Journal of Agriculture and Ecology Research International

Volume 25, Issue 4, Page 56-69, 2024; Article no.JAERI.119267
ISSN: 2394-1073

Life Cycle Analysis of the Production of Neutral Alcohol Obtained from Winemaking Byproducts for Use in Perfumery

D. Lanquetin [a++] and A. Piccirilli [b#*]

[a] *Enviro-Strategies, Poitiers, France.*
[b] *La Fabrique Végétale, Lyon, France.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jaeri/2024/v25i4614

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/119267

Original Research Article

Received: 28/04/2024
Accepted: 02/07/2024
Published: 09/07/2024

ABSTRACT

As is the case in many other industries, major fragrance brands are now incorporating circular-economy in their product-development strategies. This is in response to growing consumer demand for more environmentally friendly products. In light of this objective, perfumery raw materials must be evaluated against environmental and societal criteria. This more critical context, coupled with the fact that alcohol can constitute up to 95% of a fragrance, means greater attention is being given the origin of this fragrance solvent. Industries are now becoming keenly interested in seeking out more environmentally friendly alternatives to alcohols derived from field crops (sugar beet, wheat, corn, sugarcane) so as to use a sustainable alcohol with excellent olfactory performance. To this end, this study entailed evaluating the environmental impact of an extra-neutral grape alcohol produced in

---

**Corresponding author: E-mail: apiccirilli@lafabriquevegetale.eu;*

Cite as: *Lanquetin, D., and A. Piccirilli. 2024. "Life Cycle Analysis of the Production of Neutral Alcohol Obtained from Winemaking Byproducts for Use in Perfumery". Journal of Agriculture and Ecology Research International 25 (4):56-69. https://doi.org/10.9734/jaeri/2024/v25i4614.*

France and obtained from winemaking residues. Its olfactory performance has been proven to meet the expectations and industrial needs of perfumers. The environmental impact was assessed by a life cycle analysis (LCA) carried out per the current NF EN ISO 14040 standard. The results show that extra-neutral grape alcohol is positively comparable to sugar beet alcohol, particularly as concerns greenhouse gas emissions. Upcycled grape alcohol is also produced through sustainable management of winemaking waste and does not conflict with land needs for food production. Lastly, unlike field crops, grapevines in the form of vineyards are a perennial crop and therefore serve as major carbon sinks, much the same way forests do.

Keywords: LCA; alcohol; winemaking byproducts; perfumery.

1. INTRODUCTION

The now-palpable effects of global warming, the pollution of the earth's ecosystems, and the decline of biodiversity are manifestations that are pushing modern societies to protect the environment more effectively. The cosmetics and fragrance industries have, in fact, undertaken very extensive transformations to better align their practices with key sustainable-development principles. These industries most often rely on the United Nations' global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development [1]. Such adaptations have an impact on supply chains and the nature of the raw materials used in formulations.

In the perfumery realm, the International Fragrance Association (IFRA) recently established the Green Chemistry Compass, intended to apply the 12 principles of green chemistry to the raw materials used in making fragrances [2]. But the origin of alcohol (ethanol) is now more critically examined, because this fragrance solvent can account for up to 95% of a fragrance's composition. This alcohol is obtained from major field crops such as corn, wheat, sugarcane, and sugar beets. As such crops entail intensive agriculture that consumes vast tracts of arable land, these alcohols negatively impact biodiversity and enter into direct competition with human food production. It is therefore vital to identify sources of alcohol that are more sustainably produced.

To this end, the Coty company recently unveiled an *eau de parfum* made with an alcohol sourced from industrial CO_2 emitted by heavy industries (steel mills, glass manufacturing, thermal power stations, etc.), which consume great quantities of fossil fuels, such as coal and oil. This technology – developed by the LanzaTech biotechnology company – uses genetically modified microorganisms that transform the CO_2 of industrial emissions into ethanol which, once purified, results in a neutral-quality alcohol [3]. While this technology is innovative in its capacity to recycle a greenhouse gas, it does not help decarbonize the fragrance industry in the stricter sense, as it relies upon a fossil carbon source.

Other more environmentally responsible approaches are currently being proposed, such as those used by the sugar beet-alcohol manufacturer Cristalco. These are based on regenerative agriculture, a growing technique that is more environmentally friendly, with the objectives of regenerating soils and preserving water resources and biodiversity as effectively as possible [4]. The sugar beets from these crops are combined with those grown intensively, so as to establish a mass balance in keeping with the established Mass-Balance Approach (MBA).

Lastly, alcohols from legumes, such as peas and fava beans, are available: Regenerative cultivation is practiced here, too, and is said to have even lower impact than that of sugar beets or wheat. Nevertheless, these crops still compete with arable land intended for food production.

Another alternative is to use an alcohol made from French winemaking byproducts. Grape pomace from the crushing and pressing of grapes and wine lees from the sedimentation during fermentation are the principal residues of winemaking. They are currently recycled per the biorefinery principle into different byproducts: alcohol, tartaric acid, grape seed oil, natural dyes, biocomposts, etc. (Fig. 1) [5]. Grape alcohol is extracted from the pomace through continuous hot-water extraction. The resulting water-alcohol mixture is then concentrated by distillation. Distillation also makes it possible to concentrate the lees alcohols. The concentrated alcohols from the pomace and lees are ultimately rectified to produce an extra-neutral alcohol with an alcoholic strength greater than

96%. Grape alcohol is therefore an “upcycled” alcohol, because it comes only from wine biowaste in accordance with circular-economy precepts. This alcohol from the major French wine terroirs (Burgundy, Rhône Valley, Provence, Bordeaux, etc.) does not present any land-use conflicts regarding food production and can even come from certified-organic crops.

In 2024, French production of neutral grape alcohol will total more than 50,000 hectoliters. Grape alcohol is therefore relatively available for use in perfumery. To qualify for such use, however, it must satisfy two essential criteria:

1) present a positive environmental footprint compared to French alcohol made from sugar beets or other major field crops;
2) possess the olfactory properties that perfumers expect and be free of any sensory defects.

To assess the olfactory properties of the extra-neutral grape alcohol developed by the Union des Distilleries de la Méditerranée (UDM Group) and marketed under the Uveol® brand, a comparative sensory study with sugar beet and wheat alcohols was conducted, the results demonstrating the following key points (publication in progress) :

- A RATA (rate-all-that-apply) analysis, which made it possible to describe and discriminate between the three alcohols studied, showed significantly that grape alcohol is comparatively fruitier than sugar beet and wheat alcohols and tends to have aquatic and yeasty notes.
- Triangle tests carried out on 10 perfumery raw materials diluted in the three alcohols separately showed that there is no significant difference in the 10 materials when tested in grape alcohol and sugar beet alcohol, and that the grape alcohol typicity does not alter the odor of the materials tested.
- An olfactory time-intensity analysis showed that extra-neutral grape alcohol does not significantly alter the diffusion of the three notes tested (top, heart, and base notes).

Given the positive nature of the olfactory study of extra-neutral grape alcohol, we believed it was vital to evaluate its environmental impact with a life cycle analysis (LCA). Such a study was performed on the extra-neutral grape alcohol Uveol® developed for perfumery by the Union des Distilleries de la Méditerranée (UDM Group).

The objective of this LCA is to assess the environmental impacts of the production of 96% neutral alcohol from the distillery at the Vauvert site (Provence-Alpes-Côte d’Azur region). The calculation methods and database are those of the Product Environmental Footprint (PEF) and version v3.9.1 of ecoinvent® [6], respectively. The boundary applied will be gate-to-gate at the UDM Group. The results will be evaluated in light of the LCI [7] data on the climate change indicator for sugar beet alcohol available in the ecoinvent® database.

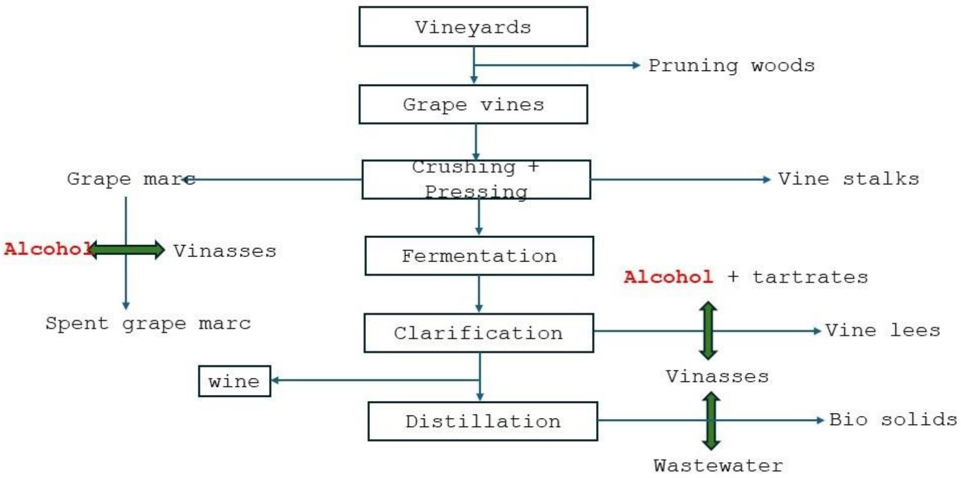

Fig. 1. Biorefinery of wine-making byproducts (adapted from Jin & Kelly [8])

Wine distilleries, in collaboration with the wine industry, have been established in France for more than a century and have historically focused on avoiding the overpressing of grapes and excessive filtration of wine lees [9]. The distillation of wine byproducts makes it possible to control the quantity and quality of wines, address customs regulations, and combat fraud.

Distillation of these byproducts also eliminates the potential impacts of soil and water pollution that could result from poor management of grape pomace and wine lees. Such impacts are primarily due to Chemical Oxygen Demand (COD) and Volatile Organic Compound (VOC) emissions [10].

While performance can be influenced by weather variations and unforeseeable climatic factors, several studies have confirmed the role of wine estates in carbon storage. Like forests, perennial crops such as grapevine vineyards can potentially store substantial quantities of carbon: Depending on the soil typology, studies suggest these quantities can range from 134 g C/m^2 to 900g C/m^2 per year [11,12] In comparison, the annual storage of sugar beet cultivation ranges from 100 to 150 g C/m^2 [13,14].

Winemaking byproducts (pomace, lees, and finer residues known as *bourbes*) must therefore be disposed of. Up until 2014, the only authorized recovery method was distillation [15].

In 2022, sources for French bioethanol production were mainly grains (63%) and sugar beets (33%). Pomace and lees constituted only 4% of this production, half of which was imported [16]. The main uses of bioethanol remain incorporation into fuels, food (i.e., potable alcohol), and industrial uses (i.e., hygiene, pharmacy, chemistry).

The UDM Group distillery collects winemaking byproducts – grape pomace and wine lees – from wine cooperatives and wine cellars/merchants located within a 40-kilometer radius around the Vauvert site. The data gathered and calculated by the UDM Group for the 2022-2023 campaign indicates collection of approximately 55,600 tons of grape pomace and wine lees, for an ultimate production of pure raw alcohol amounting to approximately 25,000 hectoliters [17].

The Functional Unit (FU) defines the focus of any LCA study. All calculations, analyses, and comments depend on this parameter, bearing in mind that all inputs and outputs of the LCI are tied to the functional unit in accordance with the current applicable standard (cf. NF EN ISO 14040).

The FU for this LCA is as follows: “Production of one hectoliter of 96% pure neutral alcohol for use in perfumery.” Unlike an ethanol used for energy, this alcohol is purified after undergoing rectification so as to satisfy the quality criteria of the fragrance industry.

2. METHODOLOGY

The LCA was carried out per the methodology of the ISO 14040:2006 and 14044:2006 series as established by the International Organization for Standardization (ISO).

2.1 Status of Grape Pomace and Wine Lees

The first methodological decision to be made for an LCA in the agricultural sector is whether it is appropriate to take upstream agricultural factors into account in the life cycle, in this case the winegrowing and winemaking stages responsible for the production of grape pomace and wine lees.

In this study, grape pomace and wine lees are considered waste and, as such, the upstream winegrowing and winemaking/marketing channels are well outside the study’s scope.

This decision is based chiefly on two factors, summarized as follows:

- **With respect to regulations**:

French decree 2014-903 of August 18, 2014 [18] establishes producers’ obligation to: “[…] meet their obligation to eliminate all residues from winemaking or any grape processing operation in compliance with regulations relating to environmental protection and marketing of fertilizing materials and growing media.”

With respect to standards: In standard EN 18027:2023 [19] (§B6) [20], it is clearly set forth that “if a residue does not have economic value, it should be considered as a process waste stream and not affect the upstream process load.” The non-economic value of winemaking residues is established by the Fédération Nationale des Distilleries Coopératives Viticoles (FNDCV) [21].

2.2 Status of Winemaking Byproducts

Production of raw alcohol in distilleries leads to production of a number of byproducts, essentially seeds, pulps, calcium tartrate, fertilizers, and compost. Great care was taken during collection of specific data for the LCA to identify only the inputs and outputs necessary and essential for the production of raw alcohol and subsequent processing into pure neutral alcohol. We are referring here to the subdivision of processes, making it possible to isolate only the environmental loads relating to our FU and thereby avoiding having to resort to mass, energy, or economic allocations.

It should be emphasized that by opting for subdivision of processes, we are choosing not to take into account the benefits and avoided production of the raw alcohol byproducts recovery. It should nevertheless be reiterated that this method used by Quantis in the reference LCA [22] clearly demonstrated the benefits of distillation by virtue of the avoided impacts.

2.3 System Boundaries

The boundaries of the system studied in the LCA can be defined as: from the "gate" of the wine cooperatives/cellars to the "gate" of the UDM distillery.

This scope encompasses the four main production stages:

1. **The stage of collecting:** grape pomace and wine lees from wine producers and transporting (TSP) them to the Vauvert site.
2. **The stage of stocking in units (STK) and handling:** grape pomace during the silage process using construction equipment (e.g., loader).
3. **The stage of production of pure raw alcohol,:** which entails these processes:
   - Processing the ensiled grape pomace (TT1).
   - Distilling the silo juices (TT2).
   - Distilling the wine lees (TT3).
4. **The stage of producing pure neutral alcohol:** requiring a process of:
   - Rectification (TT4).

These various stages are illustrated in the following diagram.

Once the pure neutral alcohol is on the market, the heterogeneous nature of its uses does not allow for identification of a specific type of packaging, packaging which is also common to pure alcohols from other origins. No packaging was modeled in this study.

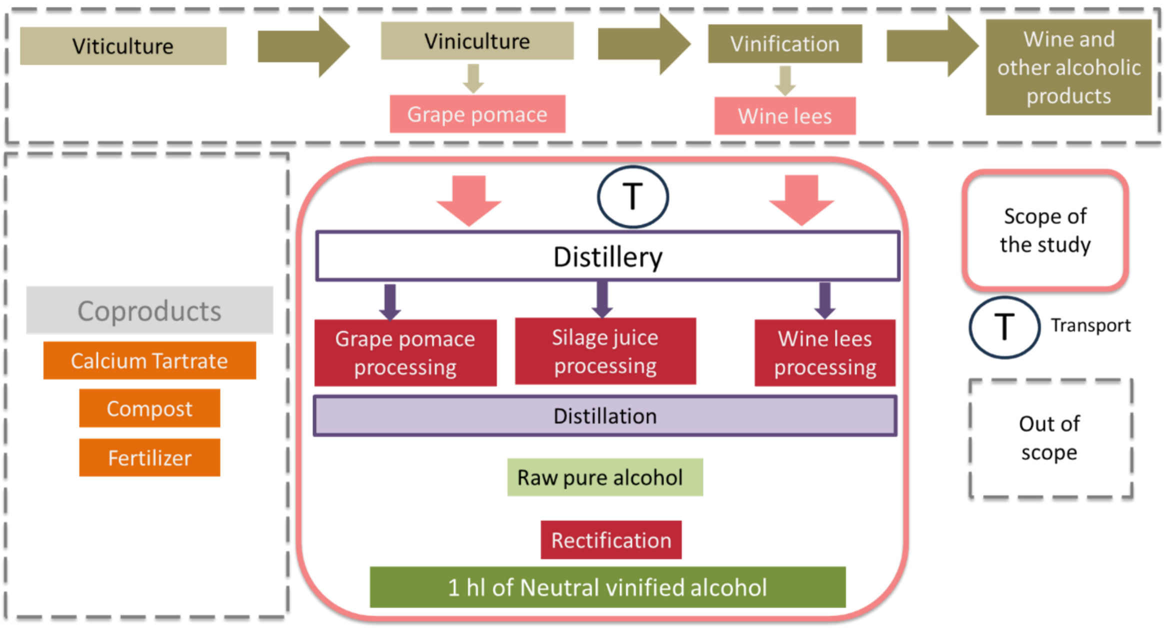

Fig. 2. Study scope

2.4 Calculation Method

The LCA was carried out with the recent versions of the calculation tool and databases, which were SimaPro v9.5 and the ecoinvent® v3.9.1 database, respectively.

This study was conducted in the methodological context of “Situation A: Micro-level decision support” of the ILCD Handbook, namely an “attributional” approach.

The calculations are based on the “EF Method 3.0,” a method developed by the European Commission as part of the Product Environmental Footprint (PEF) program with an assessment of greenhouse gas (GHG) emissions at 100 years. This method takes into account the 16 categories of indicators and models recommended by the ILCD [23].

2.5 Data Collection

The UDM Group’s internal data covers the period 2022-2023. Those specific to grape pomace are from autumn 2022, as this substance is rapidly transported to the distillery after the harvest has been pressed. The data on wine lees are also for the 2022-2023 period, bearing in mind that lees are produced throughout the winemaking process, which can last several months.

Once collected, the Vauvert site takes control of the pomace and lees as they begin the fermentation and distillation processes.

2.5.1 TSP - collection stage

The calculation of transport data for pomace and lees during the 2022-2023 harvest was done using the postal codes of cooperatives and wine cellars coupled with the quantities collected and the number of collections (approximately 140 for the pomace and approximately 200 for the lees).

The collection of pomace and lees is done within an average radius of approximately 40 kilometers around the Vauvert site (Fig. 3). All transportation over the course of a year results in an average ratio of 7.295 t/km per hectoliter of pure neutral alcohol.

2.5.2 STK - stocking stage

This stage entails stocking the grape pomace in large silage units. The use of large construction machinery (e.g., loader, bulldozer) is required and necessarily results in consumption of off-road diesel (ORD) fuel. The silage stage also makes it possible to recover the “silo juice,” which will subsequently be distilled.

Using a ratio of 0.29 liter of ORD per ton of pomace, and taking into account the portion dedicated to the stocking stage alone, we can establish a consumption of 0.52 liter of ORD per hectoliter of raw alcohol.

The wine lees are stocked independently as they are delivered to the site.

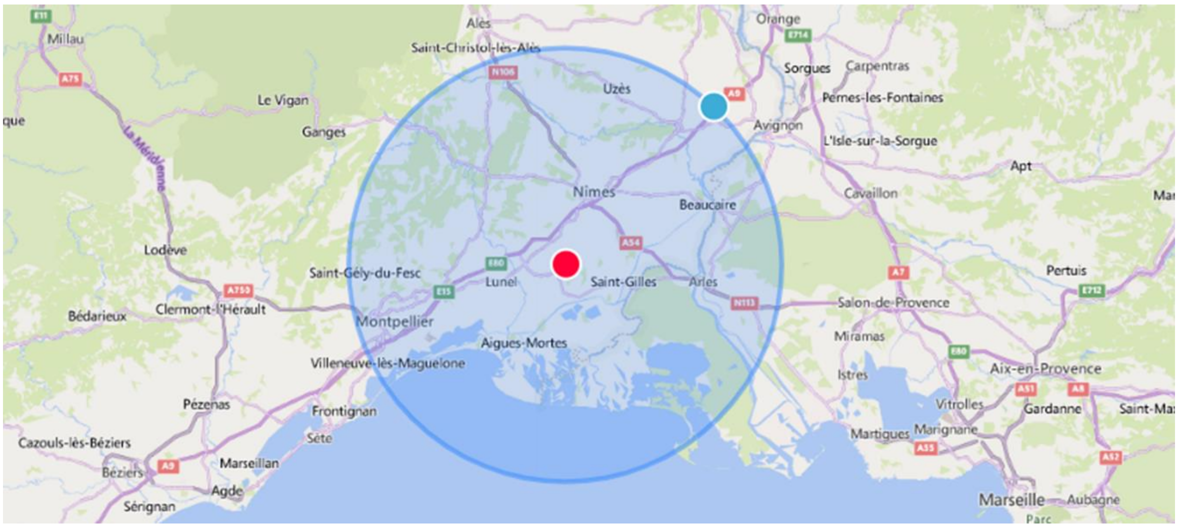

Fig. 3. Collection area of grape pomace and wine lees by the UDM Group [24]

2.5.3 Production stages - TT1-TT4

Once the pomace and lees are managed on the site, the production of 96% pure neutral alcohol then involves four distinct processes, grouped into two main stages:

- **Stages TT1 to TT3:** obtaining 92% pure raw alcohol.
  - Processing the “silaged pomace”: extraction technique on a distribution belt and distillation.
  - Processing the “silo juice”: fermentation and distillation technique.
  - Processing the wine lees: distillation technique.
- **Stage TT4:** obtaining 96% pure neutral alcohol.
  - Processing the raw alcohol: the water-alcohol mixture recovered at the extractor outlet then undergoes a distillation-rectification process.

2.6 Data Specific to the Production of 96% Neutral Pure Alcohol

In addition to the above-mentioned consumption of ORD, production of our Functional Unit entails energy and water consumption throughout the technical phases.

2.6.1 Energy consumption

Distillation is an activity that intrinsically uses significant amounts of energy: from processing the pomace to the final production of the pure, purified alcohol. To this end, the UDM Group uses two sources of energy:

- Network-sourced natural gas.
- Biomass to produce heat in the form of steam: the biomass used is wood chips.

With respect to heat production, and so as to be able to identify and correctly inform the LCIs of these two energy sources, we have determined the average distribution between “gas” and “biomass” energies for the 2021-2023 campaigns as follows [25]:

- For natural gas: 76%
- For wood: 24%

For conversions into kWh, the average Lower Calorific Value (LCV) used per ton of wood is 3,850 kWh, with a moisture content of 25%.

2.6.2 Water consumption

The net water consumption is the result of two phenomena: first, gross consumption on the distribution belt during processing of the silaged pomace and, second, during recovery of the condensates from evaporators coupled to the distillation column. The overall consumption for one hectoliter of pure neutral alcohol ultimately turns out to be negative (approximately -1 cubic meter). Nevertheless, considering the high degree of uncertainty in the calculations due to measurement challenges, we have used (kept ?) the gross consumption in the LCA inventory.

2.6.3 Life Cycle Inventory (LCI) data

To meet the Functional Unit, the reference flows for each process were established using the BOM (Bill of Material) provided us by the Technical & QHE department of the UDM Group. The objective is to associate the reference flows with the ecoinvent® LCI database to calculate the inventory. These reference flows shown in Table 1 have been grouped in such a way as to preserve a degree of confidentiality concerning the company's production process.

Table 1. Inventory data for the production of one hectoliter of pure neutral alcohol

BOM : 1 hl of Neutral vinified alcohol	Gas consumption	Water consumption	Off-road diesel	Electricity consumption	Transport
	MWh PCI	m3	liters	kWh	t/km
Grape marc and wine lees transportation to the Vauvert distillery					7,295
Storage of grape marc in fermentation cell			0,584		
Set of 4 Treatment of grape marc and wine lees	0,748	1,581	0,909	31,313	
Total: BOM for 1 hl of Neutral vinified alcohol	0,748	1,581	1,493	31,313	7,295

3. RESULTS AND DISCUSSION

3.1 Overall Environmental Assessment

The environmental impacts of a "hectoliter of neutral 96% pure alcohol for use in perfumery" resulting from the upcycling of grape pomace and wine lees were assessed for each stage of production as well as per the inputs involved.

3.1.1 Results by "Production stage"

Table 2 illustrates the results in "Single Score" (SS). This score is based on the weighting and standardization of the results: a weighted average, expressed in millipoints (mPt), of the 16 indicators of the European PEF methodology [26].

Thus, for the production of our FU, it is quite clear that three damage categories total 75% of all 16 indicators:

- Particulate matter
- The use of fossil resources
- Climate change

We can also see that the "Processing of silaged pomace" stage alone encompasses ±64% of the impacts of all production processes. The final rectification stage to obtain neutral alcohol follows with 22% of the SS.

3.1.2 Results by "Input"

An alternative approach to assessing environmental impacts involves taking into account the inputs necessary for production of the FU. As is evident, the most-impacted damage categories are logically identical to those of the stage-by-stage approach [27].

More than 90% of environmental impacts can be explained by energy consumption, excluding transportation. The emission of particulate matter (PM) comes almost exclusively from the use of wood for heat production. Gas more specifically impacts the fossil resource consumption indicator. Lastly, these three energy sources have a combined impact on GHG emissions (Table 3).

3.1.3 Climate change potential

The production of one hectoliter of pure neutral alcohol from recycling grape pomace and wine lees emits approximately 43 kg of CO_2e, i.e. approximately 0.430 kg per liter or 0.530 kg per kilogram of alcohol using a l/kg ratio of 0.81.

Fig. 4 illustrates in absolute value the breakdown of inputs on the climate change indicator. The consumption of natural gas in all stages of production generates 77% of total GHG emissions.

3.1.4 Particulate matter emissions

Unlike the advantages in terms of GHGs generated by using wood resources, such use contributes significantly to particulate matter emissions. This means that, while the biomass only contributes to 24% of heat production, it is responsible for 96% of the impacts of this indicator.

3.1.5 Use of fossil resources

Unsurprisingly, 94% of the "Use of fossil resources" indicator comes from the life cycle of natural gas (78%) and, to a lesser extent, from the production of the French electricity mix.

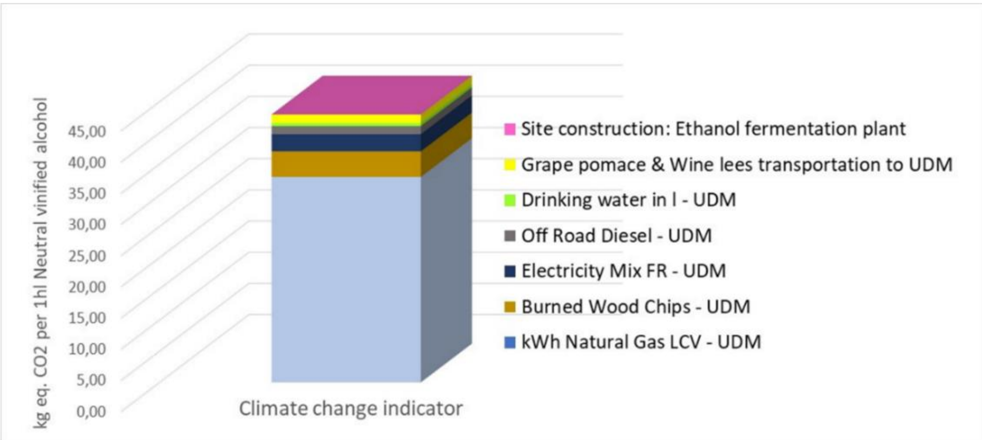

Fig. 4. Breakdown of GHG emissions by inputs for 1 FU

Table 2. LCA results in Single Score of the FU by stage

Impact categories	Unit	Grape pomace processing	Rectification: 1hl Neutral vinified alcool	Wine lees processing	Silage juice processing	Grape pomace & Wine lees transport to UDM	Site construction: Ethanol fermentation plant	Total	Relative share of damage categories
Particulate matter	mPt	2,17E+00	7,77E-01	3,40E-01	1,53E-01	1,68E-02	5,83E-06	**3,46E+00**	**33,83%**
Resource use, fossils	mPt	2,00E+00	6,48E-01	2,65E-01	1,17E-01	2,49E-02	4,12E-06	**3,06E+00**	**29,95%**
Climate change	mPt	7,54E-01	2,53E-01	1,07E-01	4,78E-02	3,81E-02	1,21E-05	**1,20E+00**	**11,74%**
Water use	mPt	2,94E-01	1,73E-01	3,61E-02	2,01E-02	5,89E-04	6,33E-07	**5,24E-01**	**5,13%**
Photochemical ozone formation	mPt	2,84E-01	9,54E-02	4,12E-02	1,85E-02	9,67E-03	2,09E-06	**4,48E-01**	**4,39%**
Resource use, minerals and metals	mPt	1,86E-01	5,15E-02	1,68E-02	6,74E-03	5,23E-03	3,63E-05	**2,66E-01**	**2,61%**
Acidification	mPt	1,47E-01	5,02E-02	2,10E-02	9,36E-03	6,30E-03	3,80E-06	**2,34E-01**	**2,29%**
Ionising radiation	mPt	1,66E-01	3,97E-02	1,00E-02	3,43E-03	3,09E-04	2,93E-07	**2,20E-01**	**2,15%**
Land use	mPt	1,11E-01	3,98E-02	1,74E-02	7,82E-03	1,12E-03	1,82E-06	**1,78E-01**	**1,74%**
Eutrophication, terrestrial	mPt	1,08E-01	3,80E-02	1,64E-02	7,33E-03	4,83E-03	1,14E-06	**1,75E-01**	**1,71%**
Eutrophication, marine	mPt	7,16E-02	2,49E-02	1,06E-02	4,76E-03	3,26E-03	7,26E-07	**1,15E-01**	**1,13%**
Human toxicity, non-cancer	mPt	7,25E-02	2,42E-02	9,57E-03	4,22E-03	1,96E-03	3,64E-06	**1,12E-01**	**1,10%**
Eutrophication, freshwater	mPt	5,99E-02	2,00E-02	7,61E-03	3,36E-03	1,67E-03	3,87E-06	**9,26E-02**	**0,91%**
Ecotoxicity, freshwater	mPt	5,52E-02	1,60E-02	6,65E-03	2,95E-03	3,25E-03	1,83E-06	**8,40E-02**	**0,82%**
Human toxicity, cancer	mPt	2,80E-02	9,92E-03	3,99E-03	1,79E-03	7,70E-04	1,51E-06	**4,44E-02**	**0,43%**
Ozone depletion	mPt	5,08E-03	1,78E-03	7,74E-04	3,47E-04	3,60E-05	4,56E-09	**8,02E-03**	**0,08%**
		6,52E+00	**2,26E+00**	**9,11E-01**	**4,08E-01**	**1,19E-01**	**7,97E-05**	**1,02E+01**	**100%**
		63,8%	**22,2%**	**8,9%**	**4,0%**	**1,2%**	**0,001%**	**100,0%**	

Table 3. LCA results in Single Score of the FU by input

Impact categories	Unit	Burned Wood Chips - UDM	kWh Natural Gas LCV - UDM	Electricity Mix FR - UDM	Drinking water in l - UDM	Off Road Diesel - UDM	Grape pomace & Wine lees transport to UDM	Site construction: Ethanol fermentation plant	Total	Relative share of damage categories
Particulate matter	mPt	3,33E+00	7,10E-02	2,83E-02	2,88E-03	2,76E-03	1,68E-02	5,83E-06	3,45E+00	**34,4%**
Resource use, fossils	mPt	6,72E-02	2,39E+00	4,78E-01	7,76E-03	8,10E-02	2,49E-02	4,12E-06	3,05E+00	**30,4%**
Climate change	mPt	1,14E-01	9,18E-01	7,67E-02	9,46E-03	3,64E-02	3,81E-02	1,21E-05	1,19E+00	**11,9%**
Photochemical ozone formation	mPt	1,82E-01	2,25E-01	1,21E-02	1,48E-03	1,66E-02	9,67E-03	2,09E-06	4,47E-01	**4,5%**
Water use	mPt	2,43E-03	2,12E-02	7,56E-03	3,43E-01	7,27E-04	5,89E-04	6,33E-07	3,76E-01	**3,7%**
Resource use, minerals and metals	mPt	3,69E-02	6,70E-02	1,53E-01	2,11E-03	6,17E-04	5,23E-03	3,63E-05	2,65E-01	**2,6%**
Acidification	mPt	1,07E-01	9,31E-02	2,14E-02	2,06E-03	3,01E-03	6,30E-03	3,80E-06	2,33E-01	**2,3%**
Ionizing radiation	mPt	1,13E-02	5,76E-03	2,00E-01	1,52E-03	2,79E-04	3,09E-04	2,93E-07	2,19E-01	**2,2%**
Land use	mPt	1,71E-01	3,23E-03	1,81E-03	1,28E-04	3,22E-04	1,12E-03	1,82E-06	1,77E-01	**1,8%**
Eutrophication, terrestrial	mPt	1,04E-01	5,68E-02	6,38E-03	7,25E-04	1,63E-03	4,83E-03	1,14E-06	1,75E-01	**1,7%**
Eutrophication, marine	mPt	6,62E-02	3,78E-02	5,62E-03	5,45E-04	1,35E-03	3,26E-03	7,26E-07	1,15E-01	**1,1%**
Human toxicity, non-cancer	mPt	5,93E-02	2,58E-02	2,03E-02	2,79E-03	1,08E-03	1,96E-03	3,64E-06	1,11E-01	**1,1%**
Eutrophication, freshwater	mPt	2,61E-02	3,83E-02	2,01E-02	3,90E-03	7,81E-04	1,67E-03	3,87E-06	9,08E-02	**0,9%**
Ecotoxicity, freshwater	mPt	1,70E-02	4,60E-02	7,73E-03	5,24E-04	9,07E-03	3,25E-03	1,83E-06	8,37E-02	**0,8%**
Human toxicity, cancer	mPt	1,71E-02	1,94E-02	4,05E-03	1,84E-03	3,43E-04	7,70E-04	1,51E-06	4,36E-02	**0,4%**
Ozone depletion	mPt	7,66E-05	7,63E-03	1,37E-04	1,15E-05	1,15E-04	3,60E-05	4,56E-09	8,00E-03	**0,1%**
		4,31E+00	**4,03E+00**	**1,04E+00**	**3,81E-01**	**1,56E-01**	**1,19E-01**	**7,97E-05**	**1,00E+01**	**100%**
		43,0%	**40,1%**	**10,4%**	**3,8%**	**1,6%**	**1,2%**	**0,001%**	**100,0%**	

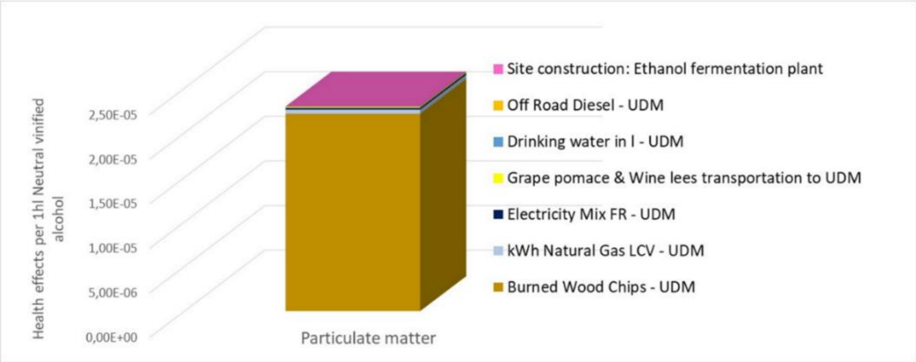

Fig. 5. Breakdown of the health effects indicator by inputs for 1 FU

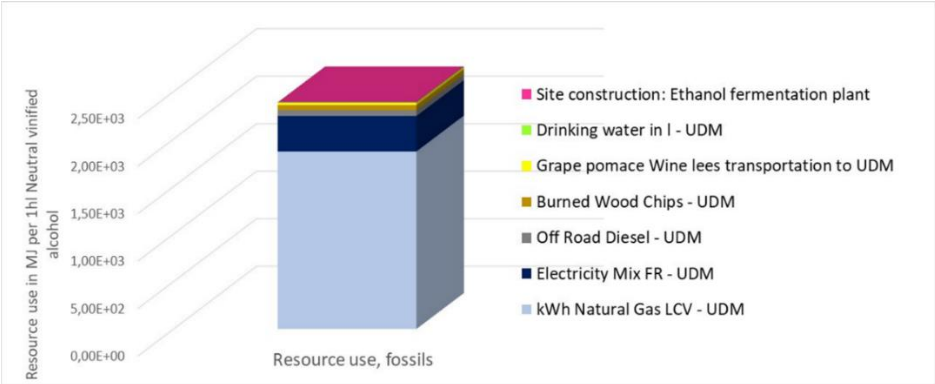

Fig. 6. Breakdown of fossil resource usage by inputs for 1 FU

4. COMPARISON WITH SUGAR BEET ALCOHOL

As mentioned in the introduction, alcohol made from sugar beets is still very widely used in perfumery today. In light of this widespread use, we have demonstrated the olfactory qualities of alcohol produced from the distillation of grape pomace and wine lees. Its comparative environmental performance remains to be demonstrated.

In the absence of specific data for the production of alcohol from sugar and molasses resulting from the processing of sugar beets, the LCA results for the alcohol of the UDM Group will be compared to those of the sugar beet alcohol (specifically in the form of ethanol) calculated using the LCIs from the ecoinvent® database [28].

4.1 Sugar Beet Alcohol: Finished Product, Coproduct, or Byproduct?

Viewing ethanol as a product in its own right, it is entirely justified to include upstream agriculture in the scope of the LCA. Demonstrating its byproduct status is more complex and taking upstream agricultural factors into account would then meet allocation criteria that are often complex to set.

The status of sugar beet alcohol can therefore change: It can be considered a finished product in its own right if it comes from:

- a first pressing of “green juice”;
- a first crystallization; or
- a second crystallization [29].

Alcohol, being produced from a third crystallization, is indeed a byproduct, in this case resulting from the fermentation of the molasses itself resulting from this third crystallization.

Furthermore, the methods chosen by industrial processors of “green juice” (sugar beet pressing), whether crystallization or fermentation, remain confidential: These choices depend on fluctuations in raw material and energy prices. For the record, the agricultural upstream of the production of 96% pure neutral alcohol from the UDM Group (i.e. winegrowing and winemaking) was excluded for the reasons given in §3.1. In the context of this study, we feel it is logical to associate sugar beet cultivation with the LCIs of ethanol as modeled in ecoinvent®.

Table 4. Comparison of GHG emissions of alcohol production from grapes and from sugar beets

ICV from ecoinvent®	GHG emissions in kg CO_2e per kg ethanol
"1 kg Ethanol, without water, in 95% solution state, from fermentation {CH}| ethanol production from sugar beet | Cut-off, U"	0,388
"1 kg Ethanol, from sugar beet molasses, animal feed, at plant {FR} U" (AGRIBALYSE project - unit)	0,518
"Production of 1 kg of neutral alcohol 96% at UDM": ratio l/kg of 0.81	0,530
"1 kg Ethanol, without water, in 95% solution state, from fermentation {CH}| ethanol production from sugar beet molasses |Cut-off, U"	0,682

4.2 A Comparative Result: "Grape" vs. "Sugar Beet"

Lacking primary data to conduct an LCA specific to French alcohol production from the distillation of sugar beet juice, we must rely on the ecoinvent® database, in which there are several life cycle inventories (LCI) relating to ethanol production.

The three LCIs selected feature scenarios similar to a French, at least European, reality. The following Table 4 shows the results of these LCIs, as well as that of our FU for the "Climate Change" indicator.

We can see that the GHG emissions from the production of pure neutral alcohol by the UDM Group compare fairly positively to those from production of ethanol from sugar beets (Table 4). Furthermore, we do not know to what extent the rectification step is integrated into the ecoinvent® LCI data. As we have pointed out, this stage involves significant energy consumption, especially for obtaining an alcohol which requires optimized purity.

5. CONCLUSION

Using a conservative scenario, factoring in all the processed data and information, and taking into account the inherent uncertainty in agro-environmental models in constructing life cycle inventories (LCI), we can nevertheless ensure that the environmental impact of the UDM's production of pure neutral alcohol is positively comparable with alcohol from the distillation of sugar beet juice, more specifically in the following ways:

- Greenhouse gas emissions per hectoliter of 96% neutral pure alcohol are comparable or lower when considering the "size" element of ethanol production sites, which are in no way comparable (25,000 hl/ year for the Vauvert distillery versus 1,000,000 hl/year for the average distillation capacity of sugar beet alcohol production facilities).
- A raw-material-collection area that is geographically limited to a radius of approximately 40 kilometers.
- Sustainable management of winemaking wastes classified as soil pollutants (COD, VOC).
- As grape pomace and wine lees are inedible, they have no impact on food-resource availability.
- Collaboration with the winegrowing and winemaking worlds and closed-loop production of recoverable byproducts in the wine industry: compost, fertilizer, TCA, etc.
- Grapevines in the form of vineyards, unlike field crops, constitute significant carbon sinks, much in the same way forests do.

Naturally, one should also consider the intrinsic quality of the "product" – extra-neutral grape alcohol for use in perfumery.

While bearing in mind the distortions inherent in the calculations of environmental impacts (i.e. specific production data for a UDM Group site and weighted LCI modeling of an agro-industrial activity for sugar beet alcohol), extra-neutral grape alcohol remains unquestionably efficient in terms of greenhouse gas emissions. Here we should emphasize the production capacity differential (factors of 20 to 40) and the resulting effects of economies of scale to the advantage of sugar beet distilleries. Lastly, we wish to highlight "non-LCA" arguments, such as the technical and economic complementarities of the

UDM Group with local wine producers and grape alcohol's intrinsic olfactory qualities.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. SDG Indicators - Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. Available:https://unstats.un.org/sdgs/indicators/indicators-list/
2. Green Chemistry Compass. Available:https://ifrafragrance.org/priorities/ifra-green-chemistry-compass
3. Quelles solutions pour l'Alcool Durable en Parfumerie? What Solutions for Sustainable Alcohol in Perfumery? Premium Beauty News. 2024;8-11.
4. Latieulle S. Chine: Inauguration de la première installation industrielle de Lanzatech. China: LanzaTech opens its first industrial installation. Formule Verte; 2018. Available:https://www.formule-verte.com/chine-inauguration-de-la-premiere-installation-industrielle-de-lanzatech/
5. Managing By-Products of Vitivinicultural Origin. International Organisation of Vine and Wine (OIV). 2018;4-16.
6. The ecoinvent® database is considered by the profession to be the world's leading source of life cycle inventory data.
7. LCI: Life Cycle Inventory
8. Jin B, Kelly JM. Biotechnology for Agro-Industrial Residues Utilisation. Chapter 15. Wine Industry Residues. Springer Science+Business Media B.V. 2009;293-310. DOI: 10.1007/978-1-4020-9942-7.
9. ACYVIA methodological framework,"Choix méthodologiques spécifiques à la filière sous-produits vinicoles et distillats de vin / eau de vie de vin. Methodological choices specific to the winemaking byproducts and wine distillates/wine brandy sector"], Appendix #11, UNGDA; 2016.
10. VOC emissions from raw marc are 850 times and 2,350 times greater, respectively, in spreading and composting than in distillation. Source: Itinéraires, Marcs de raisins, lies de vin et bourbes : Quelle gestion des sous-produits vinicoles? Grape marc, wine lees: How should wine byproducts be managed? 2013;25.
11. Pitacco A, Meggio F. Carbon budget of the vineyard - A new feature of sustainability", In Proceedings of the 38th World Congress of Vine and Wine, BIO Web of Conferences 5:01024; 2015.
12. Nadia Vendrame *et al.* Study of the Carbon Budget of a Temperate-Climate Vineyard: Inter-Annual Variability of CO2 Flux. Am. J. Enol. Vitic. 2019;70:1.
13. *Perspectives Agricoles*, "Evaluer l'évolution du statut organique des sols. Evaluating the evolution of the organic status of soils"], No. 466, May 2019.
14. Institut Technique de la Betterave. Bilan carbone de la betterave sucrière : Pistes d'amélioration. Carbon footprint of sugar beet: Avenues for improvement; 2022 Available:https://www.itbfr.org/tous-les-articles/article/news/bilan-carbone-de-la-betterave-sucriere-pistes-damelioration/.
15. IFV. Expérimentation nationale sur la valorisation des sous-produits vinicoles : Marcs de raisins, lies de vin et bourbes : Quelle gestion des sous-produits vinicoles? National experiment on recycling wine byproducts: Grape marc, wine lees: How are wine byproducts managed? Itinéraires. 2013;25.
16. France AgriMer, annual industry report, "Bioéthanol"; 2024. Available:https://www.franceagrimer.fr/content/download/72953/document/20240201_FICHE_FILIERE_BIOETHANOL_2024.pdf
17. Also includes "silo juices."
18. Ibid.#8
19. EN 18027:2023. Produits biosourcés — Analyse du cycle de vie — Exigences et lignes directrices supplémentaires concernant la comparaison des cycles de vie de produits biosourcés avec leurs équivalents d'origine fossile. Bio-sourced products — Life cycle assessment — Additional requirements and guidelines for comparing the life cycles of bio-sourced

products with their fossil-sourced equivalents.
20. §B6: Recommendations on using residues and waste as raw materials.
21. Available:https://fndcv.fr/economie/chiffres-daffaires/
22. Ibid. #14
23. Per: Fazio S, Castellani V, Sala S, Schau EM, Secchi M, Zampori L. Supporting information to the characterisation factors of recommended EF LCI Assessment methods. European Commission, Ispra; 2018.
24. Source:https://www.calcmaps.com/fr/map-radius
25. The breakdown of energy sources is based on numerical data provided by the UDM Group.
26. Available:https://pre-sustainability.com/articles/weighting-applying-a-value-judgement-to-lca-results/
27. The difference of only around 0.1% on average on the 16 indicators is due to rounding in the calculations.
28. The ecoinvent® database is the international leader in the realm of LCA data.
29. Experts are nevertheless still debating this point.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/119267