sector has been investigated.

Chapter 2 is entitled "Scientific Production on the Environmental Impact of Distilled Spirits Production" and presents a bibliometric analysis carried out in the VOSviewer software with information from the Scopus database. Patterns of development and trends in scientific publications on assessing the environmental impact of

the distilled spirit sector were visualized. This will allow readers to identify the main research groups focused on studying environmental impacts in the spirit sector. It also reports that the consumption of alcoholic beverages is in-grained in society's customs and that despite the increase in commodity prices due to the Russia-Ukraine war and the disruptions in the supply chain caused by the COVID-19 pandemic, this sector of the industry is expected to continue to grow, not at the rate of the past decades, but steadily and gradually.

Chapter 3, entitled "Environmental Impact Assessment of Craft Spirits," illustrates through graphs and figures the importance of measuring the environmental impact of the spirit sector. This chapter reports global studies, but special emphasis is placed on distillates from Mexico, Peru, and Spain, with three cases reported. According to the examination of these examples, the essential variables to consider to create a balanced relationship between the operations of this industrial sector and the environment are primarily the harvesting of raw materials, primary packaging, and transportation.

Chapter 4 is entitled "The Environmental Impact of Large Companies in the Spirit Beverage Industry" and focuses on analyzing the environmental impact of large corporations that sell distilled spirits in bulk, such as Diageo and Rémy Martin. Special emphasis is placed on the three beverages produced by these companies: cognac, tequila, and whiskey.

Finally, Chapter 5 is entitled "Sustainable Strategies and Trends in the Spirit Industry" and describes the sustainable strategies and prevailing trends that the distilled beverage industry can adopt to mitigate its environmental footprint. These strategies consider efficient water management, cultivation methods, and renewable energy sources; on the other hand, the integration of digital technology and the transition to using biodegradable materials to replace glass are trends described in this chapter.

Therefore, in this book, the authors seek to provide an overview of what the distilled beverage industry contributes to climate change and present sustainable strategies and trends that anyone interested in the industry could use as a reference for decision-making.



CHAPTER ONE

The Economic and Environmental Contribution of the Production of Alcoholic Beverages

Abstract. This chapter discusses the estimated economic and demographic figures that suggest that the consumption of alcoholic beverages, such as wine, beer, and spirits, will continue to grow despite global population loss. It also describes the changing demographics of some nations and how they are creating one of the world's most populous and economically developed regions, resulting in increased food and beverage consumption in the coming decades. In addition, the economic and demographic aspects of the alcohol industry are described, along with in-formation on the production and consumption of beer, wine, and distilled beverages. It also mentions the existence of external factors that influence the increase in the consumption of alcoholic beverages. Finally, it briefly discusses the environmental implications associated with the production of alcoholic beverages and the initiatives implemented by companies in this industrial sector and nations to reduce the carbon footprint of their production processes.

Keywords: Alcohol beverages, Consumer trends, Market growth, Sustainable, Carbon footprint.

Resumen. Este capítulo analiza las cifras económicas y demográficas estimadas, sugiriendo que el consumo de bebidas alcohólicas, como el vino, la cerveza y los licores, seguirá creciendo a pesar de

la disminución de la población mundial. Se describen los cambios demográficos en algunas naciones, los cuales están creando una de las regiones más pobladas y económicamente más dinámicas que del resto del mundo, lo que resultará en un aumento del consumo de alimentos y bebidas en las próximas décadas. Además, se examinan los aspectos económicos y demográficos de la industria del alcohol, proporcionando información sobre la producción y el consumo de cerveza, vino y bebidas destiladas. También, se mencionan factores externos que influyen en el aumento del consumo de bebidas alcohólicas. Finalmente, se discuten las implicaciones medioambientales asociadas a la producción de bebidas alcohólicas, así como las iniciativas implementadas por las empresas de este sector y las naciones para reducir la huella de carbono de sus procesos de producción.

Palabras clave: Industria del alcohol, cerveza, vino, bebidas espirituosas.

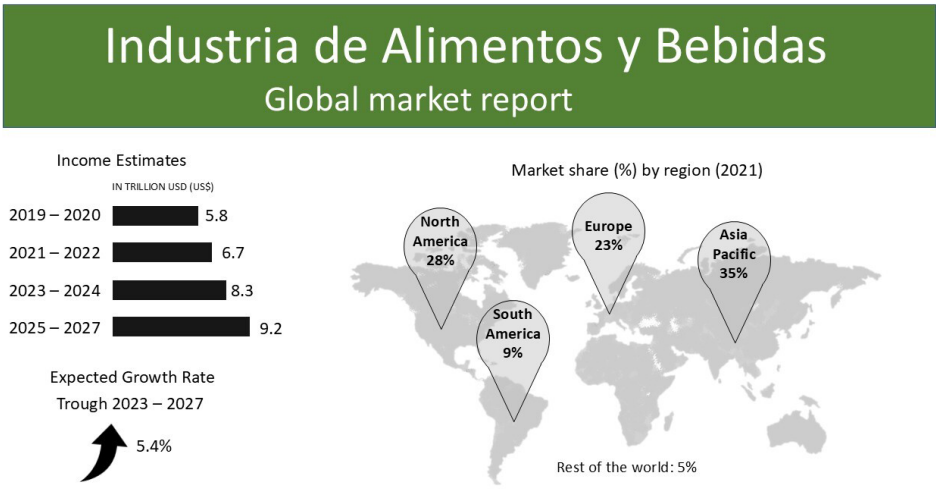
1.1 The Economic Contribution of the Alcoholic Beverage Sector

The food and beverage industry (F&B) is important to the global economy. This industry mainly produces alcoholic beverages, non-alcoholic beverages, cereal products, bakery and confectionery, frozen, canned, dehydrated, dairy products, meat, poultry, seafood, condiments, oils and general foods, animal and pet foods, and tobacco products. As shown in Figure 1, even with rising commodity prices and supply chain disruptions due to the COVID-19 pandemic and the Russia-Ukraine war, this market is estimated to grow from US$8.3 trillion from the period 2023-2024 to US$9.2 trillion between the years 2025-2027 (The Business Re-search Company, 2023). In addition, it is estimated that there is an expected growth of approximately 5.4% from 2023 to 2027, which shows that the F&B industry will

continue to grow steadily despite the negative consequences of the pandemic and recent political events.

Figure 1 indicates the trends in the F&B industry and shows that the consumption of F&B products is expected to increase in the Asia-Pacific region. In 2021, it was estimated that the F&B market in this world region would account for 35% of the total world market, followed by North America and Europe. In addition, this region is home to the world's most populous countries; for example, India has a population of over 1,428 million, and together with China, it accounts for approximately three billion inhabitants (The United Nations (UN), The World Health Organization (WHO), and the World Health Organization (WHO)) (The United Nations (UN), 2023). Likewise, these two countries, together with Brazil, Russia and South Africa, make up a trade bloc known as BRICS, which amounts to 3.16 billion inhabitants, representing more than 40% of the planet's population and 20% of the global Gross Domestic Product (GDP) (Food and Agriculture Organization of the United Nations, n.d.).

Figure 1
F&B market trend



Note. Data were estimated from Research and Markets (2023), ReportLinker (2023), and Common Thread Collective (2023). Source: F&B market trend (Image created by authors in 2023)

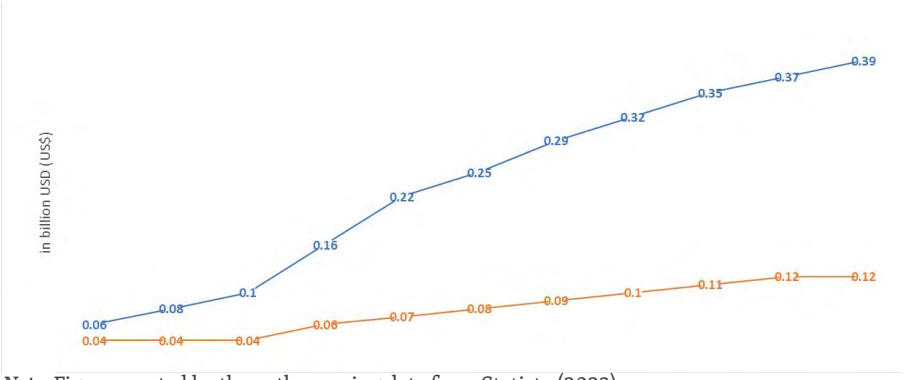
Given the above, there is expected to be an increase in food and beverage consumption due to population growth and even more due to the economic development of emerging countries that integrate new trade blocs that promote integration and free trade.

As a result of the commercial growth of this F&B industry, it is concluded that it also has an economic influence in different sectors and industries of the global market, such as the agricultural sector and the hotel, restaurant, bar, and coffee sectors. However, the F&B industry has recently initiated a close relationship with companies related to the electronic marketing of products, ordering, and payment services. Thus, if we include aspects related to e-commerce, the economic influence of this industry will increase (Orendorff, 2022).

For example, food and beverage purchases made using mobile applications are increasing yearly, as shown in Figure 2. Purchases of products derived from the F&B industry through mobile applications without cost (In-App) and with cost (Paid App) have presented marked growth since the appearance of the COVID-19 pandemic. However, In-App purchases had a growth trend compared to Paid Apps, generating revenues estimated at US$0.29 billion in 2023. It is forecasted that 2027 purchases will be around US$0.39 billion, and the trend will continue to rise.

Therefore, it is important to reflect that the greater use of information and communication technologies (ICT) by the F&B industry, the faster it will learn about consumption patterns, provide better quality monitoring, and better control methods of food preservation, storage, and transportation. All of these improvements will reach an increasing number of people, equal to an increase in consumerism.

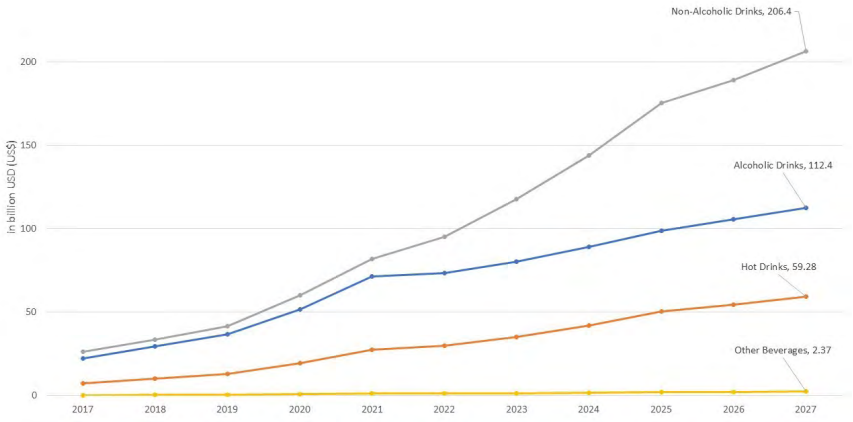
Figure 2
Profits obtained from food and beverage purchases through apps.



Note. Figure created by the authors using data from Statista (2023).

The global beverage market is projected to reach US$1.8 trillion by 2026 at a compound annual growth rate (CAGR) of 2.53% (Market Research, 2022). Beverages are categorized into non-alcoholic, alcoholic, hot beverages, and other beverages, such as lightly flavored carbonated water. Of these four categories, non-alcoholic beverages are forecasted to have the highest demand in 2027, at approximately US$206.4 billion, followed by alcoholic beverages, at approximately US$112 billion (Statista, 2023), as shown in Figure 3.

Figure 3
Estimated revenue for the global beverage alcohol market

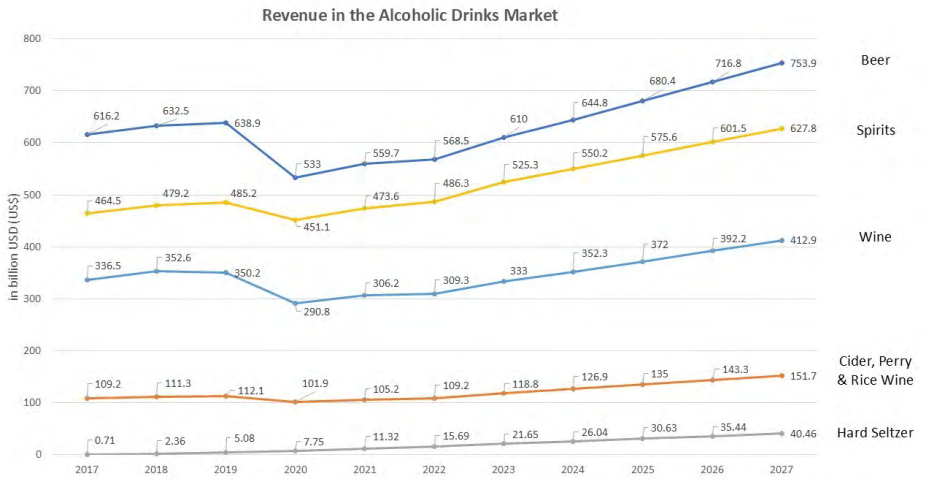


Note. Figure created by the authors using data from Statista (2023).

Alcoholic beverages contain at least 1.1% alcohol (ethanol) by volume. These beverages are categorized into fermented beverages, distilled beverages and those to which alcohol is added; for example, in the first category, we can mention beer, wine, rice wine and Perry. The second category includes beverages like whiskey, vodka, rum, and tequila. The last category includes cider and flavored alcoholic carbonated beverages, also known as ready-to-drink beverages (RTDs).

Owing to the COVID-19 pandemic, there was a considerable drop in profits in this industry sector, as can be seen in Figure 1.4. The brewing industry had the steepest profit drop, followed by wine; however, spirit beverages decreased less than in the two previous industries. After 2020, alcoholic beverages recovered their sales, as shown in Figure 4, where the most consumed alcoholic beverages were beer, distilled spirits, and wine.

Figure 4
Estimated revenue for the global beverage market



Note. Figure created by the authors using data from Statista (2023).

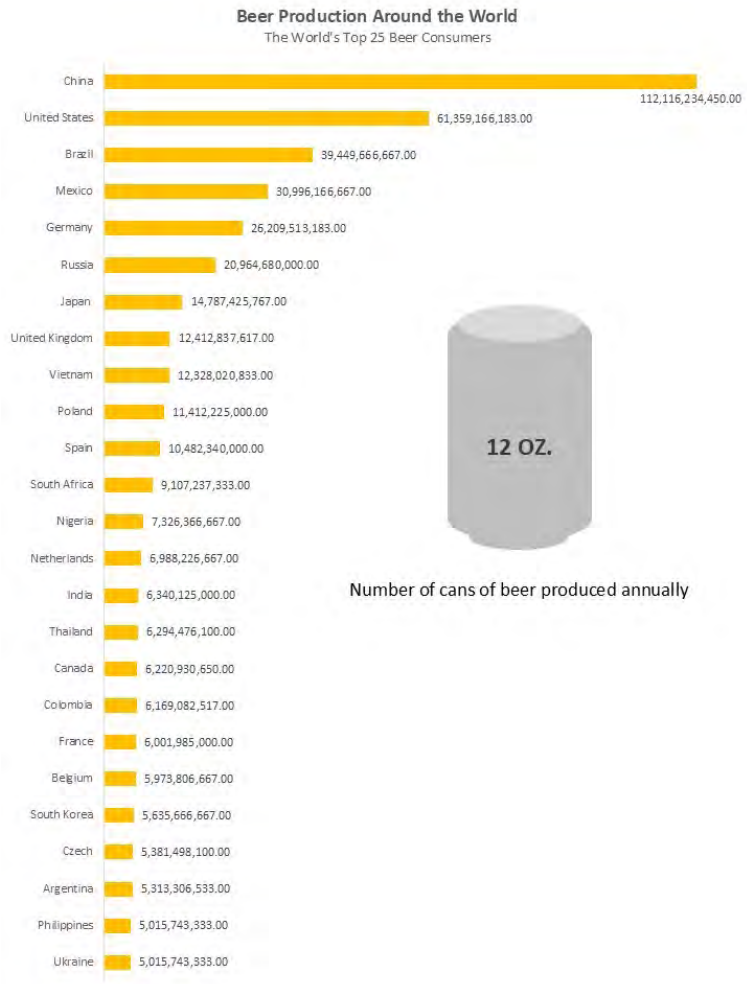
1.1.1 Beer Consumption

Among alcoholic beverages, beer is the most widely consumed beverage world-wide, accounting for approximately 80% of the total alcoholic beverage consumption. Moreover, its consumption is expected to grow favorably owing to the increase in microbreweries in several countries (Medina et al., 2023). In 2022, the beer industry was valued at US$660 billion, and it is estimated that in 2028 the market will reach US$747.7 billion (IMARC Group, 2023). Figure 5 shows the list of the 25 countries that produce the most beer cans (with a content of 355 ml), with China in the first place. Furthermore, this country produces much more of this fermented beverage than other countries that are considered large consumers of beer, such as the United States of America and countries in Europe, such as Germany, the United Kingdom, and the Czech Republic, which have the highest per capita consumption in the world.

The top five beer producers belong to one of the world's major trading blocs, such as BRICS, the North American Free Trade Agreement (NAFTA), and the European Union (EU). China, Brazil, Russia, India, and South Africa, which form BRICS, account for approximately 41% of the world's population and contribute almost 32% of the global Gross Domestic Product. After China, the United States of America is the second largest beer producer, producing about 61.3 billion cans of beer, as shown in Figure 5. This figure shows the 12-ounce beer produced by leading countries with this tradition.

The United States of America, Mexico, and Canada make up NAFTA, which accounts for about 496.84 million people and is considered the second most important trading bloc, contributing approximately 30% of the world's GDP (Broom, 2023). Germany is part of another major trading market, the European Union (EU), where approximately 447.6 million people live, with Germany being the most populous and the largest economy in the region. This European trading bloc contributes almost 16% of the world's GDP (International Monetary Fund, 2022). Thus, the BRICS trading bloc is predicted to be one of the leading markets for beer marketing in the future.

Figure 5
Countries with the highest quantity of beer cans produced



Note. Figure created by the authors using data from Alcohol.org (2023).

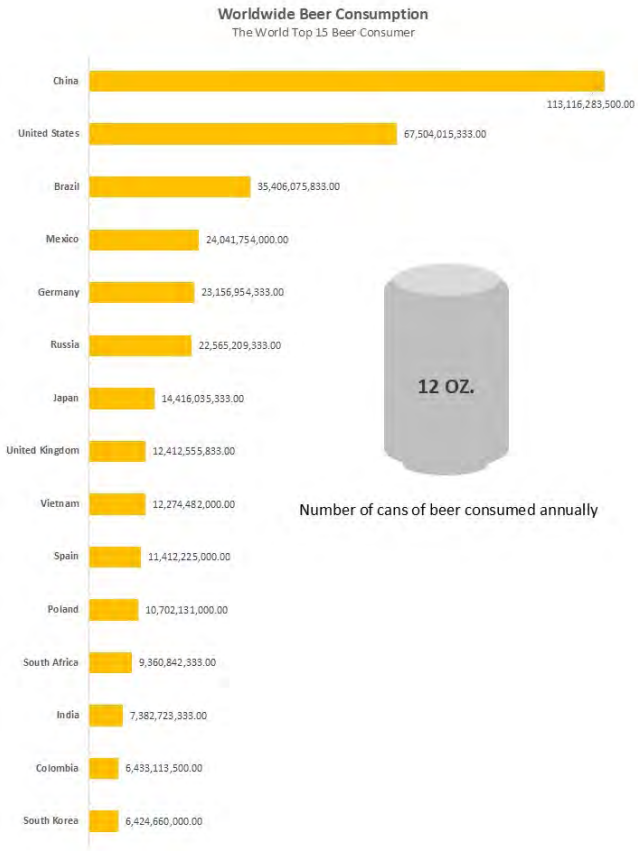
Figure 6 shows that China and the United States of America are primary beer consumers. According to the Japanese company Kirin Holdings, this country accounts for one-fifth of the total beer consumption worldwide.

Even though Asia consumed 11.7% less beer in 2020 than in 2019, this region continues to hold a 31.2% share of the global market for that beverage, remaining the region that consumes the most beer

(Kirin Brewery Company, 2022). Another country located in Asia is India, which has a larger number of inhabitants than China; it consumes much less beer, occupying a thirteenth place in the list shown in Figure 6.

The United States, with approximately 67.5 billion cans of beer, is second, while Brazil consumes almost 35.4 billion cans of this fermented beverage. The consumption of five main beer consumers (China, the United States, Brazil, Mexico, Germany, and Russia) are responsible for more than 50% of the world's total consumption of this beverage globally.

Figure 6
Countries with the highest amount of beer cans consumed



Note. Figure created by the authors using data from Alcohol.org (2023).

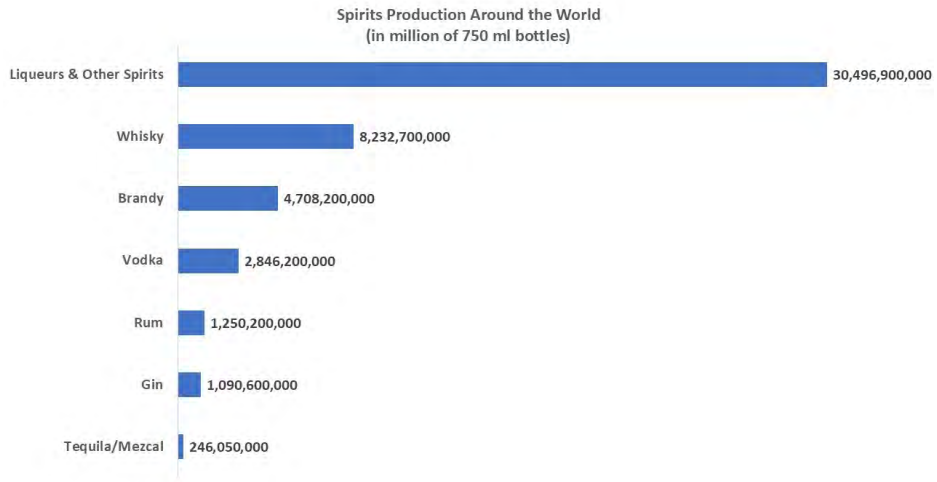
1.1.2 The Consumption of Distilled Spirits

Distilled spirits are another widely consumed category of alcoholic beverages. They are made from different raw materials, including grains, fruits or other fermentable ingredients. The most common spirits are brandy, whiskey, vodka, rum, liqueurs of different flavors, and other distilled spirits produced from fruits (Weiss et al., 2022). In 2022, the estimated profit in the global distilled spirits market was estimated to be approximately USD 1.8 trillion, and by 2030, it is estimated to make a profit of approximately USD 2.8 trillion, with a compound annual growth rate of 5.8 % (CAGR) over the period 2022-2030 (ReportLinker, 2023b). This is despite the drop in consumption in the 2019-2020 period due to the COVID-19 pandemic (Aswani, 2021).

By 2023, the world's largest spirits are whiskey, brandy, and vodka, as shown in Figure 7. Approximately 8.2 billion 750 ml bottles will be produced, followed by brandy with 4.7 billion bottles and vodka with 2.8 billion bottles. However, liqueurs and other spirits such as fruit distillate alcohol, ancestral distillates from countries such as baijiu from China, sake from Japan, tequila, and mezcal from Mexico, among others, together account for the largest number of bottles to be produced worldwide, with 30.4 billion bottles.

Concerning the most produced spirit, whiskey, the global market size for whiskey is forecasted to USD 146.5 billion by 2030 (Polaris Market Research & Consulting, 2023), while brandy could report revenues of US$25 billion by 2022 (IMARC Group, 2022).

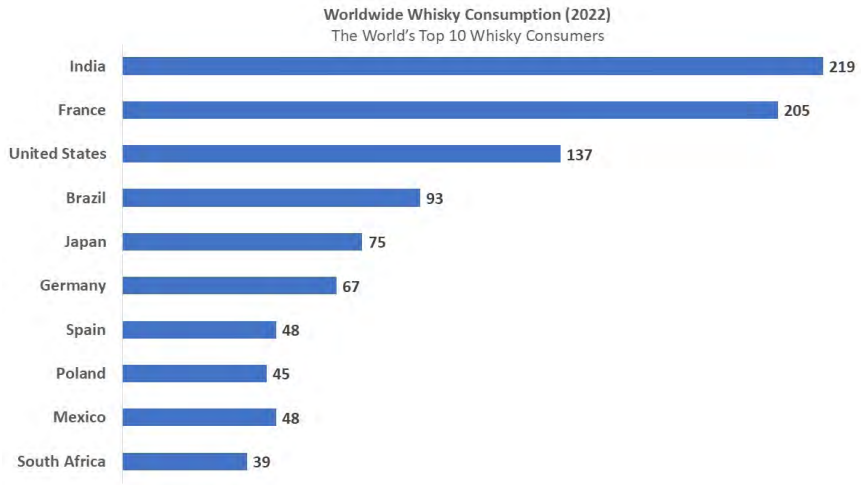
Figure 7
Distilled alcoholic beverages with the highest production in the world.



Note. Figure created by the authors using data from Statista (2023).

Of all the countries in the world, India was the leading consumer of whisky in 2022, with approximately 219 million 750 ml bottles, as shown in Figure 8. France is considered one of the countries with the highest consumption of this distilled spirit, but India now occupies that place. However, France had the highest per capita consumption in 2022, more than two liters per year or equivalent to three bottles per capita per year, while India consumed 1.24 liters per person per year (Martin, 2022).

Figure 8
Whisky consumption in the world



Note. Figure created by the authors using data from Statista (2022).

The countries with the highest consumption of distilled spirits belong to Europe, Eurasia and Asia, as shown in Figure 9. India, China, Russia, and Japan have the highest consumption of spirits, whereas, in the North American region, only the United States is among the highest consumers of distilled spirits. However, the European country of Belarus consumes the purest alcohol per capita, with approximately 14.4 liters per person, whereas France and Russia consume an average of 11.6 liters per capita. Meanwhile, in the United States, 8.7 liters per capita are consumed (American Addiction Centers, 2023). Finally, most Latin American countries have an average consumption of distilled alcoholic beverages estimated at approximately 6.4 liters per capita (Díaz et al., 2020).

Figure 9
Regions with the highest consumption of distilled alcoholic beverages



Note. Figure created by the authors using data estimated from Ghost in the Data (2023), World Wine Database (2023), and Future Market Insights (2023).

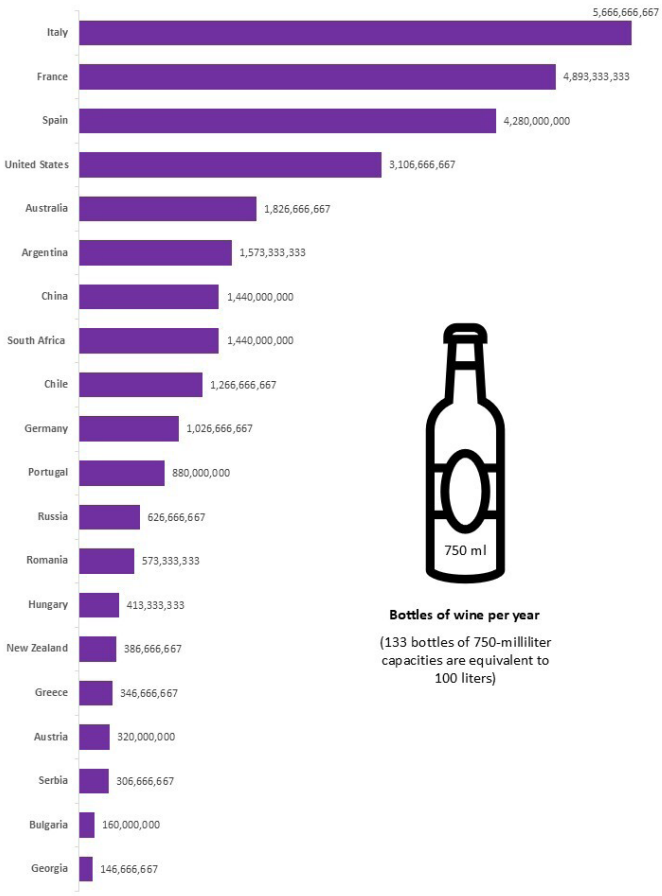
Undoubtedly, the consumption of distilled spirits will continue to increase its market share and consumer preferences. In the US alone, distilled alcoholic beverage suppliers had slightly higher revenues than beer suppliers in 2022. This revenue increase results from consumer preferences for cocktails, beverages prepared by mixing distilled spirits with other ingredients, and hybrid drinks, which are distilled spirits combined with fruit or citrus juices. Cocktail consumption is mainly linked to the hospitality industry, and the latter, in turn, is linked to the tourism market, where the distilled spirits industry has a significant influence.

Second, the increase in distillery tourism, which consists of visiting small distilleries in a region where a traditional spirit is produced, has led to increased revenue for this industry. For example, before the 2019 pandemic, spirits tourism generated $715.2 million in Texas, $546.4 million in New York, and $417.8 million in California (Distilled Spirits Council of the United States, 2023).

1.1.3 Wine Consumption

Wine is another of the most consumed alcoholic beverages. In 2021, approximately 236 million hectoliters were estimated to be consumed (Roca, 2022). In addition, the global wine market was estimated at US$379.2 billion in 2022, and by 2030 it is forecast to be US$528.3 billion, at a CAGR of 4.2% (ReportLinker, 2023a). The leading producers of this alcoholic beverage are Italy, France, Spain, and the United States, as shown in Figure 10.

Figure 10
Top 25 wine producers



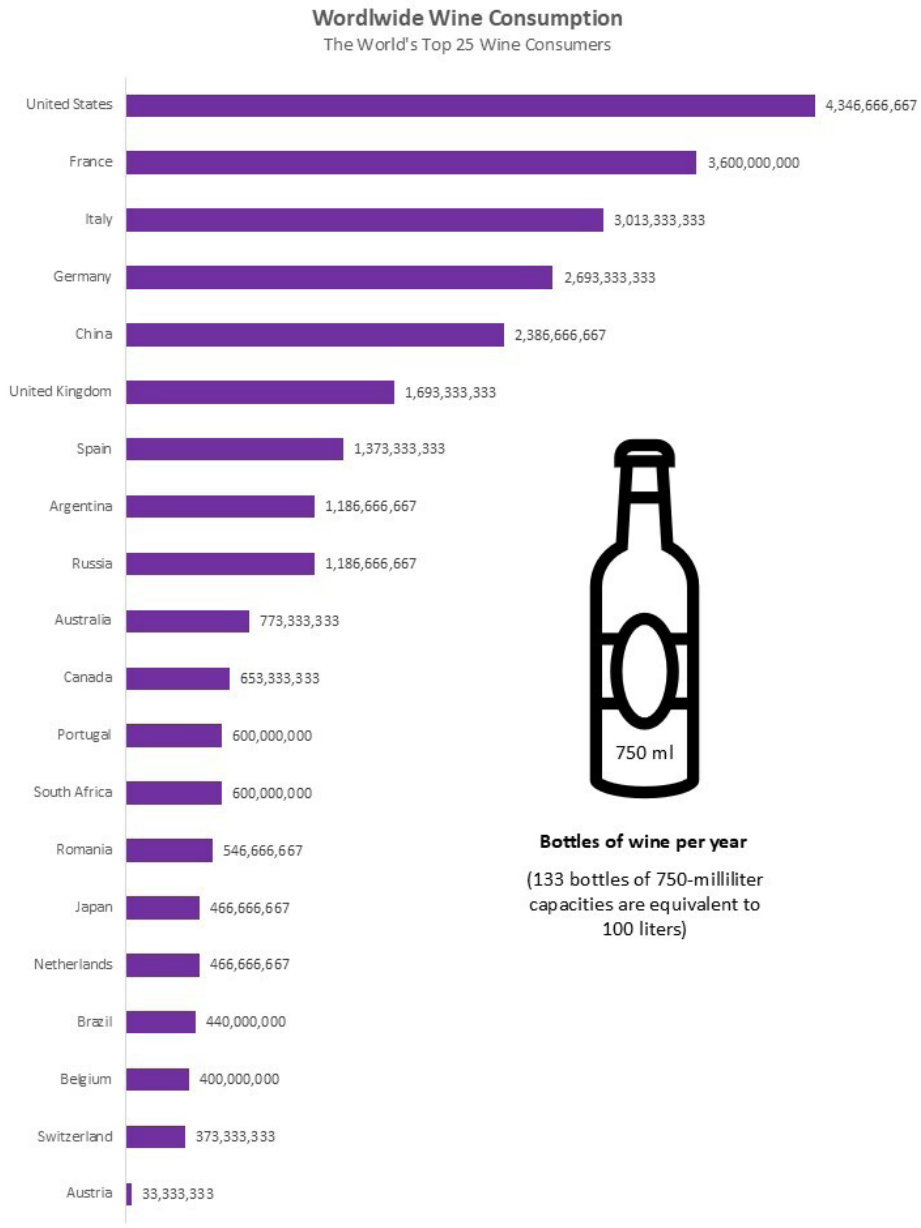
Note. Figure created by the authors using data from Alcohol.org (2023).

Italy is the leading producer, with approximately 5.6 billion 750-ml bottles of wine annually. It is essential to mention that even during the pandemic, Italy, France, and Spain continued to be the leading producers of this beverage. Notably, China and South Africa are beginning to stand out in the commercial wine market. Chinese consumers' demand for this beverage dates back to the 2000s when publications were published on the health benefits of drinking wine, such as reducing heart disease.

The idea of the health benefits of wine made this alcoholic beverage part of a healthy lifestyle in a certain segment of the Chinese population. South Africa increased its share of the wine market by increasing its exports to China. After the Covid-19 pandemic and because China imposed 212% tariffs on Australian wines due to geopolitical problems, wine exports from this African country to Beijing soared by 50% (Ford, 2021).

Concerning wine consumption, the United States ranks first with approximately 4.3 billion 750-ml bottles, as shown in Figure 11, followed by France and Italy at 3.6 billion and 3 billion, respectively. Portugal ranks first in the per capita consumption of this alcoholic beverage, with an annual average of 72 bottles, while in France and Italy, it is only 55 and 50 bottles, respectively. Regarding exports, France and Italy account for almost 50% of global wine exports (Otieno, 2023). Although the United States appears to be one of the main consumers of this beverage due to the size of its population, consumption per person is much lower than in the countries mentioned above, with approximately 16 bottles per year (Antonaccio, 2022).

Figure 11
Top 25 wine consumers



Note. Figure created by the authors using data from Alcohol.org (2023).

1.1.4 Alcoholic Beverages Market Growth Despite External Market Factors

Product consumption increased significantly after World War II due to an increase in the world population (Van Dam et al., 2021); however, there is currently no significant increase in population compared to the past decades. In contrast, some countries such as China, Russia, and Japan are beginning to decrease their populations. Thus, it is assumed that alcohol consumption decreases with a demographic decline. Another cause of the decrease in the consumption of this type of beverage is that the drinking habits of young adults have changed. However, despite this population decline and changes in consumer habits, the size of the alcoholic beverage market will continue to grow owing to several factors.

The first factor is an increase in human life expectancy. People are now living longer; thus, individuals are exposed to consumption for longer periods. The next factor is the increase in access to education, which increases the likelihood of individuals obtaining higher incomes and intensifies the options of coexistence with other people, resulting in an increase in the consumption of alcoholic beverages.

Third, a growing number of emerging economies will demand higher consumption of alcoholic beverages (European Environment Agency, 2023a). Another factor is migration, where the exodus of people from poor countries to more developed countries increase citizens' opportunities to acquire credit and economic opportunities to improve their incomes. Consequently, people demand more products (Mallick, 2023).

Although the economic growth of the alcoholic beverage industry will be constant, it will be slower than in the past decades due to the changing habits of new generations (Barger, 2023). For example, young people now spend more time using new Internet-based technologies where alcohol consumption is not warranted or is

consumed in smaller quantities (Törrönen et al., 2019). In addition, the new generations of citizens present a greater awareness of taking care of their health and therefore consuming less alcohol. For example, young people in Generation Z consume 20% less alcohol (Barange, 2022).

However, the alcohol industry seeks to innovate its products to satisfy consumers' preferences. For example, the millennial market prefers beverages with lower alcohol, non-alcoholic, and low sugar content to maintain a healthy lifestyle. Thus, this industry offers market products with alcohol content ranging from 0.0 to 1.2 %. For example, since 2017, Heineken has offered beer with an alcohol content of 0.03%, which qualifies it as a non-alcoholic beer.

The distilled beverage market offers a non-alcoholic distillate called Seedlip, made from herbs, plants, and fruits (Nicholls, 2022). This effort to offer beverages to the tastes of new generations has expanded this industry by reaching consumers outside its market segment.

1.1.5 Other Benefits of the Alcoholic Beverages Market

The alcohol industry is an ever-expanding market that affects different economic activities in a territory or state. For example, this industry generates various work environments in different economic sectors (Overproof, 2023). In addition, this industry improves government revenue collection through taxes levied on purchasing this type of product, which favors higher public spending (Urban Institute 2021). This industry has had an important impact on the state because of its eco-nomic and tax revenue.

Beer production is one of the most important factors in the alcoholic beverage sector worldwide. In Mexico alone, for every MXN$1.0 produced of alcoholic beverages, MXN$0.65 corresponds to beer production, according to the National Institute of Statistics and Geography (INEGI). This industry has a significant social impact

owing to the generation of jobs. In the United States, it generates more than two million jobs (Beer Institute, 2022), and in Mexico, more than 900 thou-sand direct and indirect jobs (CRONICA, 2022).

In addition, the alcohol industry drives a wide range of industries, including beverage and alcohol stores, food, and tourism. For example, the alcohol industry drives job creation through beer, wine, and spirits. The number of people employed in the US as alcohol merchandisers was approximately 189,213 in 2022, with an average of 4.4 employees per store (IBISWorld, 2023).

In addition, winemaking eliminates the pulp and seeds used by the food industry. These two wine by-products are enriched in products with low nutritional value, including dietary fiber, proteins, and polyphenols (Ferrer-Gallego & Silva, 2022). The alcohol industry also opens up the opportunity to create employment sources in rural communities by opening small distilleries and wine producers, many of which traditionally produce their products. Thus, new generations of young adults are attracted to visiting rural communities to have new experiences, linking the traditional alcoholic beverage industry to the rural tourism sector.

Rural tourism has great potential to generate social benefits because it avoids the migration of the rural population to large cities due to a lack of employment. (World Tourism Organization, 2021) thus, avoiding the abandonment of a region's family, cultural and gastronomic traditions (Keskin & Güneş, 2021).

Another important impact of this industry on governments is that the more alcoholic beverages are consumed, the more taxes are collected, which is the government revenue that can be used for public spending. In the United States, as in other countries, the higher the alcohol content, the higher the tax paid for its sale (Hoffer, 2023). For example, in Mexico, the collection of excise taxes on beer and distilled beverages from 2021 to 2022 has increased by up to 15%

(Saldívar, 2022). For this reason, some countries promote greater consumption of distilled beverages because they are generally subject to higher taxes, given that they contain a higher percentage of alcohol by volume. For example, the Japanese government promotes higher consumption of the traditional Japanese beverage, Sake, because it means a higher tax collection (Neate, 2022).

1.2 The Contribution to the Environment from the Production of Alcoholic Beverages.

Even during the COVID-19 pandemic, the production of alcoholic beverages has not stopped. Although profits in this sector declined from 2019 to 2020, recovery began in 2021, as shown in Figure 12. This industry continues to grow, not at the growth rate prior to the pandemic, but a growing trend is marked again, and there are even regions in the world, such as Asia, where the market for this type of product is estimated to grow more than in other regions in the world. For example, it is forecasted that China, Japan, Canada, and Germany will have an increased share of the alcoholic beverage market. China will reach a market size valued at US$632.2 billion by 2030. In contrast, Japan and Canada are estimated to grow by 1.9% and 4.8%, respectively, between 2022-2030. In Europe, Germany is forecasted to have the highest growth of 2.7% (CAGR), according to ReportLinker (2023).

However, according to the Pan American Health Organization, the greater the economic activity, the greater the risks to human health because high levels of chemical compounds are used and emitted into the atmosphere, all harmful to human beings. Even with threats to human well-being, achieving greater food production and processing is necessary. For example, due to the poverty reduction, the increase in the employment rate, and the increase in urbanization and industrialization that the BRICS nations will have due to their economic development, there will be greater exploitation

of the environment and, consequently, greater production of pollutants (National Intelligence Council (US), 2012).

Furthermore, these nations will consume more energy primarily from nonrenewable sources, such as fossil fuels, the most widely used sources for electricity pro-duction and the transportation of raw materials in the alcohol industry, increasing CO_2 emissions (Samour et al., 2023).

An increase in the consumption of any product can mean an ecological deficit; that is, there is an imbalance between the consumption of natural resources and the capacity of a region to recover the number of natural resources consumed. In addition, the degree of pollution and the capacity to process the waste that originates in producing a product are imbalanced. Thus, the greater the consumption of food and beverages, the greater the degradation of the quality of the environment and ecosystems (Filippini & Srinivasan, 2022).

The agricultural industry is an economic sector subjected to high exploitation to satisfy the food demands of countries with high economic development. The agricultural industry plays a key role in producing the raw materials required by the alcohol industry, such as grapes, wheat, hops, sugar, agave and various fruits and herbs, and year by year, it must increase its production capacity for these inputs. As a result, the agricultural industry must resort to increased consumption of fertilizers and herbicides, resulting in biodiversity loss, soil degradation, and chemical and nutrient pollution (European Environment Agency, 2023b).

Fertilizers, herbicides, and pesticides are used in agriculture to improve crop yields and increase food production; however, at the same time, they are challenges in achieving sustainability. Fertilizers contain nitrogen (N) and phosphorus (P), essential elements for life on Earth; however, their widespread overuse harms humans,

water bodies, plants, and animals. In addition, excessive fertilizer results in greenhouse gas emissions, such as carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N2O), that accelerate climate change. In 2018, global emissions caused by agricultural activity were 9.3 billion tons of CO_2 equivalent (CO_2 eq).

However, herbicides are key to weed control in crops. Weed growth in a crop reduces the yield per hectare, but using herbicides for its control causes toxicity in aquatic fauna. Pesticides protect crops from insects, fungi, and other pests. However, they are water, soil, and air pollution sources, causing loss of biodiversity and pest resistance. Human exposure to chemical pesticides is linked to chronic diseases such as cancer, heart, respiratory, and neurological diseases (European Environment Agency, 2022).

Similarly, due to agricultural activity, emissions from land use and land use change generate 4 billion tons of CO_2 eq, caused mainly by deforestation and drainage works (2.9 billion tons of CO_2 eq) and by burning organic soils (1 billion tons of CO_2 eq) (FAO, 2020).

Water is essential for the production of alcoholic beverages. Seventy percent of the water withdrawn worldwide is used in agriculture to meet the demand of the A&B industry (The World Bank, 2022). Thus, an environmental challenge is the exploitation and contamination of freshwater resources, which are becoming increasingly scarce, overexploited, and used in different production stages of alcoholic beverages (Espinosa et al., 2021). For example, producing 250 ml cans of beer requires 75 liters of water and producing a glass of wine requires 110 liters of water (Craig, 2021).

Concerning the consumption of alcoholic beverages, a study on the climate im-pact of wine, beer, and spirit consumption in Sweden revealed that a person produces between 0.73 and 2.38 kg of CO_2 eq per liter, approximately equivalent to an annual consumption of 52 kg of CO_2 eq per individual. It is the stage of agriculture, alcoholic

beverage production process, and production of packaging material that has the greatest negative impact on the environment in the production and supply chain.

However, wine emits most greenhouse gases (GHG) when consumed, followed by spirits and beer. The climate impact of wine consumption ranges between 2.38 and 2.16 kg CO_2 eq per liter. The climate impact of distilled beverages was around 2.07 CO_2 eq per liter, and beer consumption ranged from 0.73 to 0.81 CO_2 eq. The beer presents lower emissions per liter because this industry uses more recycled aluminum cans and glass bottles than other alcoholic beverages (Hallström et al., 2018).

Therefore, it was concluded that the consumption and production of alcoholic beverages significantly impact on the environment, mainly through their carbon footprint. These pollutant emissions come directly or indirectly; direct emissions are all those emitted by the companies to produce the product. In contrast, indirect emissions are generated by the purchase of energy, such as electricity, diesel, and natural gas, for the operation of the company, as well as the consumption of fertilizers and water in the agricultural stage to produce raw material (Reavis et al., 2022).

Therefore, products with a lower pollution index and greater efficiency in the consumption of nonrenewable resources are required. Therefore, it is necessary to evaluate the environmental impact of the alcoholic beverage production industry to develop strategies to reduce the pollution index. However, reducing the environmental impact of the alcoholic beverage industry is a challenge because it comprises many other activities that make up its production and supply chain, such as the production and distribution of raw materials, alcohol manufacturing process, manufacture of primary and secondary packaging, as well as the production of caps or cork, labels and barrels, retail distribution, advertising and marketing, and consumption (Núñez-Caraballo et al., 2019). However, nowadays,

activities related to commercialization and distribution by online stores, also known as marketplaces, should be included (Kellershohn, 2018; Orendorff, 2022).

1.3 The Pursuit for Sustainability in the Alcoholic Beverage Industry

The importance of sustainability in the beverage and alcohol industry has increased over the last decade. In 2020, this industry was rated one of the most backward in the implementation of strategies and practices for sustainability. However, today there is a trend regarding the importance of protecting environ-mental companies, so it is no longer considered an advertising strategy. However, this has become a criterion that influences the purchasing decisions of some sectors of society. For example, 20% of Generation Z and Millennials in the United States agree that sustainability is essential when purchasing food and beverages (Gogia, 2022). Thus, consumers consider how a beverage alcohol brand affects the environment more frequently.

To achieve sustainability in the alcohol industry, companies must focus on supply chains and their economic and social implications. The supply chain is a coordinated network of all activities required for sourcing, storage, production, packaging, distribution, and retailing alcoholic beverages. Many companies achieve significant time and cost savings by evaluating and improving supply chain management while promoting the local economy.

Sustainability in the supply chain should be a critical corporate objective to re-duce energy and water consumption and generate toxic waste while positively impacting the people and communities in and around their operations. Therefore, companies must assess the environmental and social impacts of their goods ‘and services from the beginning to the end of their life cycle (Jiang et al., 2018).

The alcoholic beverage supply chain starts with the suppliers of goods to produce a beverage. Suppliers are responsible for performing different activities, such as handling, storing, and distributing raw materials, inputs, and/or services to the company. Transportation plays an important role in the carbon footprint of alcoholic beverages. For example, the wine supply chain contributes 0.3 percent of the annual global greenhouse gas (GHG) emissions (Shabir et al., 2023). For example, Gogia (2022) mentions that the use of heavy goods vehicles is responsible for ap-proximately 25 percent of the CO_2 emissions of nations belonging to the European community, with fossil fuel being the primary energy source used for transporting goods.

The primary energy sources in the beverage industry are nonrenewable resources such as coal, oil, and natural gas, which provide approximately 80% of the world's energy (Ritchie et al., 2022). Carbon dioxide emissions from burning coal account for 44% of the world's total, oil accounts for about one-third of the world's total, and natural gas, which is cleaner than the previous two resources, accounts for one-fifth of the world's total emissions (Nunez, 2019). When fossil fuels are burned, carbon dioxide and other greenhouse gases are released, which trap heat in the atmosphere, making them major contributors to global warming and climate change (Sovacool et al. 2021).

Concerning the environmental impact of alcoholic beverages coming from packaging, glass bottles have a significantly greater environmental impact compared to PET plastic and 100% aluminum packaging, the latter being the material with the least impact on the environment. Glass is the most harmful to the environment because it is extracted from rare materials and requires more fossil fuels for its production and transportation. However, all types of packaging made from materials other than glass (Tetra Pack, aluminum, PET, paperboard, and HDPE) have environmental impacts across a broad spectrum of categories, from their global warming

potential (GWP100) to their potential to deplete fossil fuels (Brock & Williams, 2020).

However, the dynamic and complex nature of the beverage alcohol supply chain affects sustainable development. The industry has evolved from a localized, small-scale production to a global, multibillion dollar sector. The rapid global expansion of the beverage alcohol market has led to a loss of control over production. Therefore, it is necessary to assess the environmental impacts of the different sectors and activities that constitute the alcohol industry supply chain.

1.3.1 Initiatives to Lessen the Environmental Impact of the Alcoholic Beverage Industry

According to the World Spirits Alliance (WSA), protecting the planet from the challenges of climate change, preserving and protecting natural resources, and ensuring the safety of the community where a company is located are essential to guarantee a sustainable future. For this reason, governments, companies, and communities are becoming increasingly involved in initiatives to protect the environment while ensuring the safety and health of community members. This is why there are several initiatives to reduce the environmental impact described below.

As mentioned above, the production of alcoholic beverages begins with agricultural activities. To achieve sustainable agriculture, efforts have been made to apply techniques that consume less energy from fossil fuels and reduce the consumption of inputs, such as water and fertilizers. For example, drones can be used to improve the efficiency of plantation irrigation and to make the application of fertilizers, herbicides, and pesticides more efficient. We also sought to develop a vertical agriculture system to reduce soil use and water consumption. These efforts aim to keep up with demand (Fetzer, 2023).

The United Kingdom has implemented a fund to help distilleries go green and reduce emissions by switching from fossil fuels to low-carbon fuels, such as hydrogen and biomass. This support for UK distillers is expected to contribute to an annual emission reduction of 500,000 tons (Fetzer, 2022). According to the Budweiser Brewing Group and Adnams, the transportation of raw materials is where a large amount of fossil fuels is consumed, which is why this company has implemented the strategy of having shorter and more local supply chains that result in a reduction of the carbon footprint originating from the transportation of inputs. Another benefit of this initiative on the part of the brewing company was eliminating logistical complications related to the pandemic.

Initiatives have also been proposed to reduce the pollution index in large cities owing to population growth. For example, the measure called "15-Minute Cities" (15mC) seeks to reduce the use of vehicles for transportation and thus generate fewer greenhouse gases (Abdullah et al., 2022). Likewise, the Circular Economy Law has been approved for the large city of Mexico City, Mexico. This law promotes a transition towards a circular and sustainable model, establishing conditions compatible with the success of companies. Likewise, this law seeks to in-crease the value of consuming products that use fewer natural resources in their manufacturing (Government of Mexico City 2023).

Although consumers do not consider the amount of CO_2 that a product generates in their purchasing decisions (Blancheton & Hlady-Rispal, 2021), the promotion of initiatives or laws in favor of the environment, such as those mentioned above, will probably impose internal regulations in large cities, which will influence consumer decision-making and most probably even restrict the sale of products with a high carbon footprint, because it would be contradictory to consume a product with a high impact on the environment in cities that seek a low pollution index.

In this sense, the aim is to assign value to products that pollute less during their manufacture, and green labels have been developed. A product with a green label communicates to its customers the amount of carbon dioxide emitted in its manufacture, but at the same time seeks to communicate that it is a product with a low climate impact. A survey conducted in Europe found that 49% of consumers of alcoholic beverages would consider buying a beverage with a green label (Fetzer, 2022).

Concerning the environmental awareness of the population, young consumers show greater awareness of respect for the environment, which leads to the industry seeking to innovate its production processes to consume less energy and offer packaging that communicates concerning the environment through the development of biomaterials or packaging made from recycled materials (Russell & Kellershohn, 2018). For example, Buen Vato company has launched a tequila packaged in a cardboard bottle made from 94% recycled cardboard. This innovation aimed to reduce emissions by up to 84% less CO_2 /kg per bottle. In addition, offering lighter bottle results in 0.52 kg of CO_2 eq per liter of Tequila per transport, consuming less energy, up to six times less than a traditional bottle, and consuming less water in its manufacture, 1.9 liters of water (Buen Vato Company, 2022).

The reuse of waste for energy generation is another initiative. BrewDog is transitioning to clean energy, using malted barley waste to produce biogas and organic fertilizers. It also promotes using electricity from wind power and converts its fleet into electric vehicles (BrewDog Company, 2020).

Concerning primary packaging, glass is beginning to be replaced as a traditional material in the distilled spirits industry, which is being replaced by other materials with less impact on the environment. For example, the Polish vodka brand Sobieski markets its premium product in 1.75-liter bottles made of Polyethylene Terephthalate

(PET) plastic (Lindell, 2017). The use of PET plastic has less impact on the environment than the use of glass bottles or aluminum cans, and PET is considered better for human health than other types of plastics, such as polylactic acid (PLA) and polystyrene (PS) (Gomes et al., 2019).

Finally, it is important to mention that the pressure exerted by certain groups in society on companies committing to reducing their carbon footprint is increasing. Therefore, several companies have taken the initiative to comply with the goals set out in the Paris Agreement. This target, known as net zero, is reducing green-house gas emissions as close to zero by 2050 (United Nations Environment Pro-gramme (UNEP, 2022). For example, Pernod Ricard, which markets and distributes beverages such as whiskey, gin, vodka, tequila, and mezcal, committed to halving its total carbon footprint intensity by 2030 and reaching net zero by 2050. Similarly, the Diageo company, which owns several brands of different types of alcoholic beverages such as Smirnoff, Johnnie Walker, Tequila Don Julio, and Guinness beer, has committed to achieving net zero in all of its direct operations by 2030 (Fetzer, 2023).

1.4 Conclusions

The alcoholic beverage sector is among the most important sectors of the global economy. It is an industry linked to other industrial sectors such as agriculture, the glass, plastic, and aluminum industries, barrel manufacturers, and many others necessary in the production, supply, and value chain. Therefore, the strategies that emerge from this industry to reduce pollutants or GHGs directly impact other related industrial sectors, or vice versa. Thus, this industry is subject to third-party regulations, mainly those seeking to address climate change and GHGs, such as government actions linked to the company's carbon performance. Therefore, this industry will have to contribute to developing a decarbonized economy and improving the energy efficiency of its production processes.

The gradual resumption of all economic activities in the post-pandemic era, the advancement of consumer use of ICTs, migration, and the economic development of emerging countries will result in increased demand for beverage beverages in the future. In addition, as the industry offers a greater variety of options in line with the preferences of new generations, its market segment will increase. Therefore, these factors will create market growth opportunities for the alcohol industry in the coming years.

However, economic growth has led to increased pollution. There are current initiatives to encourage the alcoholic beverage industry to mitigate emissions that influence climate change. The pursuit of initiatives to be sustainable brings with it not only the mitigation of emissions but also additional benefits to companies, such as reduced alcohol industry supply chain costs, reduced administrative penalties, and tax incentives. Rising energy and food costs are challenging business conditions for the beverage industry sector, which requires innovations in its manufacturing processes to reduce the consumption of nonrenewable resources such as fossil fuels.

Overall, this chapter analyzes the economic and environmental contributions of alcoholic beverage production, emphasizing its significance in the global economy and the environmental challenges it poses. Despite recent disruptions—such as the COVID-19 pandemic and the war between Russia and Ukraine—the alcoholic beverage market is projected to experience substantial growth. However, this economic expansion is accompanied by significant environmental impacts, as beverage production contributes to greenhouse gas emissions and the intensive use of non-renewable resources.

In this context, Chapter Two focuses on scientific literature related to the environmental impact of distilled beverage production, underscoring the importance of understanding ongoing research in this field. As demand in the distilled beverage industry increases, so too does the consumption of natural resources, which in turn leads

to rising greenhouse gas emissions—particularly CO_2—with direct consequences for climate change.

To address this, Chapter Two presents a bibliometric analysis of the environmental impact of distilled beverage production, utilizing databases such as Scopus and visualization tools such as VOSviewer to examine relevant scientific publications.

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CHAPTER TWO

Scientific Production on the Environmental Impact of Distilled Spirits Production

Abstract. As the demand for the distilled beverage industry increases, so does the consumption of natural resources, which in most cases are non-renewable and considered critical. In addition, the growth of the alcohol industry results in increased emissions of greenhouse gases, such as $CO_{2,}$ which directly influences climate change. Therefore, it is necessary to know the scientific advances on the environmental damage resulting from the production of distilled products. Therefore, this paper presents a bibliometric analysis of the environmental impact of distilled beverage production to know trends on this academic topic. To perform the analysis, the Scopus database and the VOSviewer software were used to register the scientific publications and perform the statistical analysis. Although the results show few records in the data source analyzed, several thematic areas are shown, such as generating renewable energy from organic waste.

Keywords: VOSviewer, LCA, Decarbonization, Spirit, Bibliometric Analysis.

Resumen. A medida que aumenta la demanda de la industria de bebidas destiladas, también lo hace el consumo de recursos naturales, que en la mayoría de los casos no son renovables y se consideran críticos. Además, el crecimiento de la industria del alcohol

provoca un aumento de las emisiones de gases de efecto invernadero, como el CO_2, que influye directamente en el cambio climático. Por lo tanto, es necesario conocer los avances científicos sobre los daños medioambientales derivados de la producción de productos destilados. Por ello, este capítulo presenta un análisis bibliométrico del impacto ambiental de la producción de bebidas destiladas para conocer las tendencias sobre este tema académico. Para realizar el análisis, se utilizó la base de datos Scopus y el software VOSviewer para registrar las publicaciones científicas y realizar el análisis estadístico. Aunque los resultados muestran pocos registros en la fuente de datos analizada, se muestran varias áreas temáticas, como la generación de energía renovable a partir de residuos orgánicos.

Palabras clave: VOSviewer, Análisis bibliométrico, Espíritus, ACV

2.1 Introduction

One of the human activities that have the most negative impact on the environment are those related to producing alcoholic beverages. According to the United Nations, the alcohol industry emits billions of tons of carbon dioxide into the atmosphere each year due to its consumption, transportation, packaging management and waste generated (United Nations, 2021). For example, alcohol consumption in Sweden accounts for an average of 3% of Sweden's total carbon footprint (Movendi International, 2023). In addition, according to a study conducted by the University of Manchester, the alcoholic beverage sector emits around 1.5 gigatons of greenhouse gases globally each year, the same amount that 276 million medium-sized cars can emit (Bevvi company, 2023).

For this reason, several countries recognize that the state must implement mechanisms or strategies to reduce the generation of this

type of gas, mainly focused on the control of companies to reduce their carbon footprint; in this sense, several governments worldwide have created international treaties to reduce environmental pollution; for example, the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the Paris Agreement, as well as unilateral declarations such as the Cancun Pledges and Nationally Determined Contributions (NDCs).

As mentioned above, there is a concern about measuring the carbon footprint of alcoholic beverages using the life cycle analysis (LCA) methodology. LCA is a tool used to detect areas for improvement in the manufacturing process of an alcoholic beverage and thereby seek strategies to lessen its impact on the environment and human health (Fan et al., 2022). Also, applying this methodology is considered a way to convince manufacturers that their production process will be efficient by demonstrating that it will consume less energy for its operation (Alsayed & Tayeh, 2019).

In the world market of alcoholic beverages, there is a variety called distilled spirits. These beverages are produced from fermented beverages (Qian et al., 2019), and the most well-known are brandy, gin, rum, vodka and whiskey (Qin et al., 2022). However, there is a large market for beverages classified as liqueurs and other spirits that generate higher profits, as shown in Figure 12. This classification integrates distilled alcoholic beverages mixed with various substances composed of alcohol, sugars and aromatic essences.

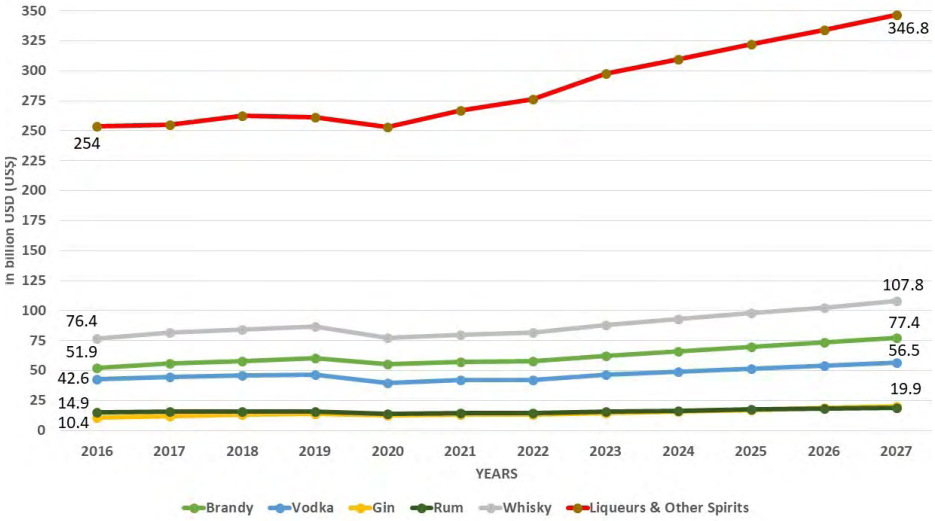
According to the Statista.com database, it is estimated that by 2027 this classification of spirits will have revenues of US$346.8 billion (Statista, 2023). Although other more well-known distilled spirits, such as whiskey and vodka, will earn lower revenues than liqueurs (as shown in Figure 12), they are estimated to grow steadily. This means that there will be greater consumption of natural resources for their production and, as a result, greater consumption of energy,

mainly from fossil fuels, which increases the generation of greenhouse gas (GHG) emissions (Samour et al., 2023).

Consequently, the main objective of this chapter is to analyze the scientific evolution of the environmental impact of the production process of a distilled beverage using the LCA methodology and the strategies proposed to achieve the decarbonization of the production process of this type of beverage. This study will make it possible to learn about the most relevant topics or trends in scientific publications and formulate future research projects to continue building the knowledge base in this thematic area.

To meet this objective, bibliometric analysis (also known as scientific mapping) helps to visualize patterns of development and trends of a given topic (Kasavan et al., 2021). Currently, this type of analysis is gaining popularity and is used in various fields of study because it is considered a tool that allows the visualization of information (Kirby, 2023). Bibliometric analyses provide an overall understanding of a topic of interest from scientific publications in different databases, such as Scopus (Hasan et al., 2023). A bibliometric analysis evaluates the number of published papers on the topic of interest, contributing authors and relevant keywords of a group of papers; it also analyzes the quantitative characteristics of a group of published papers, such as the number of citations received and H-index (Tamala et al., 2022).

Figure 12
Profits of different distilled alcoholic beverages



Note. Figure created by the authors using data from Statista (2023).

2.2 Methodology

Two resources were used for the development of bibliometric study. First, scientific publications (documents) indexed in Scopus were used, and second, the VOSviewer software was used to analyze them. The selected database is considered one of the frequently used sources of consultation to develop a scientific mapping of a topic of interest (Abdelwahab et al., 2023; Catani et al., 2022). Also, this database is considered among the most popular in different universities (Hasan et al., 2023), and there is access to scientific publications that analyze the environmental impact of the brewing process of a distilled beverage. The selected software allows for building and visualizing bibliometric networks and zooming in on the created network maps, which makes it ideal for searching for a moderate amount of information (Catani et al., 2022). Both resources are widely used for scientific mapping on scholarly publications of interest (Kasavan et al., 2021).

2.2.1 Characteristics of the Scope of the Study

This research aimed to analyze the scientific evolution of the environmental impact of distilled beverage production. This work was limited to analyzing the co-occurrence of keywords to infer the most relevant topics in the documents and to analyze co-authorship among authors, countries and institutions. Similarly, analyses of the quantitative characteristics of the scientific publications are included.

2.2.2 Search Strategy

The search for information was conducted from May 3 to May 15, 2023. This bibliometric analysis considered the trial-and-error method using keyword filtering to compile the crucial literature from the Scopus database. For the search of the documents, the following search equation was used in the first stage: (spirit OR "distilled drink" OR distillery) AND ("life cycle assessment" AND "life cycle analysis" OR "environmental impact assessment"). In the next step, the search was expanded by adding more keywords to create the following search equation: (spirit OR "distilled drink" OR distillery) AND ("carbon footprint" OR greenhouse OR "cleaner production" OR "carbon neutral production").

When searching for the data source, the records that did not meet the objective of the work were manually eliminated. From the selected documents, the data from Scopus were extracted in ".csv" format (comma-separated values) to be read by Microsoft Excel for processing in VOSviewer. It is important to mention that for the analysis in VOSviewer, all the terms mentioned in the documents were included; there was no selection or homologation stage between terms. Also, it was considered that the database itself established the search time limit.

2.3 Results and Discussion

2.3.1 Analyses of the First Stage of the Search

In the first stage of the search, 87 articles were found; however, of this number, only 11% showed an analysis of the environmental profile of a distillate production process using the LCA methodology. Table 1 shows the results of the first stage of the search. All the documents collected are articles. Considering that there is a great variety of distillates around the world, such as sugarcane-based spirits (e.g., Cachaça and Rum) (Bortoletto, 2023), gin, brandy, Cognac, tequila and baijiu (Qian et al., 2019), in addition to new offerings in the market made from different raw materials, such as those made from fruit (Oliveira et al., 2020), potato (Weber et al., 2020) and coffee beans (Lopes et al., 2022). However, the number of LCA publications on the production of distillates are few.

Table 1
Scientific publications on environmental impact analysis indexed in Scopus

s/N	Reference	Authors' affiliation	Document country	Cited by
1	(Eriksson et al., 2016)	University of Gävle	Sweden	16
2	(Vázquez-Rowe et al., 2017)	Pontificia Universidad Católica del Perú, University of Santiago de Compostela	Peru/Spain	20
3	(Leivas Ruben et al., 2019)	University of Cantabria	Spain	4
4	(Bhattacharyya et al., 2019)	University of Michigan	United States	7
5	(Becker et al., 2020)	Kedge Business School	France	38
6	(Maciel Martínez et al., 2020)	National Autonomous University of Mexico, Autonomous University of Tabasco, Michoacan University of Saint Nicholas of Hidalgo	Mexico	6
7	(Leivas et al., 2020)	University of Cantabria	Spain	18

8	(Madrid-Solórzano et al., 2021)	Universidad Autónoma de Ciudad Juárez, Universidad de La Rioja, Universidad de La Rioja	Mexico/Spain	1
9	(Madrid-Solórzano et al., 2022)	Universidad Autónoma de Ciudad Juárez, Universidad de La Rioja, Universidad de La Rioja	Mexico/Spain	0

Note. Compiled by the authors based on a literature review.

2.3.2 First Stage: Analysis of Co-authorship and Quantitative Characteristics of Journals

The paper by Becker, S., et al. (2020) has the highest number of citations, 38 in total (Table 1). This paper was published in the Journal of Cleaner Production, which has an H-index of 268 and an impact factor of 9.27. However, the paper by Leivas, R., et al. (2020) is published in a journal with the highest H-index of all, 317, as shown in Table 2, and with an impact factor of 5.98. In contrast, the most recent papers (Madrid-Solórzano et al., 2021, 2022) are published in journals of Swedish origin, Frontiers in Sustainable Food Systems and Agriculture, with an H-index of 41 and 52, respectively (see Table 2). Both journals are ranked with impact factors, the former with 5.2 and the latter with 3.8.

Of the nine documents indexed in Scopus, the co-authorship between Spain and Mexico is the one that has generated the most recent scientific publications, 2021 and 2022 (see Figure 13). In contrast, the co-authorship between Spain and Peru, a document published by Vázquez-Rowe I., et al. (2017), has the highest number of citations, a total of twenty. Then, Spain is the one with the highest production in LCA research of the process of elaboration of distillate. Additionally, it is the one with the highest number of collaborations with countries, exclusively with Latin America. However, it should be noted that Spanish and Latin American institutions do not co-author, i.e., their works are isolated. This lack of collaboration between institutions and authors is evidence that this topic

of LCA is not strengthened because there is no exchange of information to strengthen and promote the generation of knowledge on this topic.

Figure 13
Co-authorship temporality map of countries



Note. Figure created by the authors using VOSviewer.

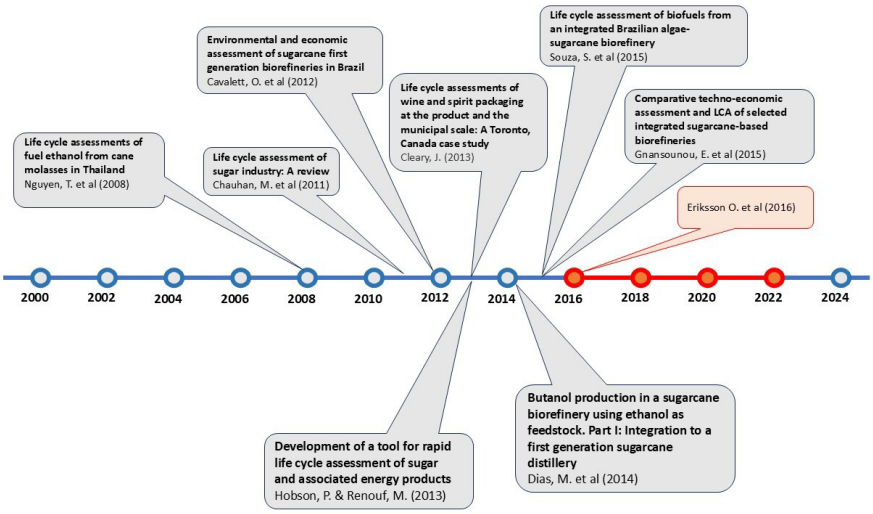
Documents published in Scopus during the period from 1996 to 2024 were analyzed; however, the first scientific publication on an LCA of the process of elaboration of a type of distillate appears in 2016, a document by author Eriksson O., et al. (2016), which has sixteen citations. Figure 14 shows a timeline of a 22-year period where the titles of the papers registered in the data source before Erickson, et al. (2016) are exposed. It is observed that the documents published prior to 2016 address the problem of assessing the environmental impact of different products derived from sugarcane, such as ethanol and butanol, as well as assessing their use to produce renewable energy (Cavalett et al., 2012; Chauhan et al., 2011; Dias et al., 2014; Gnansounou et al., 2015; Hobson & Renouf, 2013; Nguyen & Gheewala, 2008; Souza et al., 2015).

Only one paper evaluates the environmental impact of different bottle materials used in the wine and distilled spirits industry (pol-

yethylene terephthalate bottles, aseptic cartons and glass cartons) (Cleary, 2013). In contrast, the line in red shows the short period in which papers on LCA of distilled beverages have been published.

In general, it can be observed in Figure 14 that the topic of the environmental impact of the distillate production process using the LCA methodology has not been strengthened by the academic community in the last 10 years. The publications on this theme are focused on a short period of only 6 years, from 2016 to 2022. The fact that there are not so many papers on the subject of LCA in the production of distilled spirits indicates that it is an area of opportunity to consolidate this research topic since, as shown in Figure 14, the market for spirits and distilled beverages is increasing, they are the ones that generate the highest profits. In addition, as already mentioned in section 2.1, new liqueurs and distilled beverages are produced with raw materials other than the traditional ones, so it is necessary to evaluate the environmental profile of these new offers in the market.

Figure 14
Timeline of papers published before the first paper on LCA of a distilled spirit

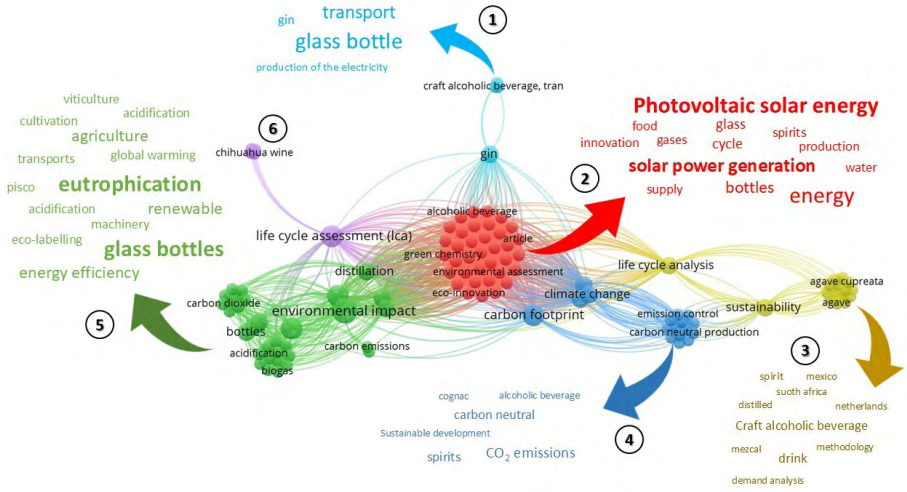


Note. Figure created by the authors.

2.3.3 First Stage: Keyword Analysis

By processing the data downloaded from Scopus in VOSviewer, a network map is created with six clusters exposing the keyword co-occurrences of the papers found in the first stage of the search, as shown in Figure 15. The analysis aims to identify significant topics of interest on the environmental impact of distilled beverages. Each of the clusters has a different color; for example, light blue (cluster number one), red (cluster number two) and brown (cluster number three).

Figure 15
Keyword network map of the first search stage in 2023



Note. Figure created by the authors using VOSviewer.

If one analyzes the keywords that are easy to visualize in the network map in Figure 15, those with solid co-occurrence links, one can infer a small number of topics, many of which are very general. For example, in cluster number two in red, the keywords "alcoholic beverage", "environmental assessment" and "eco-innovation" are easily observed, which suggests that a topic of interest is the develo-

pment of processes that contribute to the sustainable development of the distilled spirits industry.

Also, when looking at cluster number three (light green), the keywords "sustainability", "life cycle analysis" and "agave" suggest that a topic of interest is the sustainability of the production of distillates from agave as a raw material. On the other hand, if we zoom in on each cluster individually and analyze the group of keywords that make it up, we can deepen the analysis and thus be able to infer with a greater degree of certainty significant topics of interest in the documents.

For the in-depth analysis of the network map analysis in Figure 15, it was considered that keywords referring to the description and objective of the LCA methodology and a distilled spirit would be considered with a low estimation value for the analysis. For example, words such as "environmental impact", "life cycle assessment (LCA)", "sensitivity analysis", which are part of the vocabulary to describe the methodology mentioned above, had a low estimation value, even though they have a high total link strength score in the keyword network map, 109, 105 and 70 points respectively, and six, eight and two co-occurrences in the documents.

When analyzing the semantic field of the first cluster, the keywords "glass bottle" and "transport" present a total link strength score of 70 and 20 points, respectively, in the network map. The first word has the highest number of co-occurrences in the documents, four in total. It follows that the critical factors in producing a distilled spirit that contribute most to environmental damage are using glass as the primary packaging material and transporting inputs and outputs in the value chain.

Cluster two shows several keywords closely related to solar energy, such as "photovoltaic solar energy" and "solar power generation", with 47 points each. Thus, it can be inferred that a research trend

is using renewable energy sources, such as photovoltaic equipment used to reduce greenhouse gas emissions. Cluster three presents a minimum number of related keywords that refer to the artisanal elaboration of Mezcal; all present a low linkage strength score of fifteen points. Therefore, it was not possible to determine a topic of interest. The same situation occurred with the analysis of cluster four, where keywords are related to terms describing the LCA methodology and references to the concept of a distilled alcoholic beverage.

In cluster number five, it can be seen that the keywords "glass bottles", "eutrophication", "agriculture", "biogas", "energy efficiency" and "use of renewable energies" are the most relevant. Of these terms, those with the highest link strength scores are the first two, 70 and 58, respectively, and the rest have a value of 20 points. Several themes can be inferred by performing a cluster analysis of these keywords and relating them to those of the same semantic field with lower link strength scores. First, the first two keywords infer the environmental damage from using glass bottles, a theme already mentioned. Second, a new theme that results from grouping words three and four consists of the study of the environmental consequences caused by the excess of nutrients used (e.g., fertilizers) in the cultivation of raw materials of this industry. Finally, cluster six presented keywords that did not result in obtaining a trend when grouped together.

2.4 Analysis of the Second Stage of Search

Due to the small number of documents found on LCA of distilled spirits, the decision was made to perform the next search stage by adding more keywords, as discussed in section 2.2.1. Using the second search equation, 213 documents were found, of which only 14 new documents were added to those found in the first stage of the search, described in section 3.1, for 23 documents.

The remaining papers discarded for bibliometric analysis were related to topics other than the manufacture of a distilled alcoholic beverage, e.g., the impact of modern life on the water cycle (Tanika et al., 2023), evaluation of hybrid systems for hydrogen generation (Haroon Bukhari et al., 2023), commercialization of sugar-energy bioelectricity (Ferraresi de Araujo et al., 2022), the use of carbon tax to mitigate the generation of greenhouse gases (Ngwome, 2023), use of tomato plant biomass (Jamal-Uddin et al., 2023) and the techno-economic and environmental implications of the use of polylactic acid (PLA) (Bressanin et al., 2022), to mention a few references.

Likewise, a low estimation value criterion was applied to analyze all those terms that refer to the description and objective of the LCA methodology and to a distilled spirit.

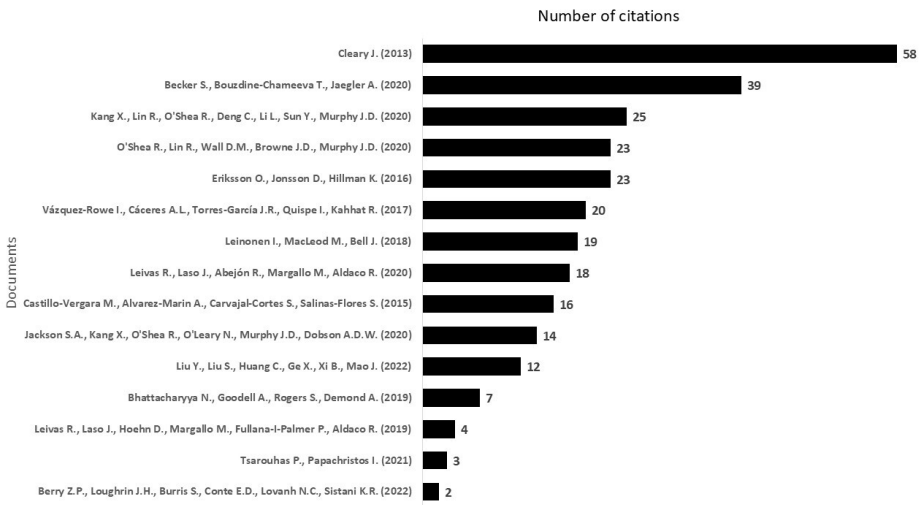
2.4.1 Second Stage: Analysis of Co-authorship and Quantitative Characteristics of the Journals

Concerning the number of citations per paper, as seen in Figure 16, in first place is the paper by Cleary J. (2013), with 58 citations in total, followed by the paper by Becker S. et al. (2020). It is interesting to note that both authors do not have papers with recent publication dates (Becker et al., 2020; Cleary, 2013) . However, if a scrutiny by collaboration between authors is performed. In that case, it can be seen in Figure 16 that authors O'Shea R. and Murphy J.D. add their jointly conducted papers with a total of 62 citations (O'Shea et al., 2023). In other words, these two authors have the highest co-authorship concerning other researchers.

In contrast, the papers with at least one citation are by Edwards et al. (2022), Madrid-Solórzano et al. (2022) and Früh et al. (2021), and those papers with no citation are Duffy et al. (2023), O'Shea et al. (2023), Aguiar et al. (2021) and Shimizu et al. (2013).

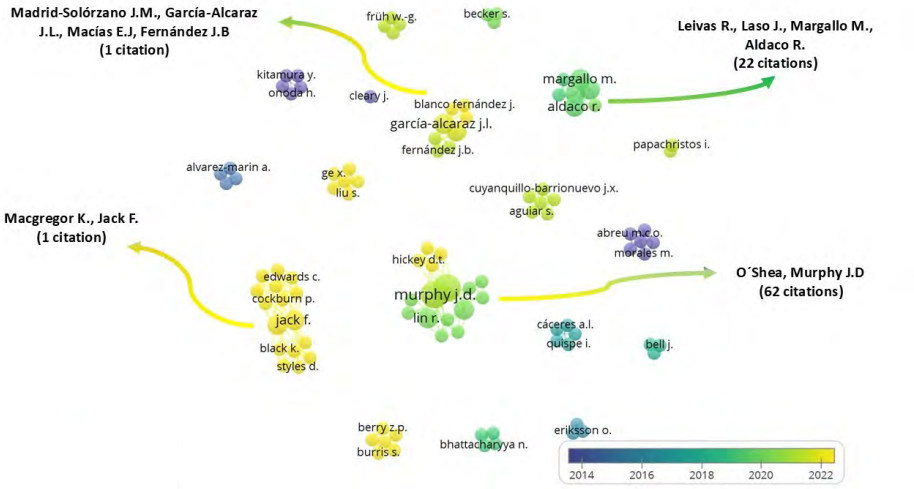
In addition, the papers of these authors are of recent publication (Aguiar et al., 2021; Duffy et al., 2023; Edwards et al., 2022; Früh et al., 2021; Madrid-Solórzano et al., 2022; O'Shea et al., 2023; Shimizu et al., 2013), as shown in the map in Figure 16, where the yellow color signifies papers with earlier publication dates registered in Scopus, and the purple color signifies papers with later publication dates. Another cluster of researchers with fewer collaborations are Leivas R., Laso J., Margallo M. and Aldaco R., with 22 citations for their papers. However, as can be seen in the network map in Figure 17, the clusters of researchers, such as those exemplified above, show a lack of connectivity between them; that is, there is no close communication between authors, probably the result of the little attention given to this field of study.

Figure 16
Number of citations per document in 2023. Image created by authors



Note. Figure created by the authors based on a literature review.

Figure 17
Co-authorship network map between authors by time of publication



Note. Figure created by the authors using VOSviewer.

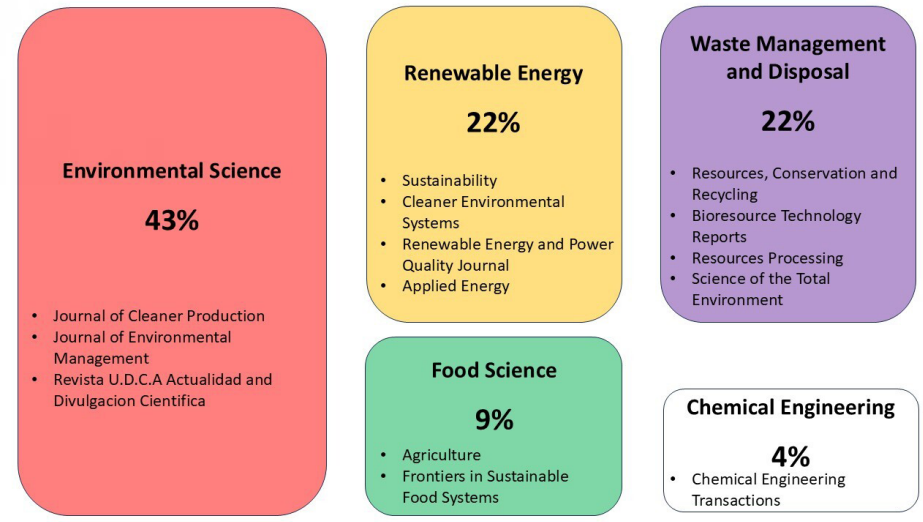
Concerning the journals in which these documents have been published (Figure 18), they are grouped into five categories according to Scimago Journal & Country Rank, based on a grouping by similarity of their thematic areas. The first category comprises a group of journals specializing in publishing research results related to evaluating the environmental impact of a production process. A total of ten papers have been grouped in this category, corresponding to 43% of the total of 23 papers. The Journal of Cleaner Production, with an H-index value of 268, is the journal that contains the most scientific publications on this thematic area, a total of eight documents.

Table 2 shows the country of origin of each journal and its respective H-index value. Category two comprises journals that predominate in the thematic area of renewable energy and has five documents, corresponding to 22% of the total number of documents analyzed. In this category, Sustainability is the journal with the most publi-

shed documents (a total of two) and has an H-index of 136 (see Table 2).

In a similar percentage to category two is the category named "Waste Management and Disposal". This category comprises four journals, the journal Resources, Conservation and Recycling, the one with two published papers and an H-index of 170. The remaining categories are Food Science and Chemical Engineering, which account for 9% and 4% of the remaining documents retrieved from Scopus.

Figure 18
Thematic classification of journals



Note. Figure created by the authors based on a literature review.

Table 2
Ranking of journals by H-index

Journal	Journal country	H-index
Science of the Total Environment	Netherlands	317

Journal of Cleaner Production	United Kingdom	268
Applied Energy	United Kingdom	264
Journal of Environmental Management	United States	218
Resources, Conservation and Recycling	Netherlands	170
Sustainability	Switzerland	136
Agriculture	Switzerland	52
Chemical Engineering Transactions	Italy	43
Frontiers in Sustainable Food Systems	Switzerland	41
Bioresource Technology Reports	United Kingdom	39
Renewable Energy and Power Quality Journal	Spain	26
Cleaner Environmental Systems	United Kingdom	12
Resources Processing	Japan	5
U.D.C.A. Actualidad and Divulgación Científica Magazine	Colombia	1

Note. Compiled by the authors based on a literature review.

2.4.2 Second Stage: Keyword Analysis

Analyzing the 23 documents with VOSviewer generated a map with nine keyword clusters, as shown in Figure 19. The result is a network map in which, from a series of intertwined relationships, different scattered connections are identified, such as "animal food", "methane" and "pollution control". However, it is possible to highlight some formations that show high connectivity; for example, clusters three and four have a high linkage with the keywords "greenhouse gases", "anaerobic digestion," and "waste disposal".

Likewise, clusters five through eight have strong links with the keywords "sustainable development", "life cycle" and "eutrophication". By developing a deeper bibliometric analysis in the semantic field of each cluster, it is possible to visualize relevant themes or trends in the documents with greater severity.

In cluster number one, it can be observed that the keywords with the most significant influence are "biogas", "anaerobic digestion", and "methane", with 204, 148 and 98 total link strength scores, respectively. When relating these terms to others that make up the semantic field of cluster number one, it can be deduced that there is a thematic trend to evaluate the potential of developing fuel from the biodegradation of organic matter that originates in distilleries as waste.

Cluster number two shows an academic topic of interest similar to the first one, and this is because the most relevant keywords are "energy resource", "biofuels" and "anaerobic growth"; in addition, these have a high link strength score, 118, 63 and 41 points, respectively. In this same sense of taking advantage of the waste generated in the production of a distilled spirit, cluster number three suggests that a topic of interest is to convert the waste from this type of production process into animal feed since the keywords "animalia", "livestock feed", "agricultural by-products" and "cattle" stand out in the semantic field of this cluster, with the first keyword having the highest link strength score, a total of 51.

Cluster number four also presents the academic tendency to take advantage of the waste resulting from the process of making an alcoholic beverage since keywords such as "distillery waste", "waste disposal", "circular economy" and "food" show a high co-occurrence in the documents and with a link strength score of 159, 118, 108 and 87, respectively. However, there are several words with low influence, such as "bio electricities", "bio-energy", "energy", and "power generation"; however, by grouping them, it can be deduced that the-

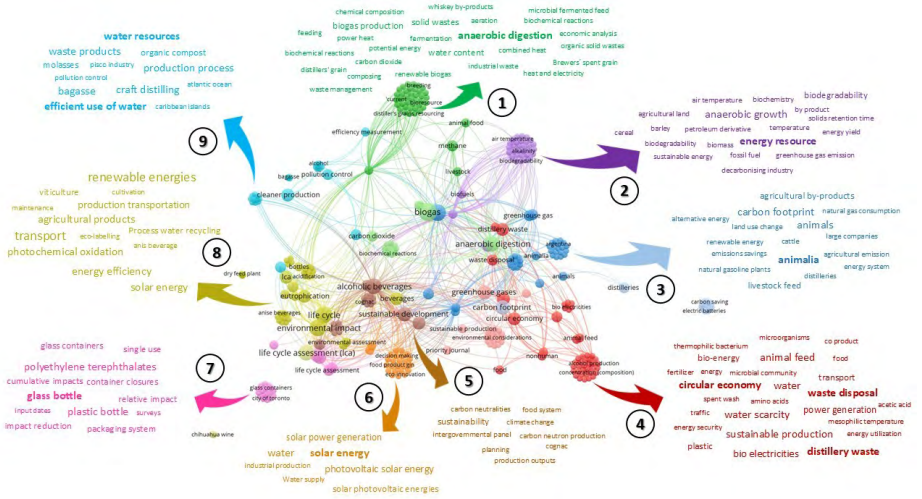
re is a topic of interest, which is to use distillery waste as a source of energy.

Cluster number five presents keywords related to terms similar to describe a distilled beverage, such as "alcoholic beverages", "spirit", and "cognac"; likewise, it presents terms that show a high degree of similarity, such as "greenhouse effect" and "greenhouse gases emissions". For this reason, a relevant academic topic was not obtained. Cluster number six shows as a topic of interest the use of solar energy as a renewable energy source since it shows keywords with high influence, such as "eco-innovation", "photovoltaic solar energy", and "solar energy", the first two terms present a link strength score of 47 and the last one, presents a score of 68.

Cluster number seven reveals that using glass bottles contributes significantly to the environmental impact of producing a distilled beverage due to water consumption. This assertion results from the predominance and high relationship of the keywords "glass bottles" and "water", with 117 and 70 total link strength scores, respectively. Cluster number eight suggests a topic of interest already mentioned in the analysis of the first stage (section 3.1.2), which is the excess of nutrients used (e.g., fertilizers) in the cultivation of raw materials for this industry.

Finally, when analyzing cluster nine, another topic of interest stands out, the excess consumption of water in the process of making a distilled spirit. This concept is created by analyzing the co-occurrence of terms related to water use. For example, from cluster eight, the keyword "process water recycling" and, from cluster nine, the keywords "efficient use of water" and "water resources" show a high relationship strength, with the first keyword having the highest link strength score, 23 points, and the rest of the terms, 14 points.

Figure 19
Keyword co-occurrence network map of the second stage



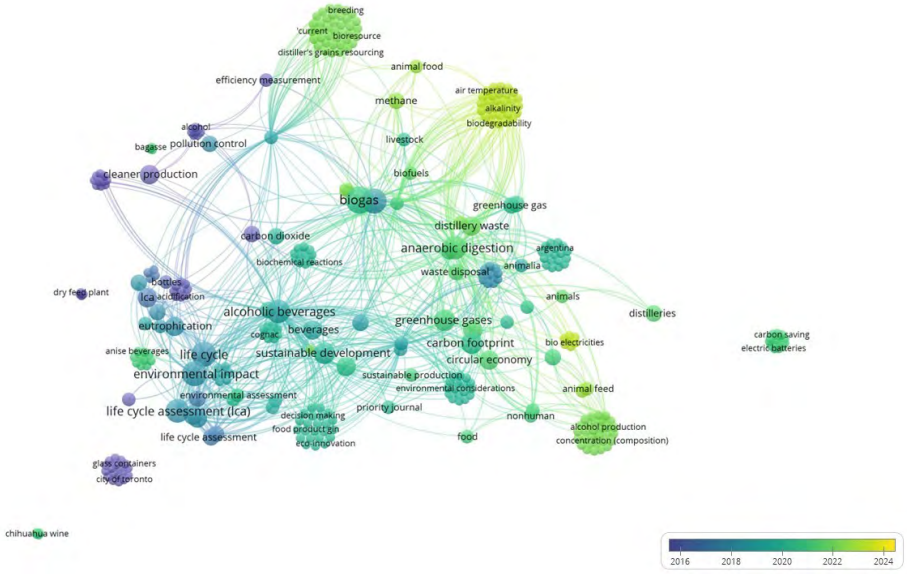
Note. Figure created by the authors using VOSviewer.

Concerning the temporal evolution of the research carried out, Figure 20 shows that the keywords "bio electricities", "biodegradability" and "biogas" are those that appear in documents with the earliest publication dates. In contrast, those appearing in documents with later publication dates are "cleaner production", "bottles" and "life cycle assessment". When analyzing Figure 18 in general and contrasting it with the map of keyword occurrences in Figure 19, it can be noted that the most recent research topic is the search for the decarbonization of the process of making a distilled beverage from the use of renewable alternative energies produced from biomass.

The co-authorship network map between countries created with VOSviewer shows the existence of two predominant clusters. Figure 21(A) shows close collaboration between Spain, Mexico and Peru, with the first country leading the research with these two Latin American countries. On the other hand, Ireland has the greatest collaboration with European countries, such as France and the United Kingdom. The most recent research has been generated with the

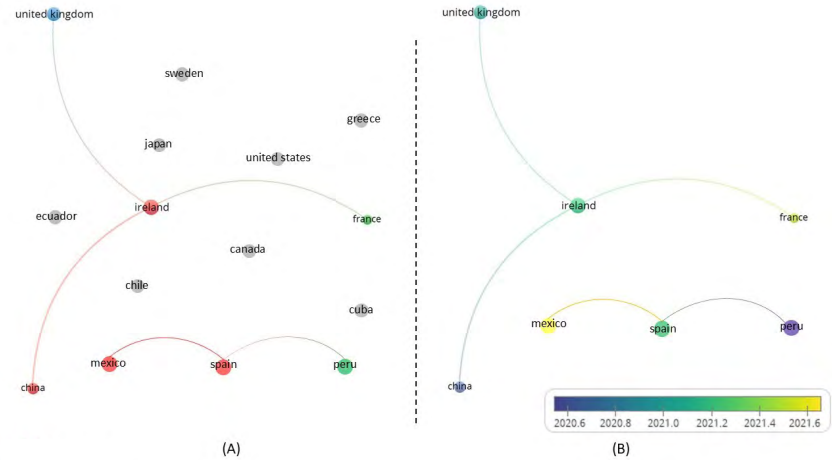
aforementioned European countries, as shown in Figure 21(B), with China being the country with the longest history of collaboration.

Figure 20
Network map of the temporal evolution of investigations



Note. Figure created by the authors using VOSviewer

Figure 21
Network map of co-authorship between countries



Note. Figure created by the authors using VOSviewer.

2.5 Main Issues Addressed in the Analysis

This chapter presents a bibliometric analysis of publications on the environmental impact assessment of distilled beverages using the ISO 14040–14044 methodology. The results of this analysis, illustrated in Figure 14, reveal a relative scarcity of academic publications directly addressing this topic.

However, it is important to consider related research that provides context for the bibliometric findings shown in Figure 19, where three relevant themes are identified. The first relates to the use of waste (see clusters 1 to 4 and cluster 9); the second concerns the use of solar energy (see clusters 6 and 8); and the third involves primary packaging (see cluster 7).

Regarding the first theme, the generation of biogas from distilled beverage production waste is a sustainable strategy for managing these by-products. Furthermore, involving the local community—by incorporating biomass from their agricultural activities—can promote job creation, strengthen the local economy, and increase the energy independence of rural areas (Roubinek et al., 2023). Nevertheless, challenges remain in optimizing the anaerobic digestion process to ensure efficient biogas production. These include maintaining an appropriate carbon-to-nitrogen (C/N) ratio, regulating pH levels (Ngabala & Emmanuel, 2024), and stabilizing the dominant microbial population (Chen et al., 2025).

The use of solar energy can reduce dependence on fossil fuels. Accordingly, fossil fuels such as natural gas are being replaced by solar energy in the production of alcoholic beverages, particularly during the distillation phase (Azzam & Obaid, 2025). For instance, solar thermal energy has been applied experimentally in the distillation of white wine to produce brandy, using parabolic solar stills (Chaparro Montoya et al., 2024) and tube systems (Klinbun et al., 2024). Thus, integrating solar energy into the production process

represents a sustainable strategy for reducing fossil fuel dependence, although these approaches remain in the development and consolidation stages.

Glass bottles in the distilled beverage industry contribute significantly to greenhouse gas (GHG) emissions due to fossil-based energy consumption, water use, and transportation impacts (Caspers et al., 2025). To mitigate this environmental impact, several strategies have been proposed: recycling, reusing, and replacing glass bottles—primarily with PET (polyethylene terephthalate) bottles. Manufacturing bottles from recycled glass reduces energy consumption and CO_2 emissions compared to using virgin glass (Baek et al., 2025). Caspers et al. (2025) estimate that reusing a glass bottle up to five times can reduce GHG emissions by up to 30%. Another viable alternative is substituting glass with PET, which emits fewer GHGs—0.178 kg CO_2 eq per liter for PET, compared to 0.493 kg CO_2 eq per liter for glass.

In summary, the key issues identified through the analysis of class words in the bibliometric study represent important sustainability challenges that warrant further exploration in future research.

2.6 Future Research

The alcoholic beverage industry is adapting to the new relationships that new generations have with alcohol. Young people like to consume alcoholic beverages with fruit and herbal flavors and with a lower alcohol percentage or even without alcohol (beverages that do not exceed 5% alcohol by volume). (Carnegie, 2022). Therefore, a variety of distilled alcoholic beverages are offered in the market to meet the preferences of young people. For example, the Swedish company Gnista offers a non-alcoholic distilled spirit, while in England, there is an alcoholic beverage known as Crossip.

The IWSC association (International Wine & Spirit Competition) reported 2022 its analysis of non-alcoholic spirits brands in eight

(Club Oenologique, 2022). Therefore, this work suggests analyzing this new type of spirit's life cycle to expand scientific knowledge in this thematic area.

In Scopus records, no analysis was found on the environmental impact of several famous spirits, such as Rum, Sake, and Baijui (Wang et al., 2021). Therefore, it is recommended to expand the number of research concerning environmental impact assessments of spirits. Increasing the number of contributions on this subject area would help to increase the number of strategies for decarbonization of this industry but under different contexts, such as climate, production capacity, primary and secondary packaging, and distillation equipment. As a result, small distillate products worldwide could have a wider range of possibilities to adapt strategies for decarbonization of the alcohol industry according to their own contexts or constraints.

2.7 Conclusions

The distilled beverage industry continues to grow despite the COVID-19 pandemic, although growth is slow. However, the economic development of this sector emits billions of tons of carbon dioxide annually, influencing climate change. Therefore, this paper examined the current status and growth trend of the scientific production that integrates LCA research related to environmental impact assessment in the distilled spirits industry and the strategies proposed to decarbonize the distilled alcoholic beverage manufacturing process.

The study was developed using the bibliometric analysis method and the VOSviewer tool; however, this research was limited in scope due to several aspects. First, the limited existing literature on the subject in the source of consultation. Second, only Scopus was used as the database for this analysis; other resources, such as Web of Science (WoS) and Google Scholar, were left out. Therefore, multi-

ple databases could be incorporated in the future for a more in-depth analysis.

Based on the analysis of 23 articles registered in Scopus, the study can state that this research topic started to flourish in 2016. In addition, it can be mentioned that the trends in papers to decrease the environmental impact of the production processes of a distilled beverage are listed below:

1. Generate alternative energy sources other than oil, such as biofuel and bioelectricity.
2. To take advantage of organic waste to be used as animal feed.
3. To estimate the effectiveness of using solar energy for zero greenhouse gas emissions.
4. Address the issue of the environmental impact resulting from the use of glass bottles and evaluations of other materials such as PET to reduce the environmental impact of primary packaging.
5. Efficient water consumption in the distillation process.
6. Reduce transportation distances of raw materials and inputs.

Chapter Two focused on scientific literature related to the environmental impact of distilled beverages, using life cycle analysis (LCA) as a tool to identify opportunities for optimization in their production processes. This bibliometric analysis highlighted the urgent need to implement decarbonization strategies within the sector. Building on this perspective, Chapter Three will explore a more detailed assessment of the environmental impact of artisanal spirits, with particular emphasis on critical factors such as raw material sourcing and packaging solutions.

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CHAPTER THREE

Environmental Impact Assessment of Craft Spirits

Abstract. Assessing the environmental impact of distilled alcoholic beverages is vital to ensuring the quality and reputation of the product, the sustainability of the production process, and the identification of development opportunities. Therefore, this chapter presents the results of the environmental impact assessment of several craft spirits. The case studies analyzed were from Mexico, Spain, and Peru. The analysis of these cases indicates that the critical factors to be considered to achieve a balanced relationship between the activities of this industrial sector and the environment are primarily the harvesting of raw materials, primary packaging, and transportation.

Keywords: LCA, Craft spirits, Carbon footprint, Sustainable, Market growth trends.

Resumen. La evaluación del impacto ambiental de las bebidas alcohólicas destiladas es vital para garantizar la calidad y reputación del producto, la sostenibilidad del proceso de producción y la identificación de oportunidades de desarrollo. Por ello, en este capítulo se presentan los resultados de la evaluación del impacto ambiental de varias bebidas espirituosas artesanales. Los casos analizados proceden de México, España y Perú. El análisis de estos casos indica que los factores críticos que deben tenerse en cuenta para lograr una relación equilibrada entre las actividades de este sector industrial

y el medio ambiente son principalmente la recolección de materias primas, el envasado primario y el transporte.

Palabras clave: ACV, bebidas espirituosas artesanales, huellas de carbono

3.1 Definition of Craft Spirit

According to the American Craft Spirits Association, craft spirit meets four basic requirements: the production process, clarity and transparency of the raw materials used to make the distillate, low production capacity, and independence in the distiller's decision-making.

The first requirement is that this type of alcoholic beverage is made by a distillation process that separates the alcohol from the water and wort using a still. Since alcohol has a lower boiling point than water (173.3 °F), it evaporates first, rises through the still's copper tubes, and condenses as it cools. The condensed alcohol distillate drips into a separate container. However, distilleries do not want the first alcohol vapors (they contain methanol and other volatile poisons and have a harsh taste and odor) or the last vapors (which have a bitter taste). The true art of distilling any distillate is extracting the "heart cut," the vapors that meet midstream and condense into a liquid with a robust flavor, seductive aroma, and smooth taste. Master distillers know when the heart cut begins to flow through the tubes of stills, based solely on their experience. At that point, the valve opens, and the distillate is diverted into a separate container. The distillation procedure is repeated two or three times, with each iteration yielding a higher alcohol concentration.

Distilled alcoholic beverages are considered to have an alcohol content between 30% and 50% v/v. This means that every 100 ml of beverage should contain between 30 and 50 ml of ethanol. The final

product is a clear spirit, ready for aging. In this last stage of storage, it is given additional organoleptic properties to those that the raw material from which it is made provides (Cleaveland, 2021).

The second requirement is a craft spirit with ingredients that are clearly and transparently presented to the customer. According to A. Williams et al. (2020), craft spirits emphasize using locally sourced ingredients and genuine production methods, which emphasizes building a narrative that they are a better-quality product than mass-produced spirits.

The third requirement is that craft distillery companies produce no more than 28,390 hectoliters per year, according to the American Distilling Institute (AMI). These distilleries are small, generally seeking to offer high-quality alcohol and not worrying about production volume; however, they can produce significant amounts of product (Roughan, 2022).

The final requirement is that the distillery owns at least 75% of the capital, allowing it to operate independently. Distilleries that exhibit autonomous ownership often emphasize quality, innovation, and community involvement. These entities enhance the heterogeneity and vitality of the spirit industry by providing distinctive and genuine goods that instill their respective regional characteristics and fervor (A. Williams et al., 2020).

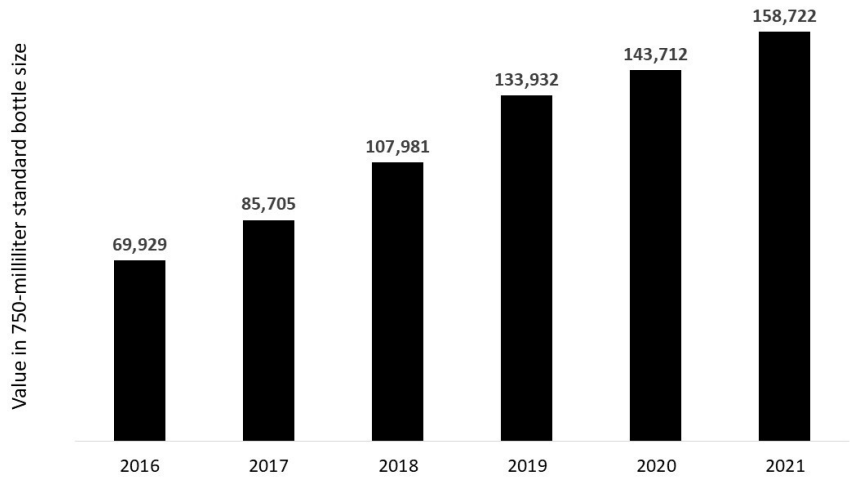
3.2 The Craft Spirit Market

After the COVID-19 pandemic, people's tastes changed, and there was a huge demand for different types of beverages that offered different flavors than traditional ones on the market, including craft spirits (Nilsson & Reid, 2019). This differentiator of craft-produced distillates caused young consumers born between the 1980s and the 2000s to be inclined to consume these types of beverages. Consequently, the demand for craft distilled beverages is expected to increase globally (Verhaal & Carroll, 2022). The craft spirits market

is forecast to reach US$17,509.70 million by 2023 and US$28,859.36 million by 2028, with a compound annual growth rate (CAGR) of 10.51% over the same period (Mordor Intelligence, 2023).

One of the most important markets for the consumption of craft spirits is the United States, and these types of alcoholic beverages are the fastest-growing in the country (Press, 2023). In 2020, the production of craft distilled spirits in the North American market increased by almost 8% annually, whereas non-craft volumes registered a growth of 5% annually (Aswani, 2021). In 2021, the US market volume of craft distilled beverages reached more than 13.2 million 9-liter cases in sales, equivalent to 158,722 750-milliliter capacity bottles, achieving an annual growth rate of 10.4%, as shown in Figure 22.

Figure 22
Craft spirit sales by bottles, 2016–2021

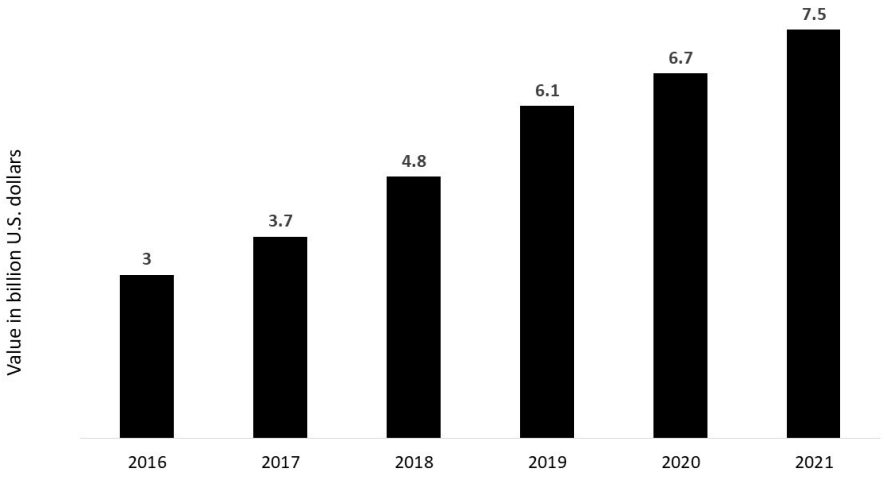


Note. Figure created by the authors using data from the American Craft Spirits Association (2022) and Park Street (2022).

The market reached US$7.5 billion in sales, growing at a CAGR of 12.2% (Park Street University, 2022), as shown in Figure 23. In the same year, the countries that made up the trade agreement between Mexico, the United States, and Canada, also called T-MEC, had the largest share of the global distilled spirits market, with 60.8% (Grand View Research, 2023), well above other world regions such as Europe and Asia Pacific (Market.US, 2023). By 2022, it was estimated that there were more than 2,687 producers of craft spirits in this market (American Craft Spirits Association, 2022), almost double that recorded in 2016, with 1,300 producers (Arthur, 2016). Therefore, the expansion of this economic sector generates significant monetary income with an upward growth trend.

Tourism is one of the factors that has driven the growth of this sector in the distilled alcoholic beverage industry. Visiting craft distilleries helps the tourism industry offer new experiences to its customers. Distilleries offer tourists various food, beverage, and recreational activity options (Knollenberg et al., 2021). Likewise, craft beverage tourism allows people to connect with people who make alcoholic beverages and with the places where they are made, creating a perception of authenticity that benefits the interest in their consumption, as well as being reputable and linked to family or ancestral traditions (Gaytán, 2019). This successful linkage between tourism and craft distilleries has made more people interested in investing in craft distilleries because of their economic benefits (Verhaal & Carroll, 2022).

Figure. 23
Craft spirits sales in US$ billions, 2016 – 2021



Note. Figure created by the authors using data from the American Craft Spirits Association (2022) and Park Street (2022).

Another factor that has increased the consumption of this type of alcoholic beverage is its use in restaurants and bars to satisfy customers' preferences. People prefer products that use natural or organic flavors, such as natural spices, botanicals, fresh citrus, vanilla, and raspberries (Club Oenologique, 2022). Therefore, smaller brands promote and sell spirits made from organic ingredients, such as non-genetically modified grains, and combinations of different raw materials to offer a flavor in line with market preferences (Carnegie, 2022). (Carnegie, 2022). In addition, beverage professionals, such as bartenders, have been incorporating alcoholic beverages to create cocktails to meet consumer demand (Mordor Intelligence, 2023).

3.3 Environmental Impact Assessment in the Craft Spirits Industry

CO_2 emissions are at a record high due to human activity, and their amount in the air is now more than 50% greater than before the Industrial Revolution (National Oceanic and Atmospheric Administration, 2023). This increase in CO_2 is the result of burning fossil fuels for transportation and electricity production as well as food and beverage manufacturing, tree cutting, agriculture, and many other economic activities that generate gaseous pollutants into the atmosphere.

CO_2, like other greenhouse gases, prevents heat from the Earth's surface from escaping into space, and this causes weather events such as heat waves, droughts, wildfires, and floods to worsen (Liu et al., 2019). Therefore, the result of an increase in greenhouse gases affects ecosystems in a way that cannot be corrected. The consequences are food insecurity, lack of water suitable for human consumption, and increased poverty in many countries, widening the gap between high- and low-income countries (United Nations, n.d.).

For this reason, international agreements have been reached, such as the Paris Agreement, which aims to halt climate change by reducing the greenhouse gas emissions generated by companies through their production processes and supply chain (The Organization for Economic Cooperation and Development, n.d.). International agreements have promoted the creation of environmental policies in companies and the measurement of the carbon footprint of production processes (Wong et al., 2020). The purpose is to know the amount of CO_2 emitted by a company to carry out actions to reduce it as much as possible (IBERDROLA, n.d.).

The craft spirits industry is also concerned with reducing its carbon footprint (Fetzer, 2023). Businesses of all sizes are doing what they

can keep from polluting the air, making their cities healthier, and keeping natural resources safe (The United Nations of Fine Spirits, n.d.). Several strategies can be implemented to reduce environmental damage (Spirit Hub, 2022), and there are studies on the environmental impact of craft distilled spirits production. Therefore, this chapter presents five craft spirits' environmental impact assessment resumes.

3.3.1 Methodology Frequently Used to Calculate the Environmental Impact of Alcoholic Beverages

Life cycle analysis (LCA) methodology is frequently used to calculate the environmental impact of a production process (Legua et al., 2021; Mikosch et al., 2022). (Legua et al., 2021; Mikosch et al., 2022). The proposed methodology presents several steps that are described in the ISO 14040 and 14041 standards (Legua et al., 2021), and all its activities are integrated into four steps: defining objectives and scope, conducting a life cycle inventory (LCI) analysis, assessing the impacts on the environment (LCIA), and formulating conclusions (Hauschild, 2018).

According to the LCA methodology, environmental damages are grouped and measured in environmental impact categories. Impact categories are a method of grouping and measuring the effects of an industrial product or process (Legua et al., 2021). There are two methods for grouping and measuring the impact categories frequently used to assess the environmental damage of the process of making alcoholic beverages: ReCiPe and CML-IA baseline (Ferrara & De Feo, 2018; Hosseini et al., 2023). The first method is commonly used to assess the environmental consequences on human health, ecosystem quality, and resource depletion. Additionally, this method is considered more comprehensive than the CML-IA baseline method (Abyar et al., 2020). The second method examines the inputs and outputs of the system in question and is considered to cover a more significant number of elementary fluxes in the acidification cate-

gory and the eutrophication category, compared to the ReCiPe (Bach & Finkbeiner, 2017), as well as provides a comprehensive view of many environmental consequences related to acidification, eutrophication, and global warming potential (Mahmud et al., 2018). Table 3 shows the differences in the impact categories of each method with a brief description and their unit of measurement.

While those interested in applying the LCA methodology have two methods that can be used to analyze the most harmful parts of the life cycle of an alcoholic beverage, they may even combine them (Vázquez-Rowe et al., 2017), making decisions to correct them. There are more methods to be used; for example, the software package known as "SimaPro", which is used to carry out an LCA, incorporates 27 methods (SimaPro, n.d.). However, the choice of these methods depends on the objective, context of the study, and breadth of the analysis (Sadeek et al., 2020).

Table 3
List of impact categories for ReCiPe and CML-IA methods

ReCiPe method			CML-IA method		
Impact category	Description	Reference unit	Impact category	Description	Reference unit
Agricultural Land Occupation (ALO)	Analyzing the extent to which human activities have displaced agricultural land	m^2	Abiotic Depletion Potential (ADP)	Figuring out how likely it is that supplies like minerals and fossil fuels will run out.	kg Sb eq.
Climate Change (CC)	Measuring the potential for global warming in terms of carbon dioxide equivalents	yr/kg CO_2 eq.	Acidification Potential (AP)	Evaluating the possibility of releasing acidic substances into the environment, which can be harmful to ecosystems and human health	kg SO_2 eq.

Fossil resource depletion (FD)	Assessing the possibility of depletion of fossil fuel resources	kg oil eq.	Eutrophication Potential (EP)	Evaluating the potential for excessive nutrient enrichment to cause harmful algal outbreaks and ecosystem imbalances in water bodies	kg PO_4 eq.
Freshwater Ecotoxicity (FEC)	Quantifying the possible toxic effects on freshwater ecosystems	yr × m^3	Depletion of Abiotic Resources-Fossil Fuels (ADPf)	Assessing the possibility of depletion of fossil fuel resources	MJ
Freshwater Eutrophication (FE)	Figuring out how much eutrophication could happen in watery bodies	yr × kg/m^3	Freshwater Aquatic Ecotoxicity Potential (FAETP)	Evaluating the likelihood of causing injury to aquatic organisms residing in freshwater environments	kg 1,4-DB eq.
Human toxicity (HT)	Evaluating the probable carcinogenic effects on human health	yr/kg 1.4-dichlorobenzeen (1,4-DCB)	Global Warming Potential (GWP)	Evaluation of a substance's potential to contribute to climate change by retaining heat in the atmosphere	kg CO_2 eq.
Ionizing Radiation (IR)	Measuring the potential environmental effects of ionizing radiation	yr/kBq Cobalt-60 eq.	Human Toxicity Potential (HTP)	Evaluating the potential health effects of toxic substance exposure on humans	kg 1,4-DB eq.
Metal Depletion (MD)	The amount of metal resources mined and used	kg Fe eq.	Marine Aquatic Ecotoxicity Potential (MEP)	Evaluating the potential for causing injury to marine-dwelling aquatic organisms	kg 1,4-DB eq.
Marine Ecotoxicity (MET)	Evaluating the possible toxic effects on marine ecosystems	m^2 × yr	Ozone Depletion Potential (ODP)	Measuring the potential for ozone layer depletion, resulting in increased ultraviolet (UV) radiation reaching the Earth's surface.	kg CFC-11-eq

Marine Eutrophication (ME)	Assessing the likelihood of eutrophication in marine environments	yr/kg N	Photochemical Ozone Creation Potential (POCP)	Assessing the potential to contribute to the formation of the harmful atmospheric pollutant ground-level ozone	kg C_2H_4 eq.
Natural Land Transformation (NLT)	Assessing the alteration of undeveloped land by human activities	m^2	Terrestrial Ecotoxicity Potential (TETP)	Assessing the likelihood of harming organisms inhabiting terrestrial environments	kg 1,4-DB eq.
Ozone Depletion (OD)	Assessing the prospective health effects of the depletion of the ozone layer	yr/kg CFC - 11 eq.			
Particulate Matter Formation (PMF)	Figuring out what effects tiny matter might have on human health	yr/kg $PM_{2.5}$ eq.			
Photochemical Oxidant Formation (POF)	Evaluation of the possible effects of air pollution on photochemical oxidants like ozone (O3) and other secondary pollutants	yr/kg NOx eq.			
Terrestrial Acidification (TA)	Quantifying the acidification potential of terrestrial environments	kg SO_2 eq.			
Terrestrial Ecotoxicity (TET)	Considering the possible toxic effects on terrestrial ecosystems	$m^2 \times yr$			
Urban Land Occupation (ULO)	Measuring the urban land occupation caused by human activities	m a^2			
Water Depletion (WD)	Assessing the prospective effects of depletion of water resources	m^3			

Note. Compiled by the authors using data from ecoinvent integrated in SimaPro.

3.4 Assessment of the Impact of Craft Spirits on the environment

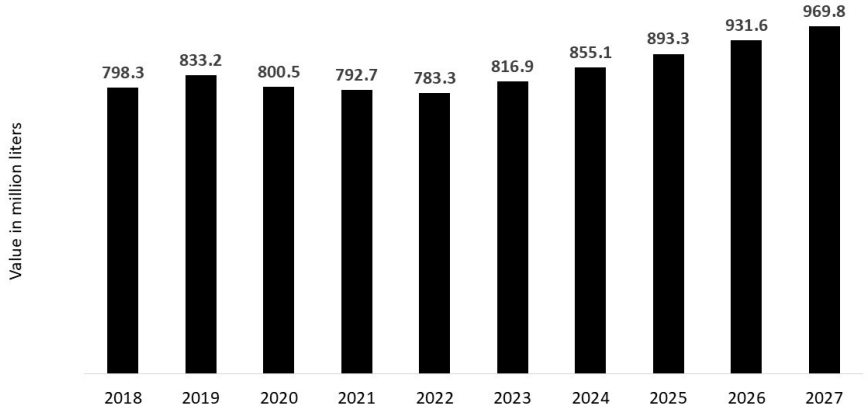
This section discusses five traditional craft spirits and their impacts on the environment.

3.4.1 Gin

Gin is a spirit made from different types of grains, such as barley, corn or rye. In addition, in order to contribute to achieving organoleptic properties attractive to the consumer, other natural botanical ingredients, such as citrus peel, coriander seeds, cardamom seeds, calamus root, and angelica root, among other ingredients that are usually rich in oils, contribute to the overall aromatic profile of gin. Thus, the geographical area where the beverage is made influences the aromatic profile of this beverage because it determines the availability of the raw materials to be used (C. Williams et al., 2023).

Craft gins are gaining popularity worldwide (Mitchell 2023). For example, in the UK, the Craft Gin Club, a company dedicated to offering monthly delivery of selected craft gins to its members, increased its subscribers. In 2016, it was around 50,000 members, but by 2019, it had increased by 100,000 subscriptions (Carruthers, 2020). Additionally, in this country, the Gin market grew by 11.4% in 2022, generating sales of approximately US$581,628m. (IBISWorld, 2022). Globally, the craft gin market is forecast to grow faster by 2030, with a CAGR of 31% (Grand View Research, 2023). Thus, the gin market is experiencing growth and popularity, although this growth is gradual, as shown in Figure 24, where a decline in gin sales volume is observed from 2020 to 2022, but a recovery is forecast from 2023 and with upward growth, albeit slowly.

Figure 24
The global sales volume of gin per year, along with the forecast for 2024-2027



Note. Figure created by the authors using data from Statista (2022).

This growth in craft gin is the result of three primary factors. First, small craft distilleries are increasing worldwide, producing gins with a wide variety of botanical ingredients, resulting in various flavors (IBISWorld, 2022). Second, consumers, particularly younger generations, are chasing spirits with distinctive flavors that are considered unique in the marketplace. Generally, millennials tend to have a greater appreciation for craft alcoholic beverages (Nilsson & Reid, 2019). Third, the increasing prevalence of cocktail culture, mixology, and gin-based cocktails has increased the demand for gin, mainly in restaurants and bars (Carruthers, 2020).

However, an increase in the production of a product results in the consumption of more natural resources, both renewable and non-renewable (Wong et al. 2020). Therefore, it is necessary to evaluate the environmental impacts of its production process as an initiative to achieve the sustainability of this type of spirit.

In the case of craft gin, an assessment of the environmental consequences of a distillery located in Cantabria, Spain, which produces classic craft gin but is classified as a premium, was carried out (Lei-

vas et al., 2020). The term "premium" is often used in marketing to indicate that it is a higher quality product and, as a result, may be at a higher price, implying that the product is of superior quality to alternatives that are termed as standard (bbb drinks, 2021).

To evaluate the environmental impact of classic craft gin production, a methodology integrating two tools was used, life cycle analysis (LCA) and linear programming (LP). The LCA was used to determine improvement actions to reduce environmental damage; in other words, it was considered a decision-making tool. Regarding the scope of the study, the stages considered in the evaluation of the production process were "cradle-to-gate", which indicates that the production of all the botanical ingredients for its elaboration, the distillate elaboration process, bottling, packaging, transportation, waste management, and its distribution in small supermarkets located near the distillery were considered.

The results of the environmental impact assessment indicated that this distillery emits approximately 0.58 kg of CO_2 per bottle of classic gin into the atmosphere. If the company produces approximately 250,000 700 ml bottles per year, this equates to 145 tons of carbon dioxide emitted annually. The results also showed that glass bottle production and transportation contributed 86% of the total carbon dioxide. Simultaneously, the distillation and packaging processes contributed approximately 5% of the total CO_2 generated.

The total energy consumption required to produce a bottle of gin was 0.92 MJ. This total energy is consumed from the reception of raw materials and inputs to the management of their waste and the distribution of the product, which is the distillation stage that consumes the most energy, approximately 0.79 MJ. On the other hand, before receiving the raw materials and inputs, the energy consumed is approximately 11.86 MJ, which is required to produce and transport the raw materials and inputs and to produce primary and secondary packaging. In contrast, the production of glass bottles

consumes the most energy, approximately 10.05 MJ, representing 90% of the energy consumed before beverage production. It is essential to mention that high energy consumption results in slow depletion of fossil fuels such as coal, oil, and natural gas.

However, water consumption to produce a bottle of gin resulted in 0.22 kg used in fermentation. In contrast, the highest water consumption originated from activities before making a bottle of gin, which resulted in 62.02 kg. For example, in the case of activities related to the production and transportation of packaging inputs, water consumption was 27.02 kg, with the production of glass for the production of bottles being the activity that contributed the most, representing 67% of the total water consumed. The remaining 28.03 kg of water consumption is attributed to activities related to electricity production, which are consumed by the distillery during the distillation and bottling stages.

Based on this environmental impact analysis, three improvement strategies were evaluated to reduce the environmental impact of this distilled spirit: reducing the weight of the glass bottles, changing the current primary packaging material to plastic (PET), and using solar panels as an alternative energy source. These actions can help to reduce energy consumption, water consumption, and greenhouse gas emissions by up to 58%. In the first strategy, if the weight of the glass bottles were reduced by up to 75% of the total weight, this would result in a 26% reduction in pollutant emissions. However, this may lead to packaging that is likely to break during transportation.

In the second strategy, substituting glass with plastic as the primary packaging material resulted in a significant decrease in greenhouse gases by up to 72%. However, while plastic bottles consume less energy and water than glass bottles, plastic degrades over a long time, resulting in waste that damages aquatic ecosystems. There-

fore, PET as a raw material in primary packaging must be further analyzed for its potential impact.

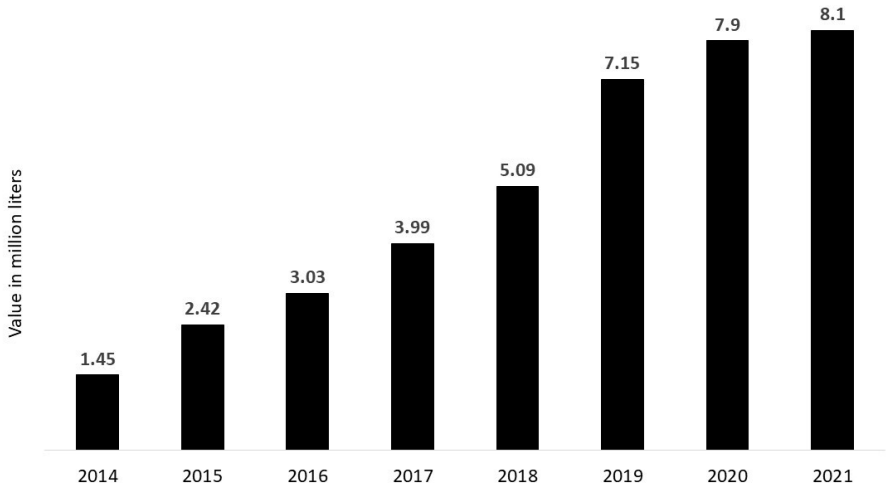
In the third strategy, the solar panels did not exhibit significant variations in electricity consumption. However, the negative environmental impact is reduced by up to 26%. In conclusion, in the distillation stage, the production and transportation of inputs and primary packaging (glass bottles) are critical points that contribute the most GHGs in the case of Spanish companies. Innovating alternative energy sources would help to consume less fossil fuel energy. Changing PET for glass as the primary packaging material will be a feasible alternative if the plastic bottles are recycled, i.e., the "consume-dispose" system is eliminated.

3.4.2 Mezcal

Mezcal is a craft spirit traditionally produced in several Mexican states, including the State of Mexico, Guerrero, Oaxaca, Durango, San Luis Potosí, and Zacatecas (Arellano-Plaza et al., 2022). Different varieties of maguey are used as raw materials to produce this alcoholic beverage, and *Agave angustifolia* is the most used variety because it is the type of agave with the broadest distribution in Mexico and is the most widely cultivated (Aguirre-Dugua & Eguiarte, 2013).

This traditional Mexican alcoholic beverage is becoming increasingly popular worldwide, as its quality improves. More than 8 million liters were manufactured in 2021, and approximately 70% were shipped to 65 countries (Becerra-Lucio et al., 2022). In Oaxaca, a state located in southern Mexico, 60% of its mezcal production is exported to the US (Oaxaca State Government, 2019). Although no specific data were found on the sales of artisanal mezcal, the information in Figure 25 presents the global production volume of mezcal and shows a gradual increase year by year of this Mexican spirit (Gutiérrez, 2022).

Figure 25
Global mezcal production volume by year.



Note. Figure created by the authors using forecast data from Statista (2022) and Reuters (2019).

Therefore, mezcal production is an attractive economic activity for the inhabitants of the Mexican states where it is produced because it is an alternative to agriculture, a traditional activity in the localities, adding value to the products (Lira et al., 2022). However, the increase in this demand means greater consumption of natural resources and energy for the production of distilled alcoholic beverages; therefore, interest has arisen in measuring its impact on the environment (Maciel Martínez et al., 2020).

A craft mezcal producer located in the municipality of Madero, in the Mexican state of Michoacán de Ocampo, was subjected to an environmental impact assessment using the life cycle analysis (LCA) methodology (Maciel Martínez et al., 2020). The system boundary considered for this study was "cradle-to-grave"; that is, this assessment considered the activities and inputs necessary for planting and harvesting the raw material (*Agave cupreata*), the beverage production process (brewing, milling, fermentation and distillation),

distribution and the transportation used to dispose of the waste from the production process in the landfill.

It is essential to mention that this analysis did not consider the inputs for obtaining the *Agave cupreata* seedlings born in wild populations and their transportation to the agave planting and harvesting site. Similarly, the use of equipment for packaging was not specified, so it must be assumed that this is rudimentary, and most of the equipment used in the transformation of the raw material is rudimentary, also called the ancestral technique.

The LCA of craft mezcal results show that a 750 ml bottle of white mezcal reports 1.7 kg of CO_2 equivalent emissions. According to Figure 3.4, 8.1 million liters were sold in 2021, considering that 100 liters are equivalent to 133 750 ml bottles. (Reuters, 2019; Washington Post, 2021), approximately 18,314 tons of CO_2 eq. were produced that year.

The inputs that contribute significantly to the environmental impact of craft mezcal production are the firewood used in the distillation phase, and the use of fertilizers and herbicides in the agave-planting phase. Adding sugarcane to the fermentation process increases greenhouse gas (GHG) emissions, owing to the inputs needed to produce and transport it. In general, agave planting (82%), fermentation (96%), and distillation (94%) were the activities that contributed most to the GWP environmental impact category.

Other environmental consequences generated by the fermentation, distillation, and planting phases of an agave are as follows: fermentation and distillation produce high concentrations of chemical substances that generate toxicity to the marine ecosystem; in terms of the LCA methodology, this environmental impact is defined as ME (Alsayed & Tayeh, 2019). In addition, these two phases emit pollutants that contribute to the creation of so-called thermal inversions in summer, an environmental impact category named POF,

which promotes the generation of particles that usually remain suspended in the air for long periods, an effect that belongs to the environmental impact category PMF (Hauschild, 2018).

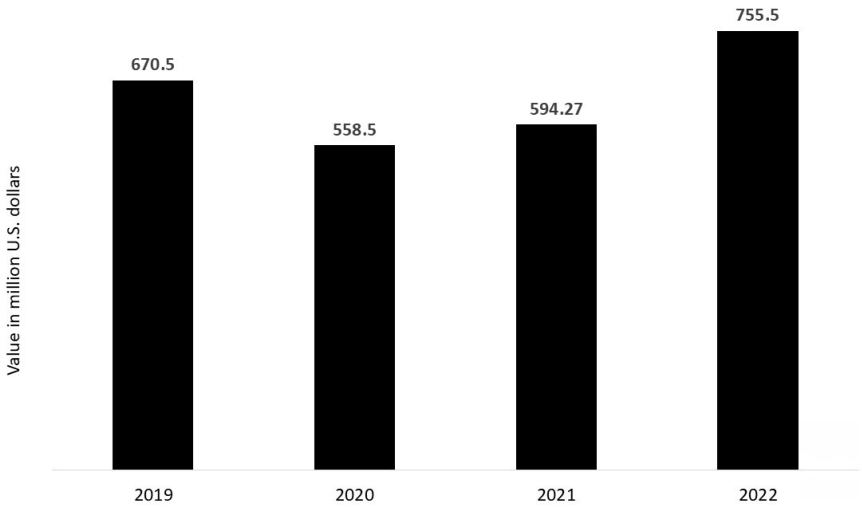
Owing to the fertilizer and herbicide used in the agave planting phase, excessive growth of aquatic plants is promoted, which is detrimental to freshwater ecosystems, an effect on the environment that refers to the FE impact category. Similarly, these agricultural products affect terrestrial organisms and plants, and affect the TET impact category (Kundu, 2021).

In conclusion, planting, distillation, and fermentation are the stages of the craft mezcal production process with a high environmental impact in the case of the Mezcal distillery in Michoacán, Mexico. Based on the results of this LCA, several practices are proposed for the production of this Mexican spirit in a sustainable manner; for example, the use of renewable energies, cultivation without the use of chemical products, and recycling of water and waste (Maciel Martínez et al., 2020).

3.4.3 Pisco

Pisco is a type of brandy produced by fermenting liquid from grapes and is native to Chile and Peru, where it is considered a national drink and of great economic value (Hamrick et al., 2022). Figure 26 shows the estimated global sales of Pisco from 2019 to 2022. This figure shows a drop in total sales of this beverage from 2019 to 2020, probably owing to the consequences of the COVID-19 pandemic. However, a recovery is expected in 2021, including a forecast that by 2027, the world pisco market will grow at a CAGR of 6.0%, reaching a value of US$842.98 million (Expert Market Research, 2022).

Figure 26
The Global Market size of Pisco from 2019 to 2022



Note. Figure created by the authors using data from Statista (2022), Fortune Business Insights (2022), and MarketWatch (2022).

Owing to its commercial value, the environmental impact of the pisco elaboration process was evaluated by applying the LCA methodology (Vázquez-Rowe et al., 2017). To determine the environmental profile of traditional pisco production, an inventory of the inputs to the process from the viticulture stage to the product's packaging ready for commercial distribution (cradle-to-gate) was conducted. The environmental impact analysis of the craft pisco production was conducted using six distilleries located in different geographical areas of Peru. The data collected were for three different presentations of this beverage bottled in a 500 ml glass bottle: pure pisco, green must and pisco "acholado".

The LCA results showed that, depending on the distillery and the types of pisco, a 500 ml bottle of pisco could generate between 2.13 kg of CO_2 -eq and 4.2 kg of CO_2 -eq, with the green must presentation generating the most, with 4.2 kg of CO_2 -eq. In contrast, pure Pisco had the most negligible impact on the environment. Most green-

house gas (GHG) emissions were related to the use of fertilizers in the viticulture phase, generating 62.9% of the total CO_2 emissions.

In LCA methodology, the effect of CO_2 on the environment is included in the environmental impact category called GWP. In this category, fossil fuel consumption during the distillation phase contributed significantly. If firewood is used in distillation, this phase contributes 15 g CO_2 eq to the total GWP. In contrast, liquefied petroleum gas contributes 350 g CO_2 eq. Therefore, the use of petroleum products significantly contributes to climate change.

Other environmental consequences of the traditional pisco production process are as follows. First, water and soil are affected by inorganic fertilizers, which results in excess biomass from using nutrients. In an LCA, this type of environmental damage is grouped into an impact category called EP. The second source contributing to EP is "vinasse," the residue from producing a distilled alcoholic beverage such as pisco. Depending on the distillery, this represents 14%–30% of the total EP. Second, another impact on the environment is the degradation of air quality due to the generation of suspended particles from the production of glass bottles, an effect that belongs to the impact category known as PMF. Third, another consequence of the process of producing pisco is soil degradation due to exposure to acidifying compounds that alter its chemical properties, an effect that belongs to the impact category called TAP. Finally, the production of glass and inorganic fertilizers generates a high consumption of fossil resources, an effect related to the impact category called FD.

Based on these results, a series of practices have been suggested to reduce environmental damage in the pisco elaboration process. For example, reducing the use of fossil fuels in the distillation stage, minimizing water consumption in the viticulture stage, and encouraging artisanal producers to work together to produce Pisco using existing infrastructure to avoid the development of new distilleries,

as well as improving the bottling stage by transporting the final product in a large container to the filling site and using a system to recycle glass bottles.

3.4.4 Sotol

Dasylirion wheeleri, *Dasylirion cedrosanum*, and *Dasylirion durangense* are native plants of northern Mexico that grow naturally and are mainly used as raw material to produce a craft spirit known as sotol (Humberto Reyes-Valdés et al., 2019). The popularity of this distilled alcoholic beverage has steadily increased in recent decades (Becerra-López et al., 2020). Moreover, according to Consejo Regulador del Sotol (CRS), the number of Sotol brands increased by 50% before the pandemic. Currently, there is a slow recovery in sales volume. The CRS does not have recent information on production volume but estimates that around 5,000 hl is produced annually in the Mexican state of Chihuahua. Therefore, calculating the carbon footprint is of interest.

An LCA was carried out in a sotol distillery in the Mexican state of Chihuahua. To calculate the carbon footprint, the primary inputs and outputs of the production system were considered, from the extraction of the raw material from its natural habitat to the packaging of the final product for distribution (Madrid-Solórzano et al., 2021).

The results indicate that the evaluation showed that a 750 ml bottle of white sotol generates 5.92 kg CO_2 eq. The same value of CO_2 corresponds to each of the product presentations, both for aged and rested sotol; there were no significant differences between the product presentations. The stages of traditional sotol production that produced the most greenhouse gases were milling (51%), packaging (27%), distillation (8%), cooking (7%), and raw material acquisition (6%).

Regarding energy consumption, the milling stage is where most energy consumption is generated, approximately 35 MJ, followed by the packaging (21.7 MJ), distillation (6.16 MJ), cooking (5.81 MJ), and raw material acquisition (4.53 MJ) stages. This high energy consumption is primarily due to two factors. First, in the milling stage, agricultural machinery with a milling capacity of 3-5 tons/h is used instead of milling equipment appropriate for the production capacity of the artisanal sotol distiller, such as 1 ton/h milling equipment. Second, the transportation of raw materials and inputs significantly influences fossil fuel consumption. In addition, firewood consumption during the distillation stage contributes to high energy consumption.

Other environmental consequences generated by traditional sotol production are an excess of toxic substances that affect marine and freshwater ecosystems, which correspond to the impact categories MEP and FAETP, respectively. Craft sotol production also affects the soil's chemical characteristics (environmental impact category described as PA). Other effects caused by milling, fermentation, distillation, and packaging stages are the release of chemical substances to affect human health (environmental impact category known as HTP) and soil-dependent organisms and their environment (environmental impact category named TETP).

In conclusion, this study indicates that most of the stages in the traditional sotol production process significantly affect biodiversity, with milling and packaging being the stages that can be improved through strategies that seek to eliminate mainly transportation because both stages account for 78% of total CO_2 emissions.

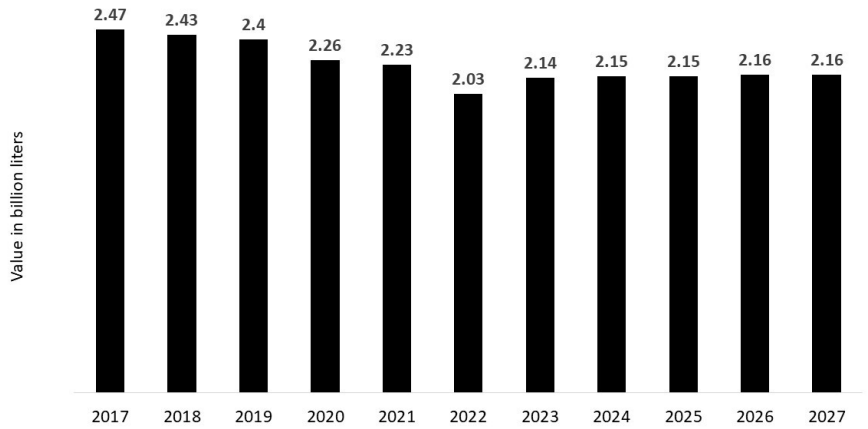
3.4.5 Vodka

The craft vodka production begins with fermentation of a carefully chosen primary material, such as wheat, barley, corn, and potatoes. Some high-quality vodkas may incorporate other ingredients such as grapes or whey. After fermentation, the substance underwent

distillation to obtain a high-proof alcohol. Subsequently, the alcohol is diluted with water and packaged in bottles (Hodel, 2023).

The craft vodka market is estimated to grow by US$590.15 million from 2022 to 2026 at a compound annual growth rate (CAGR) of 5.02% (Analytics Market Research, 2023). In general, the market for this spirit is generally recovering after the COVID-19 pandemic. Figure 27 shows the production volume of this distillate without differentiating between craft and mass-produced spirit.

Figure 27
The volume of vodka production



Note. Figure created by the authors using data from Statista (2022).

Similarly, the production volume forecast from 2023 to 2027 is shown. The market growth of this spirit shows a slow recovery, without reaching the volumes of the years before the pandemic; however, the forecast of its growth could be higher because consumption is based on a series of circumstances, such as the number of small craft distilleries and millennials who want craft alcoholic beverages (Technavio, 2023). Then, because of its economic value, the potential environmental impact of producing a 750 ml bottle of

this craft spirit was analyzed under three different contexts using LCA methodology.

The first context was craft vodka production using expired bakery products used as raw materials and locally generated. The second context was craft vodka production using locally sourced wheat; the third was mass-produced premium vodka from locally sourced wheat. The data collected for the LCA ranged from the transportation of raw materials and production waste to the product distribution and useful life of glass bottles. It is essential to mention that in this LCA case, 30% of the bottles were recycled, and the rest were disposed of in landfills. However, the data on bread production was not considered. Therefore, for the first context, the evaluated system boundary was "gate-to-gate", while it was a "cradle-to-gate" system boundary for the rest.

The LCA results are as follows. Craft vodka production with expired bakery products has the lowest environmental impact because it avoids the occupation of agricultural land (ULO) and thus lowers the consumption of fertilizers and herbicides. On the other hand, mass-produced premium vodka has the greatest impact on the environment because the transportation distance and the type of raw material used are the main sources of polluting emissions, followed by the extraction of the raw material and the production of glass bottles.

Other environmental consequences of vodka production are as follows. The main environmental consequences of producing vodka using food waste are the generation of greenhouse gases (GWP) and chemicals that affect the aquatic ecosystem (FAETP). Concerning the production of vodka from virgin wheat, chemicals affecting the health of the human body (TPH) and agricultural land degradation (ALO) caused by wheat harvesting have been produced.

The study also conducted a comparative analysis of different production scenarios, which suggested that using recycled water (approximately 80%) in wheat production and increasing recycled glass content (by 30%) for bottle production at the site would make vodka production more environmentally friendly (Bhattacharyya et al., 2019). Therefore, craft distilleries that want to sell themselves with a lower environmental impact per bottle, similar to mass-produced, can adopt these measures. Overall, the analysis suggests that transportation distance, raw material selection, and bottle production are the main factors causing environmental impacts in vodka production.

3.5 Constraints on LCA of craft studies

The results of the environmental impact assessment of craft spirits reveal significant variations in their carbon footprints due to several factors.

Firstly, the brewing process differs among distilled beverages. For example, mezcal and sotol production use firewood for distillation, whereas gin production does not specify the use of firewood. Similarly, discrepancies are observed in the life cycle stages of some distillates: energy consumption for bottling was excluded in the case of mezcal, while gin production accounted for water consumption during bottle manufacturing. In contrast, the assessment of vodka included the distribution of the beverage to points of sale.

Secondly, the distances traveled for the transport of raw materials and finished products vary. Beverages requiring transport over long distances have a higher carbon footprint due to fossil fuel consumption during transportation.

Thirdly, the use of fertilizers and water during the cultivation stage of raw materials was included in the environmental impact assessments of pisco, tequila, and mezcal but was omitted in the analyses of vodka and sotol.

Therefore, the differences in inputs and stages of the production processes make direct comparisons challenging, as each regional beverage possesses unique characteristics that define its originality.

3.6 Conclusions

The market for craft spirits is expected to continue to grow, albeit slowly, since the COVID-19 pandemic. This results in high emissions of gases and chemicals that affect ecosystems, food insecurity, a lack of adequate water for human consumption, and increased poverty in many countries. Therefore, studies have been conducted on the environmental impact of the craft spirits industry.

The results of the environmental impact assessment of several distilleries show that the critical points in the process of making a craft spirit are the seeding of the raw material, use of glass bottles as primary packaging, transportation distances of the raw material and inputs, and distillation and fermentation stages. The planting of raw materials has a significant impact on the environment owing to the use of fertilizers. The main impacts are on the marine and freshwater ecosystems. Another critical point is the high energy and water consumption required for the production of traditional primary packaging in distilleries, which is a glass bottle.

The environmental impact of bottle production is a high emission of CO_2 and other greenhouse gases (GHG), contributing to climate change; there is a high consumption of water in the production of these bottles. In addition, the transportation of raw materials and inputs significantly contributes to greenhouse gas emissions caused by the consumption of fossil fuels. The stages of making a hand-distilled beverage, mainly distillation and fermentation, require electricity consumption, which results in increased GHG emissions because fossil fuels must be burned to generate electricity.

Based on the environmental assessments, several strategies can be proposed by distilling companies to reduce the carbon footprint.

First, concerning primary packaging, three actions were proposed: reducing the weight of the bottles, increasing the recycling of glass bottles, and replacing glass as a manufacturing material with PET. Second, the environmental impact of transportation distances should be reduced by transporting raw materials, inputs, and final products in bulk to reduce the consumption of fossil fuels. Third, the use of renewable energy, such as solar panels, is proposed as a source of energy for distillation companies. Finally, the application of a water recycling system reduces the consumption of this natural resource.

Chapter Three examined the environmental impact of craft spirits, emphasizing critical factors such as raw material sourcing, the use of glass bottles, and transport distances. In contrast, Chapter Four shifts its focus to the environmental impact of large companies in the spirits industry, analyzing how climate change and greenhouse gas emissions influence both the production and quality of alcoholic beverages. Ultimately, both chapters underscore the urgent need to implement sustainable strategies to mitigate these impacts.

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CHAPTER FOUR

The Environmental Impact of Large Companies in the Spirit Beverage Industry

Abstract. This chapter discusses the threat of the climate crisis on the alcohol industry. It discusses how extreme weather can disrupt production volume and affect the quality of alcoholic beverages. These interruptions can have a significant financial impact on the economy of any industry. Likewise, reference is made to how the alcohol industry contributes to climate change, and reference is made to the evaluation of the environmental impact of three mass-produced spirits such as cognac, tequila and whiskey. Finally, this industry sector's leading causes of environmental damage are presented.

Keywords: Climate change, Spirits industry, Mass-producing, LCA, Footprint

Resumen. Este capítulo analiza la amenaza de la crisis climática sobre la industria del alcohol. Se analiza cómo las condiciones meteorológicas extremas pueden interrumpir el volumen de producción y afectar a la calidad de las bebidas alcohólicas. Estas interrupciones pueden tener un impacto financiero significativo en la economía de cualquier industria. Asimismo, se hace referencia a cómo la industria del alcohol contribuye al cambio climático, y se hace referencia a la evaluación del impacto medioambiental de tres bebidas espirituosas de producción masiva como el coñac, el tequila y el whisky.

Por último, se presentan las principales causas de daño medioambiental de este sector industrial.

Palabras clave: Cambio climático, Industria de bebidas espirituosas, Producción masiva

4.1 Alcoholic Beverage Industry and the Climate Challenges

The global alcoholic beverage market, valued at US$1,448.2 billion in 2021, is forecast to have an average growth rate of 10.3% between 2022 and 2028 (Grand View Research, 2023) due to four factors. First, there is an increase in premium beer consumption in countries with developed economies, such as the US and the UK. Second, there is an increased demand for wine and craft distilled beverages. (Globe Newswire, 2022). Third, there is a growth in the popularity of craft alcoholic beverages in pubs, bars and restaurants in the aftermath of the COVID-19 pandemic (Barger, 2023; Kellershohn, 2018; Nilsson & Reid, 2019). Fourth, the economies of the recent trading block called BRICS are expected to drive the beverage alcohol market (Grand View Research, 2021). However, these factors driving the growth of the alcoholic beverage industry could be reversed by global warming (Suter et al., 2021).

The alcohol industry is affected by climate change, particularly rising temperatures and changing weather patterns (Siapartners, 2023). Adapting to the new environmental conditions is one of the biggest challenges facing this industry sector (Beverage Trade Network, 2023). The main effects of climate change include an increase in the incidence of diseases in crops and water scarcity (Abarca-Rivas et al., 2023).

There are two critical aspects to keep under control in the production of an alcoholic beverage: the availability and quality of raw

materials to ensure the volume of production, the consistency of meeting customer expectations and maintaining product standards (Fentie et al., 2020). However, these two aspects are being affected by climate change due to the disruption of microorganism communities, such as bacteria and fungi, that play a crucial role in plant health and nutrient cycling (Elahi et al., 2022).

As a result of these impairments, the productivity and quality of alcoholic beverages are altered (Hussain et al., 2020; Paterson & Lima, 2018). For example, in the case of wine, as temperatures increase, grapes experience excessively high sugar levels, resulting in wines with higher alcohol content. Likewise, there is an affectation in the ripening time of the grapes, shifting the ripening period to a time when, due to high temperatures, they are not optimal for producing high-quality wines.

Another example is what happens with the Mexican spirit known as sotol. According to the Sotol Regulatory Council, the higher the rainfall, the more the plant used to produce this distillate, *Dasylirion spp*, is affected since it generates less carbohydrates, so more sotol biomass is needed to produce a beverage with the standard alcohol content (range between 45% to 48% alc. vol.) and reach the average annual production volume; in addition, its organoleptic properties are affected. Therefore, as in the case of wine (Suter et al., 2021) and sotol (Rodriguez-García, 2018), variations in temperature and rainfall affect sugar variations, the overall quality of the alcoholic beverage, and crop yields.

It follows from the above that declining crop yields will be a major consequence of the impact of climate change on the beverage and food industry (Ritchie et al., 2022). The production of staple cereal crops will reduce their production yields due to global warming (Wang et al., 2018); wheat and maize yields are predicted to be reduced to 6% and 7%, respectively (Kwatra, 2022). Since the human population is projected to reach nearly 10 billion people by 2050,

feeding them will be challenging, as it must meet the demand for alcoholic and non-alcoholic beverages (Gerten et al., 2020; Kwatra, 2022).

This global population increases, and climate change will aggravate water scarcity, a primary input for the alcoholic beverage industry (He et al., 2021). As climate change continues to alter weather patterns and increase water stress, the sustainability of agri-food systems, including the alcoholic beverage industry, is at severe risk (Salman et al., 2021).

The world's largest spirits company, Diageo Plc, fears that climate change will make it difficult to obtain one of the main things to make all of its alcoholic drinks: water (Afanasieva & Millian, 2023). The global scarcity of water resources poses a significant threat to the economic sustainability of crop producers, affecting the overall supply chain and the alcohol industry. Declining water resources reduce agricultural yields, lowering alcohol production capacity (Fennell et al., 2020). Water use in the manufacturing process of a distilled beverage is crucial; for example, in distilleries in the United States of America, an average of 35 to 37 liters of water can be consumed to produce one liter of distilled beverage (Siapartners, 2023). This consumption is higher than other alcoholic beverages; for example, beer needs about 4 liters of water to produce one liter, while wine needs about 5 liters (Gustafson, 2013).

In conclusion, the climate crisis is a clear danger for the alcoholic beverages industry. Extreme weather events can significantly affect the alcohol sector, causing disruptions in production that can have substantial economic consequences for the economics of any industrial sector (Xue & Song, 2020). However, on the other hand, the alcohol industry contributes to climate change (Glade & Sainte-Marie, 2020).

4.2 Environmental Impact of the Alcoholic Beverage Industry Sector

Like other components of the food systems, alcohol production has ecological consequences. The carbon footprint of producing a bottle of alcoholic beverage is the consequence of several factors, including raw material seeding, glass packaging, transportation, energy and water use (Sacks, 2020). In the beverage industry sector, companies producing alcoholic beverages are among those that emit more polluting gases into the atmosphere than producers of non-alcoholic beverages.

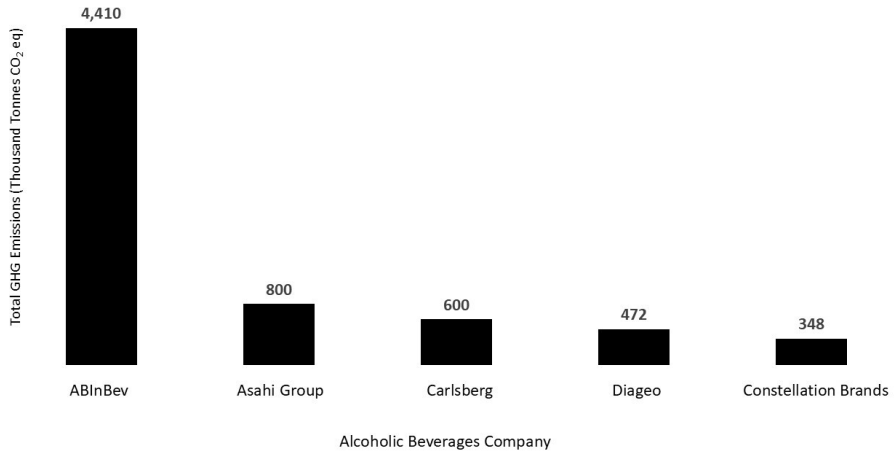
In 2021, ABInBev, Asahi Group, Carlsberg, Diageo and Constellation Brands were five of the largest alcoholic beverage producers whose greenhouse gas (GHG) emissions were monitored (GlobalData, 2022). Of these five, ABInBev was the company that generated the most GHG emissions, a total of 4,410 thousand tonnes of CO_2 (see Figure 4.1). The primary industry of this company is beer, which owns close to 500 brands, among the best known of which are Corona and Estella Artois (Anheuser-Busch InBev, 2023). Figure 28 shows the GHG emissions of the remaining companies; for example, the Asahi Group emitted 800 thousand tonnes of CO_2 eq, ranking as the second most polluting company. Diageo is the most focused on the distilled beverage market of these five companies, with a broad portfolio of iconic brands in categories such as whiskey, vodka, rum and gin. Diageo's most famous brands include Johnnie Walker (whiskey), Casamigos (tequila) and Smirnoff (vodka) (Diageo, 2023).

According to the Beverage Industry Environmental Roundtable, a 750-milliliter liquor bottle generates about 2.95 kg CO_2 eq (Sacks, 2020). In order to arrive at such estimates of the carbon footprint of a distillery, several considerations are required, for example, the cultivation of the raw material, the production process, the transportation and the type of packaging. All these considerations are what make the CO_2 emissions between companies different. Also,

variations result if direct or indirect emissions to the production process are considered in calculating the carbon footprint.

Ahmetoğlu and Tanik (2020) mention that carbon footprints can originate directly or indirectly. The direct carbon footprint is the amount of CO_2 from fossil fuel combustion, domestic energy consumption, and transportation. On the other hand, the indirect carbon footprint is composed of the CO_2 emissions that occur when producing a raw material or input used by a distillery company until the end of its proper life cycle. This can include emissions derived from the manufacture of packaging materials, such as glass bottles, and the disposal of waste produced during the manufacturing process (Ahmetoğlu & Tanik, 2020), such as wastewater, which is called "vinasses" (Moletta, 2005).

Figure 28
Emissions of greenhouse gases by alcoholic beverage companies.



Note. Figure created by the authors using data from GlobalData (2022).

Due to these variations in estimates of CO_2, carbon footprint assessments of different spirits continue to be carried out. Therefore, the impacts of some beverages are analyzed in this chapter, such as

cognac (Becker et al., 2020), tequila (Consejo Regulador del Tequila, 2016) and whiskey (Eriksson et al., 2016) in order to have a wide range of comparisons between spirits and distilleries. This allows identifying areas in which the alcohol industry sector should be improved in order to reduce its environmental impact (Vázquez-Rowe et al., 2017).

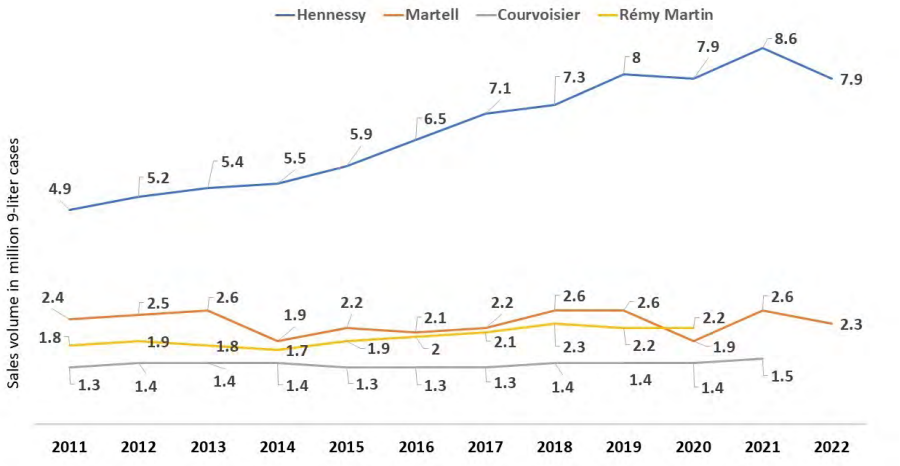
4.2.1 Cognac

Cognac is very important in the world market for several reasons. First, it is considered that due to the complex formation of volatile chemical compounds in the distillation process of this beverage, a unique and distinctive organoleptic profile originates from other beverages (Awad et al., 2017). Second, cognac has a vital cultural and historical significance, especially in France. It is considered a luxury item often associated with high social status and lifestyle (Wei et al., 2019). Third, it has a high economic value since many countries producing this alcoholic beverage see their GDP affected if there is a decline in the marketing of this beverage (Bouët et al., 2017).

Concerning economic value, due to the effects of the COVID-19 post-pandemic, cognac experienced a challenging year in 2022, with a drop in exports of 3.7% in countries such as the United States and China, as shown in Figure 29. However, economic value increased by 9.3% in the premium category (Kiely, 2023). In 2022, Hennessy emerged as the prominent cognac brand globally, with a remarkable sales figure of 7.9 million 9-liter cases (see Figure 29). Martell emerged as the second most prominent brand, with 2.3 million 9-liter cases.

In general, cognac is important in the world market due to its authenticity in smell and taste, cultural significance and economic value. However, there are several environmental implications in the production of this beverage, and one of the most important is its carbon footprint.

Figure 29
Global top cognac brands by sales volume from 2009 to 2022



Note. Figure created by the authors using data from Statista (2022).

In order to better understand, prevent and mitigate the adverse effects of cognac production, a French cognac producer applied the CarbonNeutral Protocol methodology to calculate its carbon footprint. This distillery produces around eight thousand bottles with 700 ml annually. However, it also produces this alcoholic beverage in bulk for major cognac houses such as Rémy Martin, Martell and Hennessy. The environmental impact assessment considered the inputs and outputs from raw material harvesting to final product packaging. The study results show that 270 hl of cognac produces 248 tons of CO_2 eq. It was also found that the leading causes of pollutant gas emissions were the transportation of cargo and the consumption of propane gas in the distillation phase, this being the phase of the production process that consumes the most energy in the production process. Other causes were fuel consumption and the consumption of chemical products in the cognac production process.

As the main strategy to reduce the environmental impact of the cognac distillery, it is proposed to reduce the weight of the glass bottle by 10%, from 710 g to 640 g. Using a lighter-weight bottle would require less energy consumption in manufacturing and transportation. It is suggested that using lighter-weight bottles does not affect the consumer's perception of the quality of the alcoholic beverage; furthermore, this reduction results in less CO_2, approximately 231 tons (Becker et al., 2020). Additionally, other strategies are suggested to decrease the carbon footprint, such as applying better management techniques, using efficient equipment and redesigning operational processes. In general, this study shows that the most critical points of cognac distillery are transportation and using fossil fuels as a source of energy in the distillation phase.

In conclusion, cognac manufacturing impacts the environment due to its carbon footprint, fossil fuel consumption, residual waste, transportation, and packaging. For cognac manufacturers to have the least effect on the environment, they need to use sustainable practices, primarily in primary packaging, energy consumption, transportation and waste treatment.

4.2.2 Tequila

Tequila is extremely important in the world market due to several factors. First, tequila is recognized as a "Geographical Indication (GI)," which means that it can only be produced in some areas of Mexico using specific techniques and ingredients (Bowen & Zapata, 2009). This designation guarantees the quality and authenticity of tequila, ensuring that consumers receive an authentic product. Tequila's GI status has contributed to its commercial success and worldwide recognition (Török et al., 2020). Second, tequila manufacturing has cultural and social significance, as tequila production is deeply rooted in Mexico's traditions and heritage.

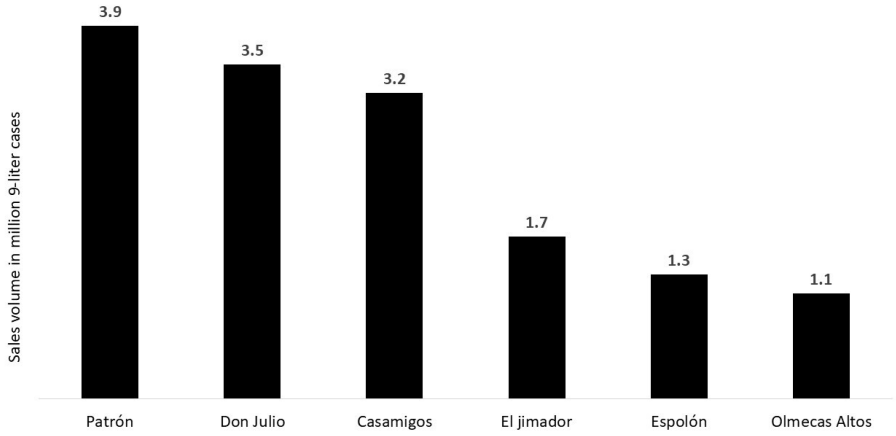
Tequila is considered a symbol of Mexican identity and is often associated with festivities (Toner, 2019). The cultural significance of

tequila increases its desirability and market value, attracting consumers interested in tasting the authentic flavors of the beverage and its cultural heritage (Gaytán, 2019). Third, the demand and consumption of tequila have increased significantly around the world as it has expanded due to factors such as increased consumer preference for craft distillates (Coelho & Castillo Girón, 2023), the growing popularity of cocktails and the rise of tequila as a contemporary and fashionable beverage (Gorjón-Gómez & Mata-Sánchez, 2021). This expansion has increased production and exports, contributing to the economic prosperity of tequila-producing regions in Mexico (Saiz-Alvarez, 2018).

Because of its economic value, transnational companies are interested in commercializing this distillate (Pérez-Akaki et al., 2021). For example, due to the commercial value of the Patrón tequila brand, it was acquired by the transnational St. Maarten Spirits in 1989. Subsequently, in 2018, Bacardi, a major global spirits company known for distributing well-known brands such as Bacardi Run and Grey Goose vodka, purchased Patrón (Montag, 2018).

Figure 30 shows the leading tequila brands worldwide in 2022, according to sales volume in million 9-liter cases. The Patrón brand led the market that year with about 3.9 million 9-liter cases, followed by the Don Julio brand, the second leading brand globally with 3.5 million 9-liter cases. This brand belongs to the British multinational company Diageo, recognized as one of the world leaders in the distilled beverages industry (Conway, 2022).

Figure 30
Global top tequila brands by sales volume



Note. Figure created by the authors using data from Statista (2022).

However, in order to guarantee the mass production of tequila and meet export volumes, some actors in the tequila industry have manipulated production standards to prioritize the industrialization and standardization of the product for mass production, which can have a negative impact on the overall quality of Tequila, on reducing the benefits that should derive from the GI designation, and to the environment (Gaytán & Bowen, 2015). Stakeholders must ensure that tequila production adheres to the principles of a GI and that respect for the environment is sought. Therefore, the Tequila Regulatory Council (CRT) has promoted the sustainability of this industrial sector, and among the actions undertaken has been to evaluate the environmental impact of this distilled beverage.

The Tequila industry in Mexico has been concerned with identifying the total greenhouse gas (GHG) emissions it produces and evaluating the amount of renewable and nonrenewable resources, energy consumed and the amount of waste generated for each liter at 40% alc. vol. CRT estimated that in 2014, the Agave-Tequila supply

chain consumed a total of 3.6 million cubic meters of water and, to produce just one liter of tequila, 15 liters of water were consumed. Concerning energy consumption, it was estimated that 2,800 Tera Joules of fossil fuel energy (mainly fuel oil) were required, and 110 gigawatt-hours of electricity were required. Of the residues from the milling process, 240 thousand tons of bagasse and 1.6 million cubic meters of vinasse were generated, of which only 59% received secondary treatment to eliminate dissolved organic matter.

According to CRT, the carbon footprint of tequila is 3 kg of CO_2 eq per liter; this value is equivalent to an annual production of 700 thousand tons of CO_2 per year. Fifty-nine percent of the carbon footprint generation corresponds to the production of inputs and transportation. On the other hand, the agricultural and industrial phase generates the rest, which is 41% of the total CO_2. The use of nitrogen fertilizers is the main responsible for the greenhouse gases emitted in the agricultural phase (0.20 kg CO_2 eq/L), while the consumption of fossil fuels (1.10 kg CO_2 eq/L) to generate steam in the production of Tequila, the production of the secondary cardboard packaging and the glass bottle (0.80 kg CO_2 eq/L) and distribution of the alcoholic beverage to the consumer (0.50 kg CO_2 eq/L) are the ones that cause the most emissions of gases responsible for global warming.

Consequently, CRT has developed strategies to reduce the environmental impact of tequila production. First, it is considering reducing the use of fuel oil and fossil fuel energy; for example, changing the use of diesel for natural gas, generating biogas from the treatment of biomass to be used in boilers, and installing solar panels. Secondly, focus on adequately functioning the company's production process equipment and facilities; for example, avoiding steam leaks in pipelines and proper lighting functioning. Also, making changes in the primary and secondary packaging, such as reducing the weight of the glass bottle and increasing the use of recycled material to manufacture glass bottles and cardboard boxes. It is also considered

appropriate to develop a supply chain that considers suppliers of local raw materials and inputs (Consejo Regulador del Tequila, 2016).

In conclusion, the use of fertilizers, the consumption of fossil fuel energy for both distillation and transportation, water consumption, waste and glass bottles are the leading causes of the tequila industry's environmental impact.

4.2.3 Whisky

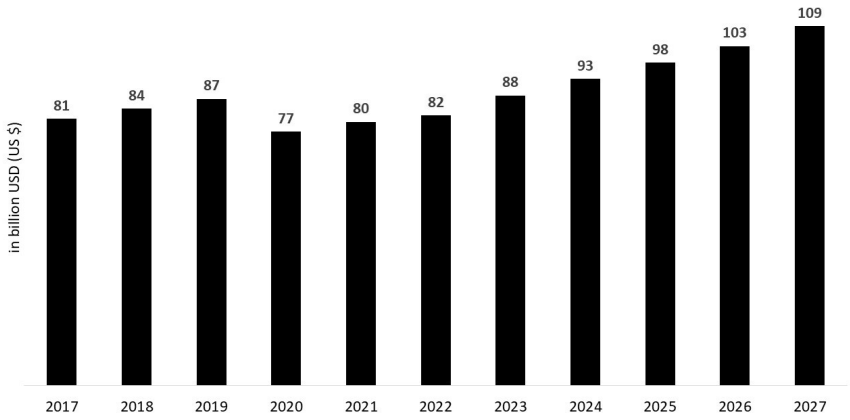
Whisky is important in the world market for several reasons. Firstly, whiskey is a widely consumed alcoholic beverage in the market and continues to expand (Dalton et al., 2022). Consumers worldwide appreciate it and are often associated with the cultural heritage and traditions of countries such as Ireland and Scotland (Kang et al., 2022). In addition to its cultural importance, whisky production has important economic implications (Power et al., 2021). However, it also contributes to job creation, tourism development and the establishment of new distilleries (Power et al., 2021).

Whisky market revenues are forecast to be around US$88bn by 2023, with market growth of 5.18% from 2023 to 2027. Whisky production is also expected to reach 6.7bn liters by 2027. These market growth expectations can be seen in Figure 31, which shows a drop in profits in 2021 and then steady growth at a similar rate to before the COVID-19 pandemic (Statista Market Insights, 2023).

In addition, whiskey has been the subject of research on its contribution to environmental impact (Eriksson et al., 2016). In a whisky distillery located in Sweden, a life cycle analysis (LCA) was carried out that included activities from growing and harvesting barley to packaging and distributing the product in whisky stores. Data from the biogas production process from the vinasse, the generation of electricity and heat, the production of yeast and the consumption of fossil fuels used in transportation were also taken into account. It is important to mention that data from secondary packaging produc-

tion (cardboard boxes), packaging waste management and barrel production were not considered for the LCA.

Figure 31
Revenue estimates for the whisky market.



Note. Figure created by the authors using data from Statista (2022).

The LCA of the whisky distillery shows that a considerable proportion of the carbon footprint in the production process of a 700 ml bottle of whisky comes from the consumption of fossil fuels in transportation, resulting in 2.1 kg CO_2 eq. per bottle, similar to 3 kg/liter. For example, transporting waste, such as vinasse, has a considerable impact on generating greenhouse gases (global warming potential, or GWP). Likewise, the production process of this distilled beverage has an enormous impact on the proliferation of compounds responsible for causing acid rain, resulting in 14.6 kg SO_2 eq. (Soil Acidification Potential, or TAP).

Furthermore, this production system generates toxicity in the freshwater ecosystem, about 8.6 kg PO_4 equivalent (Freshwater Eutrophication Potential, EP). According to energy consumption, a bottle of whiskey consumes about 53.5 MJ. This consumption is mainly due to the transport and production of glass containers. Because of

the above, three strategies are proposed for production with lower pollutant emissions. The first strategy is based on the need to reduce transportation. Another strategy revolves around replacing the use of diesel with biodiesel. Finally, shifting from road to rail transport (Eriksson et al., 2016).

4.3 The Most Significant Critical Points in a Spirit's Environmental Impact

Therefore, beverage alcohol industry leaders must address the main causes identified by the environmental impact assessment of the alcohol industry in order to reduce its environmental impact. The alcohol industry involves a wide range of sectors of the economy, from the primary to the tertiary sector, generating jobs and investments for the economic growth of farmers, producers, wholesale and retail distributors, and the tourism sector. (International Alliance for Responsible Drinking (IARD), 2018). However, in this broad group of sectors of the economy where the alcohol industry is involved, activities are carried out that contribute significantly to global warming. Among the main activities carried out to produce beer, wine, or distilled spirit are cultivation, electricity generation, water consumption and manufacture of packaging (FAO, 2022). These activities are discussed below.

4.3.1 Cultivation of Raw Materials

According to the Food and Agriculture Organization of the United Nations (FAO), annual global anthropogenic greenhouse gas emissions in 2020 reached 52 Gt CO_2 eq, a 4% decrease compared to 54 Gt CO_2 eq in 2019, as a result of the decline in economic activity induced by the COVID-19 pandemic. However, 2020 emissions were 34% larger than in 2000. One of the activities that most influenced the global GHG contribution was the agri-food system, which comprises a wide variety of upstream and downstream activities such as cultivation, harvesting, processing and distribution of agricultural

products. These activities are indispensable to ensure food security, sustainability, economic growth and, in the context of alcoholic beverage production, to secure the supply of raw materials; therefore, the alcoholic beverage sector is linked to the agri-food system. In other words, what happens in the agri-food system has repercussions for the alcohol industry (FAO, 2022).

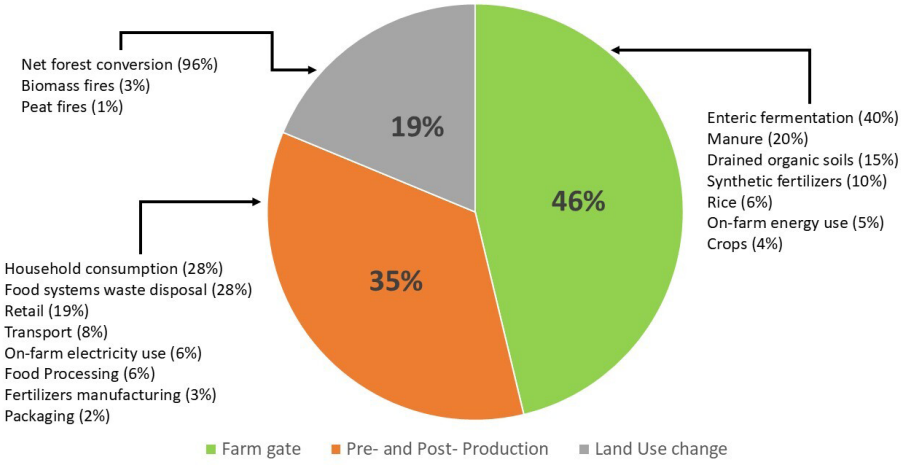
Likewise, FAO mentions that in 2020, from the total global emissions, the agri-food system contributed 16 Gt CO_2 eq, 3% less than in 2019 but 9% more than in 2000. The agri-food system comprises farm gate, pre-and post-production, and land use change. Almost half of these emissions were produced by farm-gate activities, 46%, equivalent to 7.4 Gt CO_2 eq, as shown in Figure 32. The second component contributed 35%, about 5.6 Gt CO_2 eq, and the last component generated about 3.0 Gt CO_2 eq, corresponding to 19% of the total (see Figure 32).

Regarding activities that make up the first component, enteric fermentation is the one that occupies the first place in emissions, approximately 2.8 Gt CO_2 eq, corresponding to 40% of the total. Organic material of animal origin (Manure) (1.4 Gt CO_2 eq) has a lower contribution percentage, only 20%. Concerning the activities related to before and after production, the consumption of goods and services (household consumption) and waste management (food systems waste disposal) are the activities that contributed most to the carbon footprint (1.3 Gt CO_2 eq for both activities), equivalent to 28% each. Retail (0.9 Gt CO_2 eq) and transportation (0.5 Gt CO_2 eq) are activities that account for 19% and 8%, respectively. Finally, concerning the third component, land use, net forest conversion (Net forest conversion) is the one that generated the most CO_2 emissions, 2.9 Gt CO_2 eq, almost 96% (FAO, 2022).

From the above, it can be inferred that the GHG contribution from farm gates plays an essential role in the environmental impact of distillate bottle production. Thus, major changes in the sustainable

production of grain, the predominant raw material for distillate production, will presumably decrease the environmental damage from the alcohol industry.

Figure 32
Detailed composition of emissions from agri-food systems



Note. Figure created by the authors using data from the Food and Agriculture Organization of the United Nations (FAO, 2023).

Cereals are the most commonly used raw materials for distillates. For example, barley is a cereal commonly used to produce Scotch whisky, while corn is frequently used to manufacture bourbon and other US whiskies (Shipman & Thomas, 2023). Similarly, specific varieties of vodka are produced from wheat or rye. In 2020, cereal production (excluding rice) generated approximately 0.18 kg CO_2 eq/kg. Rice also used to produce alcoholic beverages, generated about 1.11 kg CO_2 eq/kg in the same year (FAO, 2022).

Also, the cultivation of the raw materials needed for the alcohol industry has another important effect on the environment: the intensification of water scarcity. Cultivation is one of the largest consumers of freshwater resources globally, and proof of this is that

70% of freshwater withdrawal is used for agriculture (Ritchie et al., 2022) and up to 95% in some countries (FAO, 2019).

In addition, fertilizers and pesticides are used during the cultivation of a plantation, which contributes to the contamination of water ecosystems. These agrochemicals can leach into water bodies, polluting them and reducing the availability of clean water for agricultural and domestic purposes. Agriculture is responsible for 78% of the eutrophication of the world's oceans and freshwaters (Ritchie et al., 2022).

Eutrophication of water resources can be caused by two reasons: by natural processes (water-ice interactions and geological factors) and by human activities (e.g., agricultural activities and industrial wastes) (Akhtar et al., 2021). The latter causes the most damage to water sources (US Geological Survey, 2019). While inorganic substances, such as zinc, iron, copper, nickel, phosphorus, nitrogen, etc., are necessary for developing animals and plants, they become harmful when their concentrations exceed acceptable limits (US Environmental Protection Agency (EPA), 2013).

In conclusion, efforts to mitigate GHG emissions in the farm gate and pre- and post-production components of the agricultural system are crucial to the sustainability of the alcohol industry. The production of any alcoholic beverage requires a wide range of agricultural inputs, which carry a carbon footprint in addition to the carbon footprint of the manufacturing process of a bottle of alcohol itself. In addition, transporting the ingredients to make alcoholic beverage, a pre- and post-production component activity, adds to the industry's carbon footprint.

4.3.2 Energy Generation and Consumption

In the beverage industry, companies producing alcoholic beverages emit more polluting gases into the atmosphere than producers of non-alcoholic beverages. Two main reasons are the amount of

energy required for the fermentation and distillation process and the transportation of beverages (Sacks, 2020). For example, the heat exchange and water-cooling systems required for the distillate brewing process require electrical energy consumption as these systems include pumps and fans for temperature control (Becker et al., 2020; Madrid-Solórzano et al., 2022).

Most distilling companies consume electric power for their services and operation of the equipment used in the distillation process. However, the main problem with this type of energy source is that it is mainly produced from fossil fuels. Oil is the most accessible energy source to store, handle and transport as it is liquid, but it is one of those that highly damages the environment (Kåberger, 2018). In 2021, most US power plants used 61% nonrenewable resources for electricity generation, such as coal, natural gas, and petroleum fuels, resulting in a release to the atmosphere of about 1.65 billion metric tons of carbon dioxide (CO_2), an approximate 0.4 kg of CO_2 per kWh (US Energy Information Administration (EIA), 2022).

Freight transportation is included in the energy sector because every mode of transportation consumes energy. For hundreds of years, the only practical way to make distilled beverages was with local grain crops, thus laying the foundation for the local distilled beverage. As transportation has improved, this limitation is no longer a problem, and today, cheaper cereals can be obtained even when they are hundreds of miles away (Shipman & Thomas, 2023). However, the transportation of goods contributes significantly to climate change.

Transporting raw materials, inputs, and final products to marketing or distribution points results in the release of pollutant gases, such as methane (CH_4), nitrogen oxides (NO_x), including carbon monoxide (CO) and nitrogen dioxide (NO_2), as well as particulate matter (PM) that affect air quality. In the United States of America, the transportation sector is responsible for more than 50% of total

NOx emissions, 30% of volatile organic compounds (VOCs) emissions, and 20% of PM (US Environmental Protection Agency, 2023).

Transport energy consumption is increasing due to urbanization and economic development and is expected to increase by up to 40% by 2050 (Inkinen & Hämäläinen, 2020). Road freight transport, mainly heavy trucks, is responsible for most CO emissions2 in transport systems emissions (Chatti, 2021), accounting for 70% of annual freight transport in the USA (Vajihi & Ricci, 2021). The transport systems are the backbone of regional and local logistic networks, highlighting their importance in studies of pollutant gas emissions (Inkinen & Hämäläinen, 2020).

The type of transport significantly influences the amount of GHG emissions to be emitted, as there are differences between the types of transport for transporting goods. For example, due to its high emissions intensity per tonne-kilometer compared to other modes of transport, road transport is the largest source of CO_2 emissions, around 60-80 g CO_2 /t-km emissions (European Federation for Transport and Environment AISBL, 2021), while rail transport emits between 18 and 50 g CO_2 /t-km, making it one of the most environmentally benign land freight transport modes (RailFreight, 2020; Thind et al., 2023; Vajihi & Ricci, 2021).

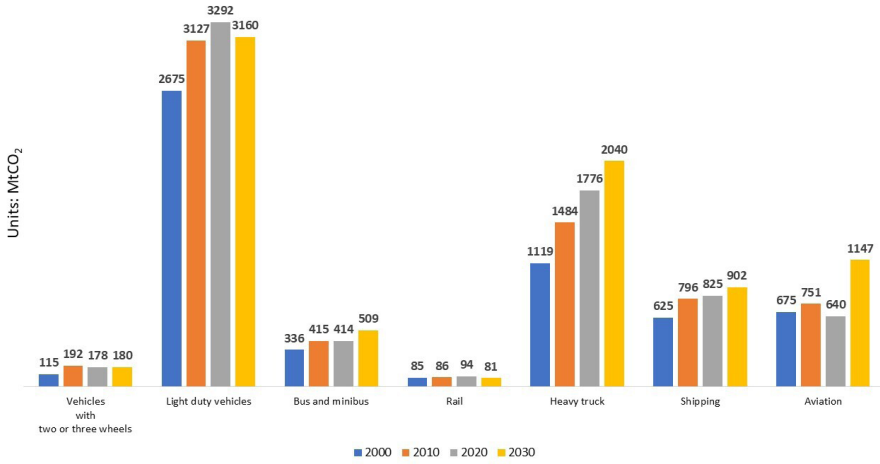
These differences between transport routes are related to the amount of mass to be transported; for example, a truck is usually much less than other types of transport (Organization for Economic Cooperation and Development (OECD), 2016). Figure 33 shows an estimate of tons of carbon dioxide equivalent ($MtCO_2$) by different modes of transport, such as “Heavy truck”, “Rail” and “Shipping”. Among these three modes of transportation, “Heavy truck” is estimated to generate the most emissions by 2030, about 3160 $MtCO_2$, contributing the most to climate change. The transportation of goods by rail is one of the least polluting; for example, by 2020,

it contributed 94 $MtCO_2$, unlike other modes of transportation used by the alcohol industry.

One of the practices that worsens the environmental effects of transportation is when a distillery buys its inputs, such as bottles, from suppliers located hundreds of kilometers away (Madrid-Solórzano et al., 2021). The environmental effects worsen as the distance traveled by their inputs increases but improve when manufactured in locations close to the company (Bhattacharyya et al., 2019). Therefore, the distance to be traveled and the type of commodity transportation to bring inputs to a distillery house is critical to reducing energy consumption.

Because of the above, the nonrenewable energy source used in a distillery's facilities maximizes the phenomenon of global warming and, therefore, the alcohol industry affects itself since, among other affectations, the burning of fossil fuels contaminates water, a renewable resource vital for making a distillate (US Geological Survey, 2019).

Figure 33
Global transportation CO_2 emissions by modes of transport, 2000-2030



Note. Figure created by the authors using data from the International Energy Agency (2023).

4.3.3 Water Consumption

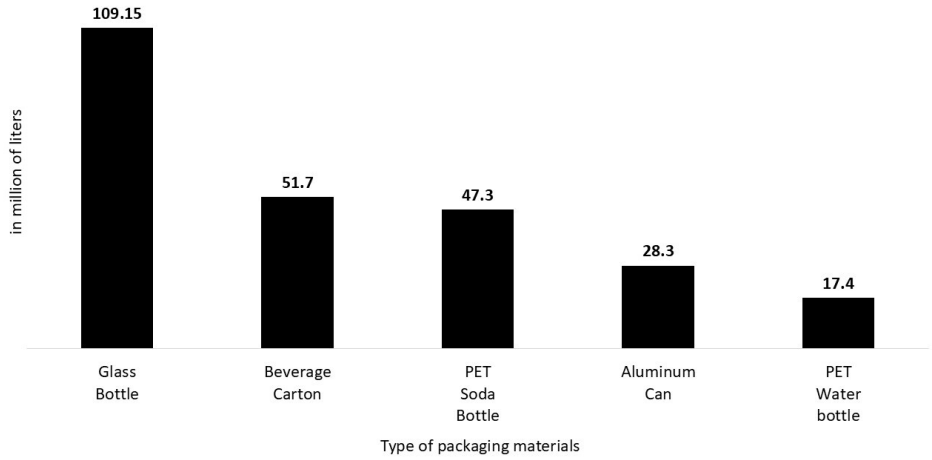
Sustainable water management is a constant concern for human health and the conservation of the natural environment. It is necessary for population growth, energy security, economic growth and poverty reduction. However, rapid economic and urban development have outpaced the infrastructures for supplying drinking water to the population (Li et al., 2019) and, additionally, the lack of waste management by enterprises results in pollution of the freshwater ecosystem (Mkwesha, 2016).

In the alcohol industry, water is an indispensable natural resource for its existence. It is estimated that a brewing company can consume about 25% of the groundwater resources of a locality where it locates its production operations (Agren, 2020). In addition, this industry sector has a wastewater production rate that exceeds the amount of alcohol produced. For example, for each liter of a distilled beverage produced, it is estimated that 8 to 15 liters of wastewater are generated (Sacks, 2020). Concerning beer, approximately 148 liters of water are used to make a 500 ml bottle of beer, while for a 125 ml bottle of wine, about 110 liters are needed (Mkwesha, 2016).

In the process of making a distillate, the boiling, fermentation and distillation stages are the ones that consume the most water. During the production process of Mexican distillates such as tequila and sotol, an autoclave that works with hot water steam, which is injected by a boiler, is used for cooking the raw material, such as agave, for producing tequila (Madrid-Solórzano et al., 2022). In the fermentation stage of distilled beverages, high water consumption is required to make the most, which will later pass to the distillation stage (Madrid-Solórzano et al., 2021). In this last stage, water is consumed so that the boiler can generate enough heat, water vapor, to separate the alcohols in the still (Siapartners, 2023).

Also, the primary packaging preferred by the distilled beverage industry, glass bottles, is responsible for much water consumption (Furszyfer Del Rio et al., 2022). (Furszyfer Del Rio et al., 2022). For example, in the bottled water industry, it is estimated that to manufacture one million 500 ml glass bottles takes about 109.15 million liters of water (see Figure 34), which is a high consumption when compared to what is consumed in the manufacture of the same amount of PET bottles, about 47.3 million liters (International Bottled Water Association (IBWA), 2022) (International Bottled Water Association (IBWA), 2020) (see Figure 34).

Figure 34
The water footprint of 500 ml containers.



Note. Figure created by the authors using data from the International Bottled Water Association (IBWA, 2020).

4.3.4 Packaging

The environmental problems concerning packaging are related to the material of its manufacture. While producing a distilled beverage, the primary packaging plays a significant role in the product's appearance. The packaging can be made of different materials, such

as PET and Cardboard. However, the most common and well-perceived by the consumer is glass. Additionally, this material is known for its inert and durable properties.

Furthermore, in wine and distilled beverages, heavy glass bottles are often associated with an alcoholic beverage that offers excellence (Siapartners, 2023). However, glass production results in a significant carbon footprint and the bottle's weight cause packaging and storage problems, resulting in reduced transportation efficiency and increased transportation emissions.

Figure 32 shows the comparison between different packages on their CO_2 contribution. The data were determined using the average weight of the sales volume in 2021 for each bottle type and size (Systembolaget, 2021). Thus, Figure 4.8 shows that glass containers for sparkling alcoholic beverages, wines and spirits generate the most g CO_2 eq/liter. Even if a glass bottle is lighter, its GHG contribution is still higher (532 g CO_2 eq/liter) than a PET container, equal to 243 g CO_2 eq/liter. The problem with using PET is that the consumer does not perceive this material, and most people think negatively about it because they relate it to a low-quality product (Otto et al., 2021).

Glass containers are manufactured by melting materials such as sand, soda, ash and limestone. The bottles' manufacturing process and weight contribute significantly to the global warming potential (GWP), about 99.62%. Applying the weight reduction strategy for glass bottles has the potential to produce a reduction in the global warming potential (GWP). A reduction in the weight of a glass bottle of about 20% is equivalent to approximately 9.43% reduction in GWP, which is not significant when compared to other materials, as shown in Figure 35.

While a glass bottle can be reused up to 50 times, resulting in an 85% decrease in global warming potential, several countries do not have an efficient system for collecting and recycling solid waste

(Gutiérrez-Galicia et al., 2021). In addition, some countries are making efforts to increase their glass recycling rate, such is the case of many European Union countries that forecast that by 2025 their glass recycling rate will be 70% (Otto et al., 2021).

The final product from a distillery is frequently placed inside a corrugated cardboard box for protection; this type of container is called secondary packaging (Molina-Besch et al., 2019). These are manufactured from wood and recycled paper waste, so their decomposition takes a few months (Sazdovski et al., 2021). But the generation of corrugated cardboard-based products contributes significantly to CO_2 emissions. For example, in the case of Germany, it is estimated that the production of 0.03 kg of corrugated board for butter products generates from 0.032 to 0.38 kg CO_2 eq (Finnegan et al., 2017). However, this range of CO_2 emissions will vary because it depends on several factors: the company's recycling system, the contamination during board recycling, and the concentrations of paper-coating chemicals (Otto et al., 2021).

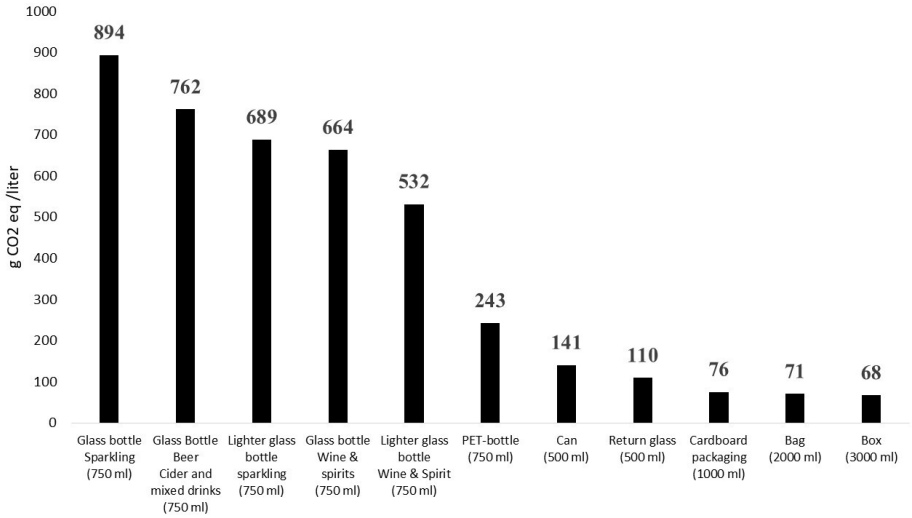
4.4 Limitations of LCA studies

Life Cycle Analyses (LCAs) reveal significant differences due to methodological and data-related variations. At the outset, the definition of each study's objectives and scope varies considerably, directly influencing system modeling and the selection of environmental impact indicators. Additionally, data quality and sources play a critical role in LCAs; reliance on primary data from manufacturers or on potentially inconsistent or outdated databases introduces variability in the results. Moreover, differing assumptions about end-of-life and recycling scenarios further impact environmental impact assessments.

As a result, these differences in methods and data cause problems in LCA results, making it difficult to compare different packaging systems. So, it is important to use the same methods and be clear

about how data is collected to get more reliable and consistent evaluations of the environmental effects of packaging systems (Bher & Auras, 2024).

Figure 35
Carbon dioxide emissions per liter of beverage produced during packaging production.



Note. Figure created by the authors using data from Systembolaget (2021).

4.5 Conclusions

The global beverage alcohol market is expected to continue to grow, although at a slower pace. Three main drivers drive this growth. The first is the increase in the consumption of craft alcoholic beverages due to the new drinking habits of the younger generations. Second, the demand for this type of alcoholic beverage by bars and restaurants to offer new experiences to their customers is another reason for the growth of this industry sector. Third, developing economies like China and India are expected to drive the alcoholic beverage market.

However, the alcohol industry presents challenges in the face of climate change. Climate change causes variations in the quality of

alcoholic beverages because there are variations in the sugar levels in the plants used for their production, and, therefore, the volume content of alcohol to be produced may be much lower than projected by the company. Another effect of the extreme heat is that it makes it difficult to obtain water, which is essential for companies that manufacture alcoholic beverages. Thus, extreme heat and weather phenomena are the main dangers for the alcohol industry, as they can result in production interruptions and substantial economic consequences.

The main causes that affect the environment of the alcohol industry are distributed in various stages of producing an alcoholic beverage. In the stage of cultivation of raw materials such as cereals, high CO_2 emissions are emitted, as well as the depletion of water resources and the excessive release of nutrients into aquifers are very high due to the use of nitrogen fertilizers. In the production process of some distillates, boiling the raw material is one of the first stages, where a large amount of water is consumed to operate a boiler to cook the raw material in an autoclave. This boiler is also used as a heat generation system for distillation, and the cooling system for distillation consumes a large amount of water.

Another cause of significant water consumption is the manufacture of glass bottles. Glass production results in a significant carbon footprint and increased transportation emissions. While glass bottles can be reused up to 50 times, some countries lack efficient solid waste collection and recycling systems.

Finally, the transportation of raw materials, inputs, waste and distribution of the final product contributes significantly to climate change, as all modes of transportation consume fossil fuels. The environmental impact of distillery operations worsens when inputs are purchased from distant locations but improves if they are manufactured nearby. Different transportation methods generate emissions, but road transport is the highest source of CO_2 emissions.

Chapter Four examined the environmental impact of large companies in the spirits industry, highlighting how climate change and greenhouse gas emissions affect both the production and quality of these beverages. Building on this understanding, Chapter Five will focus on sustainable strategies and emerging trends aimed at mitigating these impacts by promoting the adoption of greener and more efficient practices across industry. Implementing these strategies is essential to reducing the sector's carbon footprint and ensuring its long-term sustainability.

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CHAPTER FIVE

Sustainable Strategies and Trends in the Spirit Industry

Abstract. This chapter describes the sustainable strategies and trends that the spirit industry can implement to minimize its environmental impacts, such as efficient water management, use of renewable energy, application of digital technology, and proposals to achieve sustainable transportation and packaging. Although the cultivation of raw materials does not directly concern this industry sector, it is important to expose alternatives to traditional soil cultivation to achieve a sustainable crop that would directly benefit the alcohol industry since it is at this stage where the value chain of a distilled alcoholic beverage begins.

Keyword: Trends, Agriculture, Renewable energy, Water, Transportation

Resumen. En este capítulo se describen las estrategias y tendencias sostenibles que la industria de las bebidas espirituosas puede aplicar para minimizar su impacto medioambiental, como la gestión eficiente del agua, el uso de energías renovables, la aplicación de tecnología digital y las propuestas para lograr un transporte y un envasado sostenibles. Aunque el cultivo de materias primas no concierne directamente a este sector industrial, es importante exponer alternativas al cultivo tradicional del suelo para lograr un cultivo sostenible que beneficiaría directamente a la industria del alcohol,

ya que es en esta fase donde comienza la cadena de valor de una bebida alcohólica destilada.

Palabra clave: Sostenible, Estrategias, Bebidas espirituosas, Tendencias

5.1 Importance of Sustainability in Modern Business Practices

It is important to mention the difference between sustainability and sustainable in the context of the alcohol industry, as these are related concepts; however, there are differences. Sustainability means maintaining or sustaining something long-term without depleting resources or harming the environment and society (Rodriguez-Sanchez & Sellers-Rubio, 2021). It encompasses a holistic approach that considers the economic, environmental, and social aspects. Sustainable beverage alcohol production involves environmentally sound, socially equitable, and economically viable practices (Ruggerio, 2021). In contrast, sustainable or sustainable production can be considered as sustainable strategies or methods that help minimize the negative impact on the environment at the enterprise level (Schaltegger & Wagner, 2011).

Sustainable practices are a strategic priority for businesses today for several reasons. First, it helps companies address problems arising from natural resource depletion and climate change and protect existing natural resources (Haseeb et al., 2019). Second, it is directly related to long-term profitability, as sustainable methods can save money by using energy and resources better, reducing waste, maximizing reuse and recycling, and better managing the supply chain (Chinomona et al., 2020; Obeidat et al., 2022).

Third, by incorporating sustainable methods into their operations, companies can enhance their reputation, build trust, and attract

and retain customers and employees who share environmental stewardship beliefs. In today's society, customers, workers, investors, and communities are increasingly concerned about how companies affect society (Dressler & Paunović, 2019). Finally, Dressler & Paunović (2019) commented that sustainable practices promote creativity and product differentiation, allowing companies to reach new markets and meet changing customer needs, which results in increased competitiveness.

In addition, a survey of global leaders revealed that 93% believe that companies are stewards of society, not just employers, and therefore, consider it necessary to take stronger positions on socially responsible initiatives. This survey reveals that senior executives of large corporations take serious action to ensure that their companies balance being socially responsible and making profits (Cruickshank & Deloitte Touche Tohmatsu Limited, 2019).

Sustainable methods are important for a country's economy and people's lifestyles, as long-term growth must balance ecosystems (Zhang et al., 2022). Therefore, governments and regulatory bodies seek to be stricter to protect the environment, keep natural resources in good condition, and curb climate change by applying environmental regulations to businesses (Campbell Gemmell & Marian Scott, 2013). For example, in the United States of America, the Environmental Protection Agency (EPA) has implemented pollution control regulations such as The Clean Water Act (CWA), which establishes guidelines for industrial wastewater (US EPA, 2013), and The Hazardous Waste Program, which establishes regulations for the management of hazardous waste to prevent harm to human health and the environment (US EPA, 2015). Therefore, the spirits industry must follow these regulations to stay out of trouble with the law and contribute to helping the world.

From a public policy perspective, the implementation of environmental regulations benefits everyone equally, more so if the aim is

not to produce damage to the environment but also to guide companies to make efforts to adapt strategies to meet the objectives for sustainable development set out in The Sustainable Development Goals (SDGs), which were suggested by member countries of the United Nations (Sompolska-Rzechuła & Kurdyś-Kujawska, 2021). Among the strategies promoted by the spirits business are the incorporation of more sustainable agricultural systems, efficient water management, use of renewable energy (Santeramo, 2022), reuse (Shen et al., 2022) and making use of digital technologies to streamline their operations (Du et al., 2022). By implementing these types of strategies, the alcohol industry contributes to meeting three of the 17 SDGs targets that fall under its purview: clean water and sanitation (target six), affordable and clean energy (target seven), and industry, innovation, and infrastructure (target nine) (FootPrint Intelligence & Pernod Ricard UK, 2022).

In general, sustainable methods in business are important for protecting the environment, maintaining a good image in the eyes of society, making long-term monetary gains, and complying with environmental regulations. The distilled spirits industry can do good for itself, society and the planet by incorporating sustainable methods into its operations.

5.2 Sustainable Agricultural Strategies in Spirits Production

Sustainable agricultural strategies are essential to ensure the long-term viability of producing the ingredients needed to make distillates. In addition, these strategies aim to meet the growing global demand for crops in an environmentally friendly and socially responsible way (Rockström et al., 2017). By 2050, the world's population will need 60% more food than is currently available (FAO, 2023a). Due to the development of emerging economies, the amount of land available for cultivation will be less. This widens the gap between food demand and supply (Khan et al., 2021). Therefore,

strategies are required that meet future food needs but at the same time do not put profit, environmental health, employment and productivity at risk (FAO, 2023b).

One of the strategies to meet the challenges of crop demand for the coming decades is sustainable intensification (SI) (Godfray & Garnett, 2014). This strategy consists of farmers getting more from the same amount of land and with fewer inputs to have less adverse environmental effects (Rockström et al., 2017; Tilman et al., 2011). This farming approach proposes using various practices to make crop inputs such as water, fertilizers, and herbicides, among others, more efficient.

Among the most common practices are crop rotation and diversification to reduce the number of pests and the use agricultural chemicals through biological techniques (Beltran-Peña et al., 2020). However, there is also a trend in using digital technologies such as the Global Positioning System (GPS), sensors and data analysis to best use water (Bolfe et al., 2020) to improve nutrient circulation and efficient herbicide and fertilizer application (Sawinska et al., 2020).

Another strategy for making agricultural systems more sustainable and adaptable to climate change is agroforestry (Yasin et al., 2023). This consists of deliberately integrating timber or fruit trees with crops to maintain soil moisture and nutrients, providing good insects a place to live, and increasing carbon sequestration and drought resilience (Achmad et al., 2022). Also, agroforestry brings economic benefits because farmers derive income from deliberately planted trees (Quandt et al., 2023).

Water is a primary input in cultivating cereals, one of the preferred raw mate-rials in the distillates industry. Thus, efficient water management is an essential strategy for developing sustainable agriculture. Irrigation systems are critical to reduce water waste and

ensure that water is used efficiently in agriculture. For example, drip irrigation is a sustainable irrigation method that optimizes soil water content and plant growth and continues to be developed to improve performance and efficiency (Sidhu et al., 2021). Nowadays, there is a trend to apply intelligent systems to drip irrigation, using sensors and microcontrollers to measure soil moisture and pipe pressure and detect the amount of moisture in the weather to allow precise and targeted irrigation, only using this natural resource where it is needed and when it is needed (Klyushin & Tymoshenko, 2021).

In the same sense of consuming fewer resources, such as water and soil, and developing more sustainable food production, there are new proposals for cultivation, such as vertical and hydroponic crops. These proposals seek to produce food in an intelligent and ecologically responsible way to reverse the deterioration of resources (FAO, 2022).

Vertical farming can withstand climate change more than traditional soil-based farming, avoids using pesticides or fertilizers, and saves space and water. However, because it is a relatively new technology, it is not cheap and still consumes high energy (Van Gerrewey et al., 2022). The consolidation of the vertical farm shortly increases the possibility that it could be considered as an alternative for the seeding of the raw material of small distilleries since these could be located in places close to the distilling house, helping to minimize travel distances and transportation costs, up to 60%, because there would be less energy consumption, in addition to supporting local economies by attracting more people to become suppliers of raw mate-rials to the alcoholic beverage industry in their location (Al-Kodmany, 2018).

Hydroponics is a widely used method for growing plants without soil; from 2016 to 2019, its use increased by 20% worldwide, and it is estimated that by 2050, it will increase its application by 45% (Ci-

fuentes-Torres et al., 2021). It has several advantages over traditional soil-based cultivation; for example, it is easy to maintain, saves space, facilitates the control of nutrients, and reuses a high amount of water. However, more research is still needed in designing this cultivation method to reverse its high initial cost, increase the range of plants to be grown and decrease its energy consumption. Recently, there has been a trend to incorporate artificial intelligence (AI) for efficient hydroponics management, such as monitoring crop diseases and improving productivity (Ramakrishnam Raju et al., 2022).

One food production system related to sustainability is organic farming (Eyhorn et al., 2019). This consists of using natural and sustainable methods and not using synthetic herbicides, fertilizers or genetically modified organisms (GMOs). Organic farming focuses on improving soil health, plant and animal diversity, and environmental balance. Also, it considers improving the health of farmers and customers as a goal (Röös et al., 2018). However, yields are often lower than in conventional agriculture. There is a renewed interest in increasing yields in organic farming to provide more organic food for a growing, wealthier population with less adverse environmental effects (Eyhorn et al., 2019).

5.3 Renewable Energy Adoption in Distilleries

In the value chain of the distilled beverage industry, high amounts of fossil fuels are consumed, from the cultivation stage to the distribution stage of the product. For this reason, the industry is looking for alternatives to replace energy from non-renewable resources with renewable resources such as wind, sun and biomass (Dalton et al., 2022; O'Shea et al., 2023). Absolut Vodka, for example, has adopted measures to reduce its carbon footprint in its production process. In 2021, this brand emits nine times less CO_2 per liter of alcohol than an average distillery. This achievement was thanks to be using up to 75 percent renewable energy (The Absolut Company,

2021). Generating energy from renewable sources has several advantages, such as decreasing greenhouse gas (GHG) emissions, being inexhaustible, allowing energy independence, and being freely available (Žarković et al., 2022).

Wind power is another reliable and abundant form of renewable energy and contributes to diversifying a distillery's energy portfolio. For example, the Montanya distillery in the USA uses wind energy in some facilities (Montanya Distillers, n.d.). However, the intermittent nature of wind power poses significant challenges in integrating it into large-scale power grids, leading to greater uncertainty and fluctuation in its consumption (Li et al., 2020). In general, as wind energy is not always available, it is important to consider its use in its entirety, as it will depend on wind speed (Wang et al., 2021).

The sun's energy is another renewable energy source becoming increasingly prevalent. The way in which solar energy is harnessed is through solar panels that produce electricity, heat, and motion. The advantages of using this energy source are several; for example, solar panels have a long-life span of 25 to 30 years (Ahmad et al., 2020). It is more economical than other sources of energy generation; also, it does not require much maintenance, can be placed in different ways and can be located close to where it is needed (Rabaia et al., 2021). For example, in France, a cognac distillery house has installed solar panels on its roof with an approximate capacity of 34,000 kWh/year (Becker et al., 2020). The Tattersall distillery located in Wisconsin in the USA has installation of 1,080 solar panels on its roof that produces an average of 477,900 kWh of electricity per year, thus avoiding the emission of about 373 tons of CO_2, similar to the amount that can be absorbed by approximately 168 hectares of forest (Manning, 2022; New Energy Equity, 2022). These two examples demonstrate a trend to generate electricity for distillery operations by solar energy and become less dependent on fossil fuels.

However, there is still a need to improve the performance of solar energy storage, as the currently used batteries have several disadvantages, such as battery degeneration, limited storage capacity, high cost, safety issues, and environmental impact (Tan et al., 2021). The production processes are not environmentally friendly. The manufacture of solar cells uses minerals such as cadmium, which can have adverse effects on the environment (Rabaia et al., 2021). Therefore, energy storage technologies need to be further developed to provide a longer lifetime at a lower cost.

To reduce carbon emissions in the alcohol industry, another alternative to generating energy is the use of anaerobic digestion (AD) plants in which biodegradable materials are converted into biogas. In Mexican craft spirits such as sotol, the residues resulting from the distillation stage are not used (Madrid-Solórzano et al., 2021), which could be used to produce biogas. Most distilleries are estimated to convert 88% of their raw material into waste, making them a significant pollution source (Davey, 2022). However, an AD plant is reported to supply up to 61% of a distillery's natural gas needs (O'Shea et al., 2020).

Biogas directly impacts 12 of the 17 SDGs by increasing renewable energy, improving waste management, and creating jobs (Obaideen et al., 2022). It is presumed that more than 700 million tons of biomethane could be produced sustainably today, which is equivalent to more than 20% of the global demand for natural gas (International Energy Agency (IEA), 2020). Because the waste from a distillery contains low phosphorus content, which is the essential nutrient for the microbial organisms involved in anaerobic digestion, mono-fermentation in whiskey distilleries in Poland has been proposed to produce sufficient biogas and methane (Roubinek et al., 2023).

While renewable energy consumption has a positive impact, clean energy technologies may be less competitive due to their high initial capital cost and long payback period; for example, the increase

in the average growth rate of distilled alcoholic beverages globally is driven by the growth in popularity of craft spirits (Globe Newswire, 2022). However, these craft distilleries are generally small or medium-sized and do not have sufficient financial resources to venture into the use of renewable energy throughout their production process. However, large corporations could take a step in investing in these small distilleries to use renewable energy, since in many cases it is these large corporations such as Rémy-Martin, Martell and Hennessy who buy the product from these small distilleries (Becker et al., 2020). Therefore, the transition to the use of clean energy by a majority of the distilled alcoholic beverage industry, such as craft spirits, is linked to a long period of time for implementation (Žarković et al., 2022).

Nowadays, there is a trend for the use of information and communication technologies (ICTs) in several companies to perform different activities, such as remote work, training and digital payments, as well as this so-called "fourth industrial revolution" that facilitates supply management (Baker, 2019). It is estimated that companies that used ICTs well before the COVID-19 pandemic could react to the economic problems caused by the pandemic, continue running their businesses, and have greater resiliency (Kim et al., 2022). For this reason, ICTs are seen as a key part of the transition to low-carbon economies and the effective fight against climate change. This is because they can facilitate the efficient connection and control of renewable energy sources, which can be better monitored, controlled, and optimized (Žarković et al., 2022).

Overall, global growth is being driven by decarbonization and the digitization of renewable energy sources. Decarbonization aims to reduce the amount of carbon that comes from energy production. In contrast, digital technologies add value in a cost-effective way.

5.4 Water Conservation Strategies

Fresh water is a threatened natural resource, and more than a billion people did not have access in 2019, so water conservation is a key part of sustainable and responsible production in the distilled alcoholic beverage business (Mekonnen & Gerbens-Leenes, 2020). Most of the water consumption that goes into the production of alcoholic beverages results in the fermentation and distillation stage, cleaning, maintenance, bottle washing, boiler use and cooling towers (Arellano-Plaza et al., 2022; Consejo Regulador del Tequila, 2016; Duffy et al., 2023; Madrid-Solórzano et al., 2022). Wastewater from a distillery, which can be considered a by-product of distilleries, contains high concentrations of nitrogen, phosphorus and other organic materials. These compounds inhibit photosynthesis and reduce oxygen in the water, killing aquatic plants and animals (Hines, 2021). For this reason, this sector seeks to implement strategies to save water and reuse its wastewater.

Several distilleries are currently using the technology called membrane filtration to reuse water. Distilled beverages such as brandy, whiskey, vodka and others need particle control by means of this technology to clarify and clean the product resulting from distillation while allowing the best flavors, colors and clarity of the distillates to be obtained (3M Company, 2023). But also, membrane filtration is a way for distilleries to reuse water by removing undesirable particles that are generated at different stages of the distillation process (Yu, 2021). However, this technology continues to be improved to make the cleaning of distillery wastewater more efficient, incorporating the use of composite materials such as aluminosilicate and natural polymers such as cellulose triacetatepara (Ratna et al., 2021).

In the same vein, Marble Distilling is a company that has implemented technology to take advantage of its wastewater from the distillation stage. This company is located in Colorado, USA, where it is predicted that by 2026 there will be a water shortage. Due to this

forecast, this distillery took the initiative to partner with Siemens and Holbrook Services to develop a Water Energy Thermal System (WETS) that reuses and recycles water for its distillery. The hot water from the distillation process is pumped to other parts of the building for heating and heating domestic water. In winter, the heat generated by this system is used to melt snow. With this system, the company saves more than 15 million liters of water per year and 1.8 billion BTUs of energy, which is enough to power 20 homes (Marble Distilling Company, 2022).

Most distilleries incur waste management costs, such as transportation, when the wastewater could be utilized as a wastewater treatment plant (Becker et al., 2020). In order to help water conservation and reuse wastewater, the whiskey distilling house Five & 20, located in New York, USA, partnered with TimberFish Technologies to develop technology to reuse their wastewater for fish farming (Hines, 2021). Wastewater, rich in nitrogen and phosphorus, feeds microorganisms that subsequently convert distillery waste into water suitable for maintaining aquatic species, such as rainbow trout, largemouth bass, and freshwater shrimp (Chriest, 2018).

One trend to make a distillery's water use more efficient is streamlining its operations through the Internet of Things (IoT). This technology improves an industry's operational efficiency by digitally monitoring its manufacturing operations (Demir & Dincer, 2020). Therefore, the distilled beverage industry could make use of IoT to make water use more efficient. Applying an IoT system for real-time water monitoring would help to identify the causes of waste and reduce water consumption (Jagtap et al., 2021). Similarly, an IoT system can measure impurities, minerals, and contaminants in the water used in the production process of making a beverage for the effective operation of reverse osmosis technology (reverse osmosis technology) so that the water remains optimal for reuse (Hines, 2021).

In conclusion, water conservation in the distilled spirits business can be accomplished in several ways, by using systems to remove undesirable particles in the water, encouraging new wastewater reuse practices, and streamlining the production process with IoT. These tactics can help make beverage production more sustainable and responsible while saving water resources. While the use of new technology would be expensive for most distilleries, more so for those new or small to the market, as potable water becomes scarce, new technologies for reprocessing it will have to be migrated.

5.5 Sustainable Transportation

Sustainable transportation in the distilled spirit sector refers to the measures taken by distilleries to make their transportation reduce carbon emissions as a result of the high consumption of non-renewable energy. Two factors determine the amount of energy consumed in transporting raw materials and inputs and waste management in the production of distilled spirits: the mode of transportation and the distance to travel (Becker et al., 2020; Coudard et al., 2021; Eriksson et al., 2016; Madrid-Solórzano et al., 2022). Therefore, it is necessary to implement strategies to reduce the transportation sector's carbon footprint. Distilleries can follow three strategies to make their transportation methods more efficient. The first strategy is reducing transportation kilometers, the second is the consumption of alternative fuels, and the third is using electric or hybrid vehicles.

The first is for the distilled spirit industry to purchase raw materials and inputs locally. This strategy entails not only environmental benefits such as the reduction of air pollution, but also economic benefits (Bartle et al., 2021). It is predicted that by 2030, U.S. beverage companies (alcoholic and non-alcoholic) will spend approximately US$30 billion on transportation (Mulvey, 2020). Therefore, collaborative work between distilleries and local farmers brings economic benefits and cost reductions by reducing the need for long-distan-

ce transportation and the need for more efficient and cost-effective transportation(U.S. Department of Energy, 2023) and also means job creation (Rodriguez-Sanchez & Sellers-Rubio, 2021).

The second strategy is to optimize fuel consumption. In developing countries, older model cargo trucks tend to be used, resulting in higher pollutant gas emissions (Inkinen & Hämäläinen, 2020). While changing the cargo vehicle could be costly for a small distillery, exhaust technology could be implemented (Mahon, 2023). This technology is more economically available and consists of devices to control and treat emissions from internal combustion engines to minimize pollutants, such as catalytic converters (Bakyt et al., 2023).

While vehicle emissions can be significantly improved with the use of exhaust technology, heavy-duty trucking still requires diversification of fuel sources, for which the use of alternatives, such as biodiesel, is one proposal (Yan et al., 2021). In addition, the use of natural gas and hydrogen has been evaluated as a long-term solution to climate change.

Natural gas is a clean, cheap, and abundant source of energy that can help reduce emissions; however, it has the disadvantage of insufficient infrastructure and established supply chains (Rodrigues Teixeira et al., 2021). Although hydrogen is a versatile fuel, it is currently not suitable for large fleets because hydrogen engines consume more energy than they produce; therefore, light vehicles require large storage tanks. By contrast, medium and heavy vehicles have more space to store sufficient hydrogen, but ample storage tanks reduce the overall carrying capacity (U.S. Department of Energy, n.d.).

Another sustainable approach is using electric vehicles to significantly reduce the carbon footprint of the transportation business. Electric vehicles (EVs) are a renewable option; however, they still

present several unique challenges for freight trucks. According to the American Transportation Research Institute, a fleet of all-electric trucks in the U.S. requires more than 40% of the energy currently being produced. Second, no battery can currently support long distances on the road or the weight of trucks and trailers (Ahmad et al., 2020). Additionally, the extraction of raw materials for battery manufacturing, such as lithium, causes environmental damage, pollution, water consumption, and labor exploitation, making it imperative to consider viable alternatives (Tan et al., 2021). Third, the infrastructure for electric truck charging faces problems in terms of cost, location, and parking, which can take 8–12 hours (Mahon, 2023).

With the advent of Artificial Intelligence (AI) and IoT, the trend of intelligent mobility has emerged. With the use of digital technologies, the aim is to optimize the supply chain and make the maintenance of a company's fleet of cargo vehicles more efficient, as well as reduce idle times and use of routes more efficiently (Chatti, 2021). Using IoT devices and sensors, predictive maintenance systems can monitor vehicle equipment, alert drivers, and maintain the highest level of fuel efficiency. This reduces roadside emissions and disruptions (Romagnoli et al., 2023).

In addition, with the further development of AI models, the use of autonomous vehicles (AVs) is expected to help reduce fuel consumption and support climate change (Demir & Dincer, 2020). However, safety concerns must be addressed before their widespread adoption (Cugurullo, 2020). A hybrid transportation model combining human and machine drivers will likely emerge with advanced driver assistance systems (ADAS) already in use (Abduljabbar et al., 2019). Ultimately, in the near future, driverless freight vehicles could be used in limited circumstances, such as short routes, while AI algorithms will continue to be developed.

5.6 Packaging Innovations for Sustainability

In the post-pandemic market, the distilled spirit industry faces several challenges, such as a declining workforce and rising raw materials and input costs caused by supply chain problems (Kumar et al., 2020). However, one of the biggest challenges has been concerning the preferred primary packaging for this industry sector, glass bottles. The demand for glass bottles has outstripped supply, resulting in increased shipping costs and inflation (Pitts & Witrick, 2021). Glass shortages affect the tequila, vodka, and whiskey sectors, with large distilleries opting for bottle sizes different from their requirements; therefore, this could result in a smaller supply of smaller-volume bottles in the future. Consumers may have to work harder to find their favorite drink when presenting their preferences (Lucas, 2021).

While glass shortages affect the beverage industry in the post-COVID-19 pandemic period, glass continues to be a consumer favorite. A Friends of Glass survey of more than 4,000 consumers in 13 European countries revealed that glass is the packaging material of choice because it is considered an integral part of a healthy lifestyle, as it is reusable, recyclable, and safe even when recycled. In addition, consumers believe in glass as a material for the future and expect brands to offer sustainable packaging choices (Hendry, 2022). In addition, the results from Friends of Glass align with the research conducted by Boesen et al. (2019), who examined the environmental sustainability of different types of packaging among young, well-educated consumers in Denmark. The results show that young people prefer glass bottles over other types of bottles, such as plastic or aluminum, because they consider that they are safer, can be used more than once, and that the damage to the environment resulting from glass bottles lies in the melting of glass. Additionally, it was found that consumers positively evaluate the sustainability of primary packaging if they meet two characteristics simul-

taneously: the bottle material is perceived as more recyclable than others, and if the material is also conceived as reusable, associated with another use that the consumer can give it (Boesen et al., 2019).

Both consumer preference studies point to consumers being interested in seeing distilled spirits brands with eco-credentials in the market; they are environmentally friendly and responsible. Research by FootPrint Intelligence and Pernodr Ricar UK found that 53% of spirits consumers are interested in their favorite brands with sustainable strategies to mitigate climate change and are recognized as socially responsible (FootPrint Intelligence & Pernod Ricard UK, 2022).

Facing the trend of new consumers committed to protecting the environment (PricewaterhouseCoopers International Limited (PwCIL), 2021). The distilled alcoholic beverage industry is seeking to implement sustainable strategies to mitigate the environmental impact caused by the use of glass bottles. Single-use glass containers consume a lot of energy and require large amounts of raw materials such as sand and water. In 2020, it is estimated that 40 billion single-use glass bottles will be produced, causing 22 million tons of carbon emissions (Miller, 2023). Therefore, the distilled spirits industry is interested in implementing sustainable packaging strategies in addition to traditional glass packaging.

One sustainable strategy a distillery company can implement at a lower cost is reusing glass bottles. For example, the Rémy Cointreau Group is implementing a pilot glass bottle deposit system in Barbados to reuse 30-40% of their locally produced rum, and they estimated that this strategy would result in 60% CO_2 savings per bottle (Rémy Cointreau, 2022).

Another time-saving strategy to reduce the carbon footprint resulting from the use of single-use glass bottles is to switch to bottles made from recycled glass rather than virgin glass. For example, the

Ellers Farm distillery in England switched from a traditional glass bottle to a 60% recycled one. It weighed up to 50% less than an average bottle weighing approximately 450 g. This change resulted in a reduction in the carbon footprint. This change reduced its carbon footprint by 0.5 kg CO_2 eq, a value considered low. Recycled glass significantly reduces carbon emissions as it requires less energy to melt and does not emit additional CO_2 from virgin glass, saving 185 kg of CO_2 eq for every ton used. Using recycled glass bottles reduces solid waste and energy consumption and reduces air pollution (Ellers Farm Distillery, 2021).

Rémy Martin is a French company that manufactures and sells high-quality alcoholic beverages, especially spirits. It has promoted a system for refilling cognac decanters an infinite number of times to its customers. Refilling takes two days, including inspecting, cleaning, and digitally documenting the decanter before attaching a medal engraved with a fill number. With this reuse concept, the company seeks to contribute to environmental protection while offering consumers a different experience when purchasing distilled spirits (Rémy Martin, 2022). Other distilleries, such as East London Liquor Company and York Gin, have considered the concept that their customers can refill their bottles with the distilled alcoholic beverage of their choice and, in addition, put back a label and tax stamp (East London Liquor Company, 2023; York Gin, 2022).

While this bottle-refill approach requires customers to travel to participating distilleries or stores with an empty bottle, other distilled spirit producers have adopted different reuse strategies. For example, Global Ethics Liquor proposed reusing the glass bottle of its One Gin brand. The glass bottle has an engraving on the front with the word "Water" that appears when the consumer removes the label; with this idea, it is intended that the consumer provides a second use to the bottle, a water container (Kerrigan, 2022). On the other hand, the distiller Isle of Raasay promotes different uses for

its whiskey and gin bottles on its website, such as using it as a lamp, vase, and candlestick (Connor, 2023).

However, there is a trend for several distilling companies to explore alternatives to glass bottles. For example, distillers Silent Pool Distillers and Greenalls Gin are exploring consumer acceptance of packaging a distilled beverage in a bottle other than a glass. These distilleries companies offer a bottle made from 94% recycled paper, developed by FrugalPac (Frugal Company, 2023), with a food-grade pouch inside where the spirit is deposited. This bottle reduces the carbon footprint by up to 84% compared to a glass bottle and is up to five times lighter for transportation (Greenalls Gin, 2023).

However, due to high paper prices, concerns about high levels of water consumption, and the risks of water pollution in paper production, the French distillery company A. de Fussigny presents an alternative to traditional glass bottles. The bottle is called 2050 Organic Cognac, made by Green Gen Technologies, and it uses natural wool fiber and organic resins as raw materials (Nichole, 2022).

In this vein of using naturally sourced raw materials to develop primary packaging, the packaging industry increasingly uses food waste from food production to create more sustainable packaging. Oranges are a vibrant resource for this purpose because only half of the fruit is lost when transformed into orange juice. Some brands such as Bombay Sapphire, Sipsmith, and The Macallan have been used for this purpose (Miller, 2023) and are beginning to experiment with waste in food production, such as using orange peel to obtain biopolymers that allow the development of biodegradable packaging (Sabater et al., 2022).

To move towards the use of other materials for distilled spirits packaging, Scotland's Shoogle Spirits and Harris Distilley distilleries have moved towards the use of 100% recycled 500 ml aluminum bottles. The benefits of aluminum are widely recognized; it is recy-

clable and lightweight (Shoogle Spirits, 2020). Likewise, the second distillery company is betting on reusing its aluminum bottle, as the consumer can refill their bottle before it is empty, thereby reducing the carbon footprint (Harris Distillery, n.d.).

Similarly, the Dunnet Bay Distillers of Scotland offer gin in a ceramic bottle (Murray et al., 2023a). Although the carbon footprint of a ceramic bottle is not known for comparison with other materials, it also promotes the reuse of its bottle by encouraging consumers to convert it into a soap dispenser. The distiller offers a 70-cl lightweight plastic bag filled with soap and a plastic pump for the soap dispenser. Similarly, this company offers consumers the free return of their bottles to be reused by the distiller (Murray et al., 2023b).

Today, the distilled spirit industry has new options to replace cork and plastic closures and avoid toxic inks primarily used in its labels. For example, the Cork Supply Group has developed corks from bio-based polymers that can be customized, colored, and scented to reflect the liquid inside the bottle and enhance the consumer experience (Talis, 2023). Regarding using more environmentally friendly labels, North Point Distillery uses environmentally friendly inks and plastic-free caps on its bottles (North Point Distillery, 2022). Similarly, Johnnie Walker's premium whiskey bottles feature artwork using Air-Ink® (Miller, 2023), a manufacturer of printing inks with air pollution as raw material. For example, pollution produced in 45 min by a diesel vehicle can produce 30 mL of Air-Ink® (Magazine & Lallensack, 2019).

Although primary packaging must have physical attributes that make it attractive to consumers, secondary packaging must also be addressed. In the whisky industry, both primary and secondary packaging are crucial to marketability. The secondary packaging frequently used in the distilled spirits industry is "packaging cylinders," which are considered packaging to offer the spirit as a gift. However, this type of packaging is difficult to recycle because it

contains a mixture of various materials such as cardboard, metal caps and bases, and plastics (Miller, 2023).

Another alternative is to generate less polluting secondary packaging. For example, the Don Julio Tequila brand offered the market a Margarita cocktail kit. Still, for this secondary packaging, the material was minimized by placing the products that made this gift kit so close to each other that they were only a few millimeters apart, using as little space as possible. This was made possible through Spearhead Group's pressure-fit packaging system. As plastic thermoforming is eliminated, this packaging system is more environmentally friendly (The Spearhead Group, 2021).

To use fewer bottles, it has been proposed to distribute spirits in bulk in containers that can be used by people working in bars. The ecoSPIRITS company has developed 4.5-liter containers to store and distribute distilled spirits in bars or restaurants to pour a drink directly from the dispenser or refill empty alcohol bottles. With this proposal, it is estimated that up to 90% of CO_2 associated with primary packaging and distribution can be eliminated (ecoSPIRITS, 2020).

As mentioned earlier, the IoT is becoming a key driver for addressing challenges in the alcoholic beverage industry (Gayialis et al., 2021), such as avoiding spirit counterfeiting, as the alcoholic beverage can be tracked from the moment it leaves the distillery, avoiding impacts to both consumers and the brand reputation of the distilled spirit. However, this technology can be used to promote commitment to the environment by the distillery, primarily with the new generations of young people (Mooiman & Andersson, 2022) and, in this way, generate a customer shopping experience to ensure customer loyalty to the brand (Ramšak, 2022).

In general, the distilled spirit industry seeks to protect the environment through sustainable strategies such as recycling, reuse, and

the transition to the use of materials other than glass, such as recycled paper, aluminum, ceramics, and the use of biopolymers for caps and inks, with less impact on the environment.

5.7 Conclusion

Sustainable strategies are priority for the distilled spirit industry, as they help address the problems derived from the depletion of natural resources and climate change, as well as protect existing natural resources, such as water, which are indispensable for the existence of this industrial sector. It also improves long-term profitability by promoting creativity and product differentiation, optimizing raw materials and inputs, and meeting the expectations of environmentally conscious consumers. However, clean energy technologies can be less competitive owing to their high upfront costs and long payback periods. The transition to clean energy is linked to a long implementation period, but it must be implemented if a critical time is reached due to climate change.

There are examples of distilleries that have started to adopt sustainable methods for the efficient management of the inputs and outputs of their production processes, and there is a clear trend to incorporate the use of digital technologies, such as AI and IoT, to streamline their operations. In addition, the use of this technology allows us to consider that monitoring systems for glass bottles can be developed to determine their life cycle from the time they leave the distillery until they are deposited in the trash and then improve current reuse strategies.

In the future, the distilled spirit industry will have to adopt the best innovations in their production processes to have the best sustainable methods to cause less damage to the environment, achieve business profitability, and be more competitive in the market, but also to promote a more sustainable future among their customers as part of their corporate image and brand. Sustainable practices will

become a key industry issue, affecting the minds of consumers and influencing their purchasing decisions; therefore, distilled spirits makers will need to consider the new trends.

Finally, the transformation of the spirits industry reveals two interrelated trends that offer new pathways for collaboration and sustainability. First, the shift toward renewable energy—such as solar power—has become a critical strategy for reducing fossil fuel dependence and cutting CO_2 emissions. While this transition may be challenging for artisanal distilleries, the growing fragility of global supply chains in the face of climate-related disruptions may prompt larger companies to collaborate with smaller producers.

At the same time, the growing popularity of craft spirits—driven by younger consumers' demand for authenticity and regional character—creates momentum for more resilient, low-carbon supply chains through localized production. These partnerships can accelerate renewable energy adoption among small-scale distillers and strengthen supply chains by minimizing transport distances and prioritizing local sourcing, reducing the industry's overall carbon footprint.



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ISBN (Digital): 978-628-7937-18-5

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