Environmental and Economic Life Cycle Assessment of a Spanish whisky

Paola A. Cely-Parra, Guillermo San Miguel*, Marcos Beltrán

Universidad Politécnica de Madrid, Grupo de Agroenergética, ETSII, Department of Chemical and Environmental Engineering, c/ José Gutiérrez Abascal, 2, Madrid, 28006 (Spain)
*corresponding author: e-mail: g.sanmiguel@upm.es

Abstract

A considerable literature has been dedicated to evaluating the carbon footprint of fermented beverages such as wine and beer. However, far fewer studies have been committed to assess the environmental and economic sustainability of spirit distillates. The aim of this paper was to compile a complete life cycle inventory of a commercial whisky produced in Spain and to identify environmental and economic hotspots from a streamlined LCA. The system boundaries covered a cradle-to-gate approach, which included production and transport of raw materials (barley and corn), whisky manufacturing including distillation, packaging and distribution. Two functional units were considered: 100 l of whisky and one degree of alcohol content. The analysis considered four impact categories including climate change, acidification, eutrophication, and tropospheric ozone formation, calculated using the EF 3.0 impact assessment method. The results described that most of the impacts associated with this product were attributable to packaging, followed by grain alcohol and cereal production. Environmental impacts generated by the fabrication were very limited, although this stage contributed significantly to the life cycle cost of the final product. Packaging burdens (mainly from the glass bottle) can be minimized through reuse or recycling strategies.

Keywords: whisky, spirituous, LCA, life cycle assessment, carbon footprint.

1. Introduction

Among the few studies available on the environmental sustainability of whisky, Eriksson et al., (2016) reported the LCA of a 70 cl bottle of malt whisky, which included the following life cycle stages: barley cultivation, yeast production, water supply, malting, distillation, maturation, distribution, and sales. In addition, they consider transportation phases even the one related to the distillery residues which were used for biogas production, regardless the biogas production was not included due to lack of information. The results showed that the contribution of the distillation process was insignificant in the environmental categories evaluated. The transportation phase had a relevant contribution to GWP, particularly the transport of final product and residues. Other phases such as the bottle production and agriculture have also an important role on GWP category. Acidification was mainly attributed to SO_2 emissions from bottle production, transport, and barley cultivation, while eutrophication was primarily caused by barley cultivation. Eriksson et al., (2016) also reported that the main contributors to total primary energy use was transport, bottle/glass production and the distillation process (which consumed biomass fuel). However, commercial whisky distilleries have been reported to consume fossil fuels such as natural gas and fuel oil in this stage (Kang et al., 2020). Chetrariu & Dabija, 2021 found that the recovery and reuse of wastes and by-products from whisky industry allows both the reduction of production costs and ensures the sustainability and protection of the environment. Likewise, the use of biogas as a substitute for fossil fuels leads to reduced fossil fuel consumption in the distillation process (Leinonen et al., 2018).

In the absence of information about the economics of whisky, publications about the life cycle costing (LCC) of other alcoholic beverages like beer were evaluated. Amienyo & Azapagic, (2016) found that, in agreement with the environmental impacts, the main contributor to the LCC are the raw materials due to the costs of barley, hops, process water and light fuel oil. The next largest cost contributor was packaging: steel cans, glass bottles and aluminium cans. The remaining costs are due to waste management, followed by beer production and transport.

2. Methodology

The life cycle assessment was carried out following the protocols of ISO 14040. The input data were mainly primary data provided by the local distillery, and using secondary data from life cycle inventory databases (Agri-footprint v.3.0 for barley and corn production phases and Ecoinvent v.3.6 for all other phases). The model of the whisky life cycle was performed using SimaPro 9.2.0.1. For the analysis conduction the EF 3.0 Method was used, and the impact categories climate change, acidification, eutrophication, tropospheric ozone formation and fossil resource use were evaluated.

2.1. Goal and scope definition

Three goals were defined for this study: i) quantify the resources involved in the production of whisky by elaborating a detailed inventory, ii) quantify the environmental impacts and costs associated with the whisky and iii) identify the life cycle phases with a significant contribution to environmental and economic impacts.

2.2 Functional unit and system boundaries

Two functional units (FU) were considered: 100 l of whisky and also one degree of alcohol (0.01 l alc.). Alcohol content allows for a more effective comparison of whisky with other alcoholic beverages (Saxe, 2010).

The system boundaries cover a cradle-to-gate approach which include upstream: raw materials (barley and corn) production; Core: raw materials and barrels transportation, grain and malt alcohol production, alcohol transportation, whisky elaboration, packaging; downstream: distribution (Figure 1). Due to its preliminary approach, this streamline LCA does not include the EoL of the packaging elements.

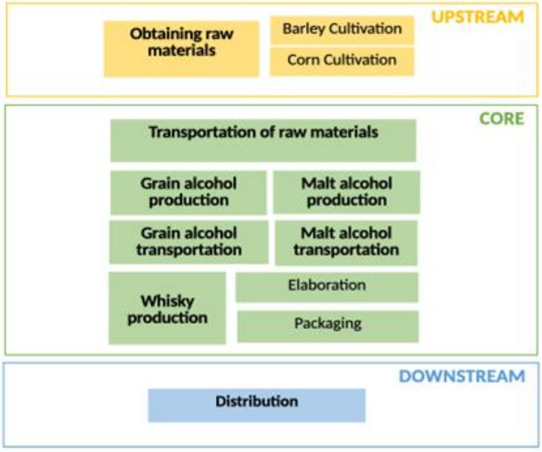

Figure1. *System Boundaries. Life cycle phases of a whisky production.*

2.3 System Description and allocation

The distillery where the whiskey under investigation is produced also makes gin (75% v/v of total production) and other types of whiskey. The whisky under study represents 5% of the total beverage output. The bottling plant receives these gins and whiskies plus other external products (whisky, anise liqueur and tequila).

The whisky is produced in two locations: the distillery (production of grain and malt alcohol) and bottling plant (whisky production, distillation, bottling and packaging). The primary data provided by the distillery correspond to their operations in 2019, while the secondary data was taken from background inventory LCA databases, publications, statistics and sectorial data.

A mass allocation approach was used to define the mass, energy and economic flows assigned specifically to our whisky. A more detailed description of the processes and allocation criteria involved in the whisky production is given below.

2.3.1. Upstream

Barley and corn used in the distillery come mostly from Castilla y León, Spain. Agri-footprint v.3.0 LCIA database was used to model the production of barley and corn considering process that accurately portrays the typical agricultural methods and conditions in Spain.

2.3.2. Core

The core begins with the transportation phase, which includes not only road transport of barley and corn from the farm to the distillery but also shipping of barrels from the USA. Those barrels are transported by ship to the port in Valencia, Spain and then by lorry to the distillery.

The electricity supply come from the Spanish power mix and the heating supply come from natural gas boilers. Furthermore, in relation to water requirements at the distillery, it was assumed that 3% of the water come from the drinkable water network and the remaining 97% come from a natural source (river). The distillery has its own water treatment plant, so all the water consumed was assumed to be returned to the ecosphere after being treated. The barrels made of American oak are used for the ageing in the grain and malt alcohol production, and they are used 4 times on average. At the distillery not only grain and malt alcohol are produced, but also by-products such as draff and pot ale. The by-products produced are not included in the system boundaries. The production and transportation of yeast and malt slurry were also left outside the system boundaries of this LCA. An estimation of their production was made based on data from previous publications (Chetrariu & Dabija, 2021; Edwards et al., 2022; White et al., 2014).

Malt and grain alcohol are then transported from the distillery to the bottling plant where malt and grain alcohol are blended, and the alcoholic strength is adjusted. Once the final product is obtained, it is bottled in glass bottles of 0.7 litres and distributed. At the bottling plant it is assumed that such as in the distillery, the electricity and heating supply come from the Spanish network and the natural gas boilers respectively. Based on information from the wholesale alcoholic beverage distribution sector, an estimation of cardboard boxes used for distribution phase was made. For this study, the whisky elaboration phase includes blended and bottling while packaging refers to the obtention of glass bottles and cardboards.

2.3.3. Downstream

The distribution phase assumes nationwide transportation by road of the whisky and its packaging from the production site to the retailer. The retail phase was left outside system boundaries as was the end-of-life of the packaging elements.

2.4. Life cycle Inventory

The results described that the distillery produced more than 13,000,000 litres of pure alcohol (LPA) per year which are distributed among different products. Concerning the whisky, it was found that about 457 LPA are produced for each tonne of cereal used. This finding is consistent with the results of other studies, where alcohol yields were around 400 to 500 litres per tonne of cereal (Agu et al., 2006, 2009). By-products from whisky production were estimated at 2.4 kg of draff and 8-18 litres of pot ale per LPA (Chetrariu & Dabija, 2021; Edwards et al., 2022; White et al., 2014), equivalent to 1096 kg of draff and 4569 l of pot ale per tonne of cereal consumed. Table 1 summarizes the inputs and cost involved in the production of whisky per functional unit.

Table 1. *Life Cycle Inventory per FU.*

	Unit	100 l	0.01 l alc.	€/100 l	€/0.01 l alc.
Obtaining raw materials				28	12,76
Barley Production	t/FU	0.04	17		
Corn Production	t/FU	0.05	22		
Transportation of raw materials				24	10,84
Alcohol Production				46	20,63
Water from river	m^3/FU	2	924		
Water from network	m^3/FU	0.07	30		
Electric energy	kwh/FU	17	7,712		
Thermal Energy	MJ/FU	1,115	501,647		
Alcohol Transportation				5	2,07
Whisky Elaboration				0.73	329
Water for plant	m^3/FU	0.03	14		
Water for dilute	m^3/FU	0.06	27		
Electric energy	kwh/FU	3	1,250		
Thermal Energy	MJ/FU	2	900		
Packaging				43	19,29
Glass Bottles	t/FU	0.08	34		
Cardboard boxes	t/FU	0.01	3		
Distribution				0.60	270

Regarding cost inventory, secondary data were used for upstream, so prices of barley and corn were obtained from an official report (MAPA, 2023). Moreover, costs related to bottles for packaging and transport, such as transportation of raw materials and distribution were collected from experts in different sectors such as wholesale of glass bottles for beverages, wholesale distribution, transport of goods etc. On the other hand, data related to costs of distillery operations, employees' salaries, insurance, maintenance, equipment, etc. were obtained as primary data. Electricity, water and natural gas costs were consulted from official sources such as supplying companies and government information.

Figure 2 shows that among all phases, the highest cost arises from malt and grain alcohol production (29.6%) probably due to the increases in prices for electricity and natural gas. The next major cost contributor was packaging (27.7%) due to the higher prices of glass bottles and finally for acquisition of cereals (18.3%). Nevertheless, it should be noted that the LCC represents only an approximation due to both, the substantial variability in costs and the generic nature of some utilized inputs. As an illustration of this, it is important to highlight that the cereal market commonly experiences prices fluctuations over time and according to agriculture ministry a weekly report of those fluctuations could be found.

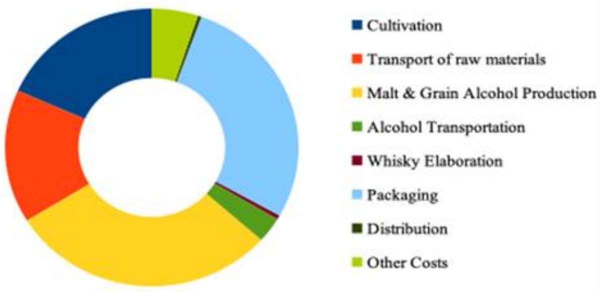

Figure 2. *Life Cycle Cost per FU.*

3. Life cycle impact assessment

Table 2 shows the characterized results for each impact category. The carbon footprint was 2.2 kg CO_2 eq. per litre of whisky, within the range reported for other whiskies and spirituous beverages, but higher than lower alcohol beer (Amienyo & Azapagic, 2016; Eriksson et al., 2016; Saxe, 2010).

The major contributors of CO_2 eq. emissions were the packaging phase due to the energy consumed in the production of the glass bottles. Please note that the impact value and overall contribution of this packaging stage will be considerably reduced when the streamlined LCA is expanded to include the EoL stage (recycling) of the glass.

This is followed by alcohol production, primarily from grain as it constitutes a majority portion of the total alcohol content in the whiskey and demands considerable thermal energy for its distillation, that was assumed to come from fossil sources. Finally, the cultivation of barley and corn phase followed due mainly to the use of fertilizers. An analogous pattern was observed for the fossil resource use category.

For the rest of the environmental categories evaluated the hotspot were the barley and corn cultivation and packaging phase. These results are similar to those reported by previous works where cultivation and glass bottles exhibited the most significant impacts (Amienyo & Azapagic, 2016; Bhattacharyya et al., 2019; Eriksson et al., 2016). In contrast, transportation phases have not significant impacts in none of the categories evaluated. For raw materials and alcohol transportation the reason could be that distances are relatively small, while for barrels transportation from the USA the impacts were distributed among the number of times barrels are used. Regarding the distribution, the limited impacts could be related to the scenario evaluated where international distribution is not included (Gazulla et al., 2010).

Table 2. *LCA results per FU and 1% alc.*

		100 l	0.01 l alc.
Climate Change	kg CO2 eq	219	98,8
Acidification	Mol H+ eq	2	849
Eutrophication	kg P eq	0	12
Tropospheric Ozone Formation	kg NMVOC eq	1	278
Fossil resource use	MJ	2,924	1,315,818

5. Conclusions

- The carbon footprint measured 2.2 kg CO_2 eq./l and this result is mainly attributed to the production phases of packaging and grain alcohol. The indicator for use of fossil resources followed a similar trend to climate change.

- The packaging phase significantly contributed to tropospheric ozone formation, accounting for 51.7% respect all whisky life cycle phases. Eutrophication was by far the impact category dominated by cereals production, mainly owing to the nutrients that compose fertilizers. Acidification followed the same trend but to a lesser extent.

- The hotspots of the whisky life cycle are linked to the production phases of glass bottles packaging, grain alcohol and raw materials (barley and corn cultivation). The environmental burdens associated with the production of the glass bottles should be reduced when the streamlined LCA is expanded to include the EoL of the packaging elements.

- The major contribution to the LCC came from the grain and malt alcohol production, followed by packaging and cultivation phases. The higher costs are partly tied to an important demand of electricity and thermal energy required for the processes which is also related to the category use of fossil resources.

References

Agu, R., Bringhurst, T., & Brosnan, J. (2006). Production of Grain Whisky and Ethanol from Wheat, Maize and Other Cereals. *Journal of the Institute of Brewing*, *112*. https://doi.org/10.1002/j.2050-0416.2006.tb00737.x

Agu, R., Bringhurst, T., Brosnan, J., & Pearson, S. (2009). Potential of Hull-less Barley Malt for Use in Malt and Grain Whisky Production. *Journal of the Institute of Brewing*, *115*. https://doi.org/10.1002/j.2050-0416.2009.tb00357.x

Amienyo, D., & Azapagic, A. (2016). Life cycle environmental impacts and costs of beer production and consumption in the UK. *The International Journal of Life Cycle Assessment*, *21*. https://doi.org/10.1007/s11367-016-1028-6

Bhattacharyya, N., Goodell, A., Rogers, S., & Demond, A. (2019). Environmental impacts of wheat-based vodka production using life cycle assessment. *Journal of Cleaner Production*, *231*, 642-648. https://doi.org/10.1016/j.jclepro.2019.05.226

Chetrariu, A., & Dabija, A. (2021). Characterization of Spent Grain from a Malt Whisky Romanian Distillery. *International Multidisciplinary Scientific GeoConference : SGEM*, *21*(6.1), 33-39. https://doi.org/10.5593/sgem2021/6.1/s25.10

Edwards, C., McNerney, C. C., Lawton, L. A., Palmer, J., Macgregor, K., Jack, F., Cockburn, P., Plummer, A., Lovegrove, A., & Wood, A. (2022). Recoverable resources from pot ale & spent wash from Scotch Whisky production. *Resources, Conservation and Recycling*, *179*, 106114. https://doi.org/10.1016/j.resconrec.2021.106114

Eriksson, O., Jonsson, D., & Hillman, K. (2016). Life cycle assessment of Swedish single malt whisky. *Journal of Cleaner Production*, *112*, 229-237. https://doi.org/10.1016/j.jclepro.2015.07.050

Gazulla, C., Raugei, M., & Fullana-i-palmer, P. (2010). Taking a life cycle look at crianza wine production in Spain: Where are the bottlenecks? *The International Journal of Life Cycle Assessment*, *15*(4), 330-337. ProQuest One Academic. https://doi.org/10.1007/s11367-010-0173-6

Kang, X., Lin, R., O'Shea, R., Deng, C., Li, L., Sun, Y., & Murphy, J. D. (2020). A perspective on decarbonizing whiskey using renewable gaseous biofuel in a circular bioeconomy process. *Journal of Cleaner Production*, *255*, 120211. https://doi.org/10.1016/j.jclepro.2020.120211

Leinonen, I., MacLeod, M., & Bell, J. (2018). Effects of Alternative Uses of Distillery By-Products on the Greenhouse Gas Emissions of Scottish Malt Whisky Production: A System Expansion Approach. *Sustainability*, *10*(5). https://doi.org/10.3390/su10051473

MAPA. (2023). *Evolución de los precios de los principales cereales* [Ministerio de Agricultura, Pesca y Alimentación]. https://www.mapa.gob.es/es/agricultura/temas/producciones-agricolas/cultivos-herbaceos/cereales/evolucion-de-los-precios-de-los-principales-cereales/

Saxe, H. (2010). *LCA-based comparison of the climate footprint of beer vs. Wine & spirits* (N.º 207). University of Copenhagen. https://core.ac.uk/download/pdf/269200388.pdf

White, J., Traub, J., Maskell, D., Hughes, P., Harper, A., & Willoughby, N. (2014). Whisky by-products: A valuable source of protein and potential applications in aquaculture. *New Biotechnology*, *31*, S118. https://doi.org/10.1016/j.nbt.2014.05.1899