DOMECCO - Development of Environmental Management Tools for the Charente COgnac sector To support changes in winegrowing practices and increase corporate social responsibility (CSR)

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DOMECCO - Development of Environmental Management Tools for the Charente COgnac sector *To support changes in winegrowing practices and increase corporate social responsibility (CSR)*

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Abstract

The aim of the DOMECCO project (2019-2022) was to equip the Cognac sector's environmental management approach with life cycle analysis (LCA) tools and indicators.

Following an analysis of needs, data and existing tools, two simplified calculation tools were developed. One was a pre-existing, Vit'LCA®, for viticulture and the other, DistCo'LCA, was developed *ex nihilo* for distillation. Two case studies were worked on, based on a field trial of soil management and on survey data at Protected Designation of Origin (PDO) level: vineyard soil management and distillation. Life cycle analyses were carried out for each case study, in order to characterize the impacts and contribute to the development of calculation tools.

A participatory eco-design workshop was organised with the appellation stakeholders to redesign low-impact herbicide-free soil maintenance on the basis of the LCA results, enabling them to discover the LCA and eco-design approach.

At the end of the project, the sectorial eco-design levers have been identified, databases have been structured and fed at PDO level to carry out LCAs, and the LCA calculation tools are operational. However, some tools and indicators still need to be completed thanks to new research in order to provide better support for the sector.

Keywords: life cycle assessment, soil management, distillation, serious game, streamlined calculation tool, Cognac

1. Introduction

The European Union has included the "*Farm to fork"* strategy (action programme up to 2030) for "fair, healthy and environmentally friendly food systems" (Hanna Schebesta *et al.*, 2020) and a transition to sustainable agriculture (Langlais, 2023) in its latest environmental policy for 2020, the "*Green deal"*. These institutional factors and public expectations (Zollet and Maharjan, 2021) are leading winegrowing interprofessions to develop an environmental component in their strategy.

Since 2009, the Cognac sector has regularly carried out its Bilan Carbone© (carbon footprint) assessment. This single-criteria analysis of the sector's activities has enabled the identification of the highest emitting items.

The sector stakeholders felt that they lacked the tools to support their environmental management approach. The main aim of the "DOMECCO" project (2019-2022) was therefore to build an innovative and collective agro-ecological transition process on a regional scale, involving multiple partnerships, as part of the Cognac industry's CSR (Corporate Social Responsibility) approach. The project, led by the Bureau National Interprofessionnel du Cognac (BNIC), was supported by a consortium comprising a research laboratory (GRAPPE, ESA, USC INRAE), a technical institute (Institut Français de la Vigne et du Vin, pôle Sud-Ouest), the Syndicat des Bouilleurs de Professions de Cognac, an agricultural college (LEGTA - Lycée d'Enseignement Général et Technologique Agricole, L'Oisellerie) and an accountancy and business management centre (CER France). It was divided into 5 main actions, which were carried out successfully even if the pandemic context disrupted its operation:

1. Identification and construction of tools and indicators to support the environmental management approach
2. Testing tools for eco-design at local level
3. Development and implementation of the environmental management approach on a collective regional scale - Facilitation of participative workshops with stakeholders - Integration of relevant indicators into the CSR policy.
4. Publication of the results and training of stakeholders. Dissemination - communication
5. Steering and governance

Two case studies in particular were studied during the project and are the main focus of this article: vineyard soil maintenance and distillation.

2. Identification and construction of appropriate tools and indicators to support the environmental management approach

2.1. Diagnosis of needs

The Cognac sector has had an environmental approach in place for many years (Bilan Carbone©, environmental certification, etc.). As the BNIC had identified gaps in the assessment tools available, the DOMECCO project began by identifying and creating simple tools adapted to the specific needs of Cognac. A diagnosis was carried out to clarify the needs of the industry, combining a general analysis with an in-depth examination of uses (Lefeuvre *et al.*, 2020).

This diagnosis of uses took into account the decision-making processes of users in the face of problems, the constraints encountered when implementing solutions, and their understanding of biophysical processes. It also examined how users use existing tools. Three stages were followed: analysis of an existing situation, consideration of a wine-growing tool and consideration of a distillation tool.

Work with the user committee has continued despite the sanitary constraints in 2019-2020. To model cognac production techniques using Life Cycle Assessment (LCA), it was decided to continue developing a tool selected for viticulture and to develop a new tool for distillation.

2.2. Development of environmental assessment tools

For vines, the Vit'LCA tool ® (Renouf *et al.*, 2018a) was chosen and updated to assess practices in the Cognac Protected Designation of Origin (PDO). For distillation, no tool previously existed, necessitating the complete creation of a new calculation tool, DistCO'LCA.

2.2.1. Adaptation and development of the Vit'LCA tool®

2.2.1.1 Methods

Vit'LCA® is a Life Cycle Assessment (LCA) calculator developed by the GRAPPE research unit, which has adapted it for the Cognac sector as part of this project. Vit'LCA® aims to understand and reduce environmental impacts, compare the eco-efficiency of winegrowing practices and assess the environmental benefits of changing practices. The tool takes into account both background and foreground processes. By entering field data on 9 tabs, it calculates environmental impacts using LCA. To do this, it first performs so-called inventory calculations, including direct field emissions of nitrogen compounds, phosphorus compounds, pesticides and heavy metals, prior to impact calculations. Two functional units were available at the start of the project to express the impacts: per kg of grapes harvested and per hectare of vineyard cultivated for one year. Two LCA characterisation methods are available, ILCD 2011 (European Commission Joint Research Centre, 2010) and Recipe 2016 (Huijbregts *et al.*, 2016).

Although functional, Vit'LCA® needed to be developed further, to take better account of pesticide emissions, fuel consumption and water consumption, and to adapt to the specific situation of the Cognac vineyards, which are dedicated to the production of eau de vie.

2.2.1.2. Results

For the calculation of pesticide emissions, an abacus of emission factors for 1,110 scenarios specific to viticulture was calculated using the most recent version of the PestLCI model ® (Nemecek *et al.*, 2022). This considerably improved the accuracy of the calculations, allowing sensitivity to the type of sprayer, the presence of a buffer zone and the development of vine canopy. Fuel consumption calculations have also been improved by adjusting the formulas to take account of the load induced by towed implements. A new standardised presentation of the results makes it easier to compare with a benchmark, while the volumes of water used for spraying can be taken into account to assess the impact of the water source used. Initial modelling of electric machinery (tractors and robots) has been carried out. Finally, in order to meet the future needs of users and the industry in relation to environmental labelling, the LCA was reduced to the product unit (the functional unit hl AP (i.e., pure alcohol) per hectare produced in one year), commonly used in the appellation.

These developments are helping to make LCA results more robust, providing users with more accurate information for the environmental assessment of winegrowing techniques.

The Vit'LCA tool® was awarded a Bronze SIVAL at the SIVAL fair (Salon International de technologies des productions végétales) Innovations competition in 2023.

2.2.2 Building a simplified LCA calculator for distillation, DistCO'LCA

A new, simplified LCA calculator has been developed to make it easier for players in the Cognac sector to adopt the LCA approach.

2.2.2.1 Methods

Based on surveys, interviews and data provided by distillery suppliers, precise information was obtained on the various elements involved in the construction of a distillery, its stills and its operation. Calculations of the impacts of the various elements required to complete a distillation process were carried out in SimaPro® (Pré Consultants) using the ILCD 2011 characterisation method (impacts of 1 kg of copper, 1 kWh of electricity, etc.). The results were exported to DistCO'LCA developed on Excel®. Using this information and the impacts associated with materials/energy/rejects, calculated upstream using the ILCD 2011 method, DistCO'LCA will calculate the impacts per hectolitre of pure alcohol.

To facilitate the user experience, DistCO'LCA has been structured with different sheets. Users enter data relating to the systems studied (known as foreground data) in sheets such as: system definition, installation, combustion, cooling, water treatment and vinasse treatment. The results of the LCA are then displayed in secure sheets. DistCO'LCA has been designed to allow five alternatives to be modelled, compared with each other and a graphical interpretation output.

2.2.2.2 Results

When we wanted to go into more detail about the activities and elements used during distillation, new problems emerged:

- In terms of the completeness of the Ecoinvent (Wernet *et al.*, 2016) or Agribalyse® (Colomb *et al.*, 2014). Most refrigerants are absent as manufactured products;
- While the manufacture of stills and the origin of the copper used are easy to obtain, the end-of-life of stills is very poorly documented;
- The composition of cooling water treatment products is not indicated on suppliers' technical data sheets.

Testing the DistCO'LCA tool with cases modelled in the SimaPro® expert software has validated the results obtained with this new tool. DistCO'LCA makes it possible to compare different technical itineraries for the same site and to calculate the effects of technical changes (burners, etc.) or inter-annual variations.

Comparisons between different sites are also possible, but not completely relevant if precautions are not taken beforehand. Depending on the site, the scope of the data varies (water, electricity) and the characteristics of the refrigerants are not all available in the LCA databases for impact calculations.

The initial modelling was carried out using aggregated data (water, electricity, gas). A number of additions and changes were made during the course of the project, including the addition of wine transport data for distillers and the updating of data from new versions of the EcoInvent and Agribalyse® databases.

3. Soil maintenance practices and alternatives to chemical weeding

Like elsewhere in France, the study of vineyard soil maintenance practices and their alternatives in the Cognac PDO is becoming a priority due to regulatory changes linked to herbicides.

3.1 Assessment of soil maintenance practices at PDO level

3.1.1 Materials and methods

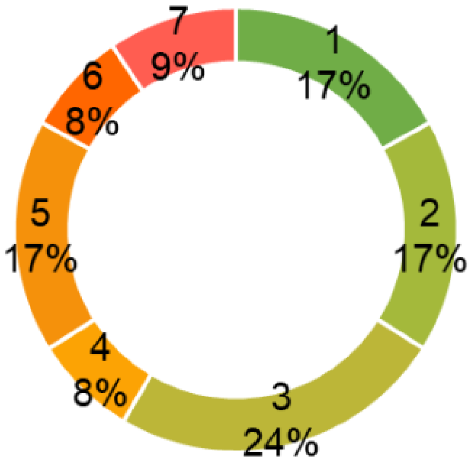
Since 1990, the BNIC's viticultural station has maintained an observatory of viticultural practices on 55 plots representing the appellation. This observatory provides a basis for extracting qualitatively and quantitatively the variables of interest for the LCA modelling of wine-growing pathways of technical operations (PTOs) in 2019. This approach included the creation of a database of practices from the multidimensional analysis observatory to produce a typology of soil maintenance PTOs, and the carrying out of LCAs on one case per type. The typology was determined by a multiple component analysis on 12 quantitative variables and 5 qualitative variables, followed by a hierarchical ascending classification, consolidated using the K-Means method (Renaud-Gentié *et al.,* 2014). For each group resulting from the typology, a paragon was identified as a test case for the LCA calculation by Vit'LCA®. To quantify the emissions and impacts, a life cycle inventory (LCI) was carried out on the test cases, involving the collection of field data and the use of the Vit'LCA tool®.

3.1.2.Results

The first result is the creation of a usable database of 53 plots to characterise practices at PDO level, which can continue to be added to each year to monitor changes in practices.

The database showed that most of the vineyard plots monitored were using chemical weed control under the rows in 2019. This observation prompted the users' committee to commission a study into the environmental performance of weed control methods in the context of the potential withdrawal of herbicidal active ingredients.

The typology identified 7 contrasting groups of soil maintenance techniques for the PDO, shown in Figure 1.



Group 1: One inter-row out of two weeded with disc and tines, the other inter-rows grassed; Rows weeded chemically (low dose) or mechanically.
Group 2: One inter-row out of two weeded with a harrow and tines, the other inter-rows weeded; Rows weeded chemically
Group 3: One inter-row out of two weeded with all tools, few passes, other inter-rows weeded; Rows chemically weeded
Group 4: One inter-row out of two weeded with discs, the other inter-rows grassed; Rows weeded chemically or mechanically.
Group 5: All inter-row weeds; Chemically weeded rows
Group 6: All inter-rows weeded with tines; Rows weeded chemically
Group 7: All inter-rows weeded with tines; Rows weeded mechanically.

Figure 1: Types of vineyard soil maintenance practices on a sample of 53 plots in the Cognac PDO in 2019.

The comparative LCA carried out with a paragon from each group shows strong contributions from the following elements, depending on the environmental criteria (Figure 2):

- The operation of diesel engines on the following potential impacts: global warming (Figure 2a), particulate emissions and the depletion of fossil fuels,
- Fertilisers, on the following potential impacts: soil acidification (Figure 2b), depletion of water resources, mineral resources and the ozone layer,

- Fertilisers and pesticides on the potential impacts of freshwater ecotoxicity and eutrophication (figure 2c and d), with different breakdowns between production and emissions,
- Pesticide emissions on potential marine and terrestrial ecotoxicities.

The LCA results (Figure 2) also show that some PTOs, such as 6 and 5, have a lower impact on most of the impacts, while others, such as 1 and 2, perform differently depending on the impact category. Finally, some itineraries, such as 3, have higher profiles for most of the impacts. These results need to be consolidated by a study of several vintages. It should be noted that the different fertilisation strategies of the itineraries evaluated play an important role in the differences observed between the itineraries in many impact categories, whereas fertilisation was not considered in building the typology.

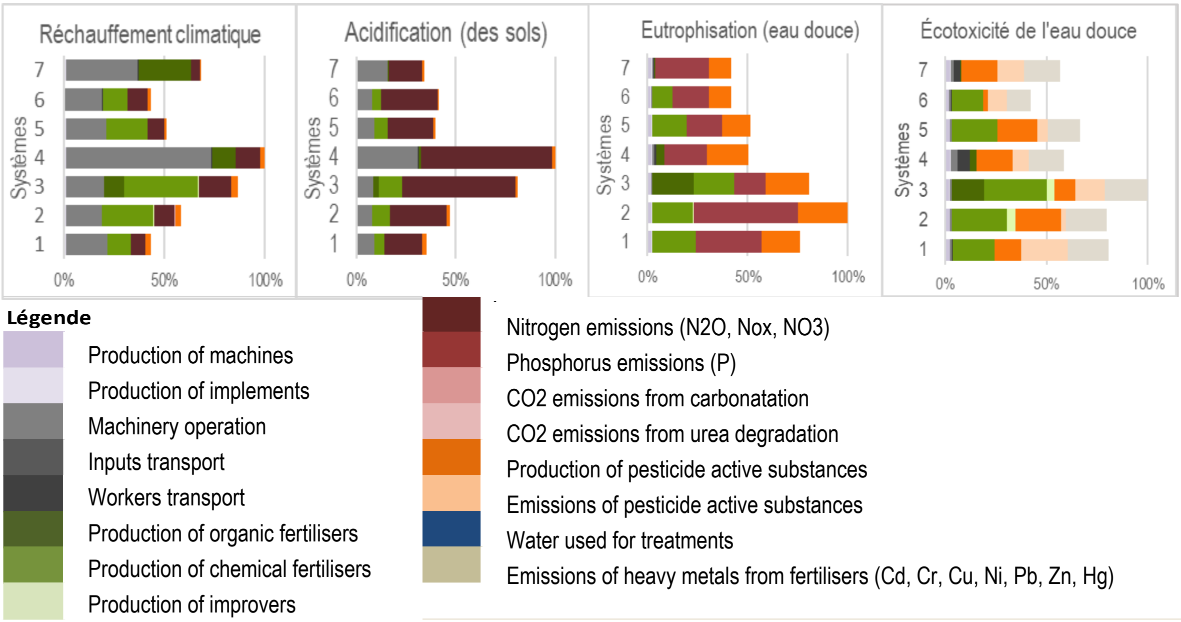


Figure 2: Extract from the results of the comparative LCA on the parangons of the 7 groups of pathways of technical operations in Cognac 2019, Recipe 2016 method, UF Hectare (Billaud, 2021)

3.2 Field trial of alternatives to chemical weed control

3.2.1. Methods

3.2.1.1. Test set-up

A field trial was set up at the Lycée d'Enseignement Général et Technologique Agricole (LEGTA) de l'Oisellerie, an agricultural high school, in collaboration with several partners, to acquire real baseline data with a view to developing LCA assessment tools for the Cognac sector. The trial explored three methods of maintaining the row (the soil under the vines): 1. chemical weeding, 2. mechanical weeding and 3. mown grass, over 4 ha, for 4 years, with agronomic, economic and environmental assessments. All other practices will be unchanged (fungicide/insecticide treatments, fertilisation, pruning, etc.). The years 2019 and 2021 were marked by spring frost, with a loss of harvest, while 2020 and 2022 showed high yields. This yield can be explained by a "catch-up" effect by the vines.

3.2.1.2 Environmental assessment

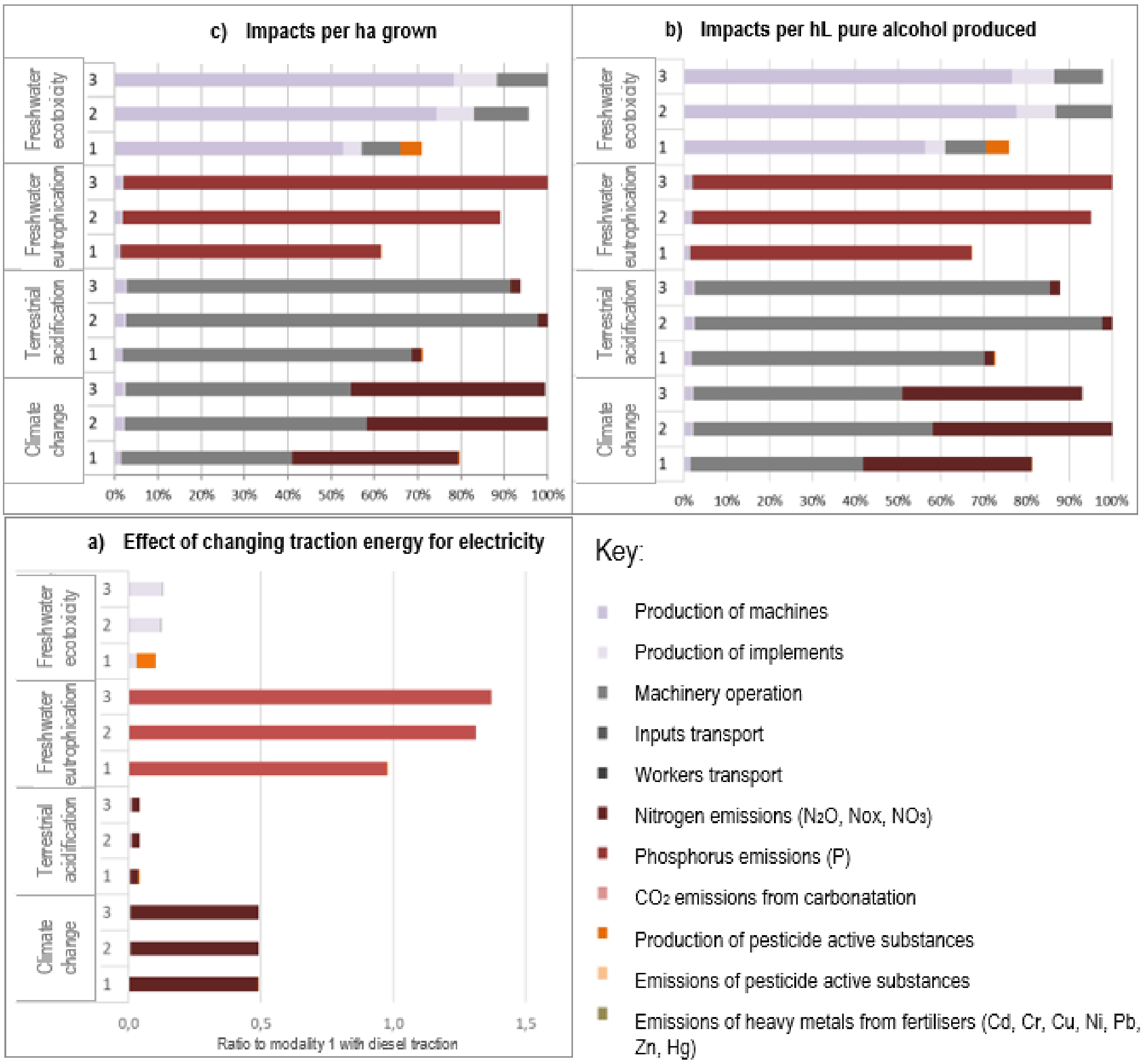
The experimental data from l'Oisellerie was used for LCA modelling, with the Vit'LCA tool®, from 2018 to 2022, assessing the comparative environmental performance of soil maintenance PTOs (only soil maintenance practices were taken into account). These data were used to adapt Vit'LCA® to the specific characteristics of the PDO vineyard.

The development of the Vit'LCA tool® as part of the project has also made it possible to carry out modelling of changes in practices, in particular the switch from diesel to electric traction.

To do this, the 3 weed control methods were modelled using electric tractors and the impacts were compared with method 1 (chemical weed control) using diesel tractors.

3.2.2 Results

The comparative LCA results for the 2022 soil maintenance technical itineraries (Figure 3 a and b) show that diesel consumption (in grey on the graph) is the main contributor to impacts.



For the three charts, the impact categories are: Climate change, Terrestrial acidification, Freshwater eutrophication and Freshwater ecotoxicity

Figure 3: Comparative LCA results (Recipe 2016H method) for the soil maintenance technical itineraries of the experiment on methods of weeding the row at l'Oisellerie in 2022 for four impact categories and two functional units: a) per hectare of vines cultivated for one year and b) per hl of pure alcohol produced. Modalities: 1, chemical weeding, 2, mechanical weeding and 3, mown grass.

c) LCA results for the three modalities with electric traction energy, standardised on the values for modality 1 with diesel traction.

The second item is the production of machinery, the third is the production of tools and the fourth is the production of herbicide products for modality 1 (chemical).

The alternative PTOs (2 and 3) appear to have a greater impact than the reference method in almost all impact categories. Generally speaking, the additional impacts of the alternative methods are linked to the increase in fuel consumption and the use of machinery per unit area. The differences in eutrophication are not significant, the absolute value being very low.

There is little change in the order of modalities when the impacts are expressed per hectolitre of pure alcohol produced, due to the small variations in yield between modalities over the 2022 campaign.

This analysis will need to be supplemented by indicators other than those contained in the LCA, such as a biodiversity indicator, which requires further methodological development.

The change in traction modes with the use of an electric tractor, three times lighter than conventional tractors (with diesel), was modelled. Figure 3 c) shows the ratio of the three electrified modes to mode 1 with diesel, with a ratio of 1 corresponding to an identical impact. For method 2 (mechanical weeding), the main criticism is the increase in fuel consumption, which has a greater impact on climate change and acidification. The results show that switching to electric weedkillers avoids this problem. However, it should be noted that the impact of freshwater eutrophication is increasing (Figure 3c) and that the manufacture of electric tractors has a significant impact on the consumption of water resources.

4. Distillation and cooling circuit case study, first LCAs

The specifications for the Cognac appellation set out the requirements for distillation, including the use of a copper "Charentais" still, double distillation and the distillation period. In the Cognac appellation area, there are 1,150 Bouilleurs de Cru (distillers), who distil their wines on their own farms, among the 4,295 winegrowers, and 120 Bouilleurs de Profession (distillers by profession), who buy wine and distil it or do custom distillation. The alcohol produced is then aged to produce Cognac. In France, ICPE regulations (Installation Classée pour la Protection de l'Environnement, heading 2250) require distilleries with a capacity of more than 50 hL to cool the alcohol vapours with a closed-circuit cooling system, which involves the use of refrigeration units, additional electricity consumption and water treatment products. Smaller distilleries, on the other hand, can operate in an open circuit. This is the criterion used to compare two populations of distilleries.

4.1. Methods

In order to allow the necessary acculturation between the project partners, two distillation schemes were co-constructed to identify the material and heat flows of the two systems. Analysis of the BNIC's survey results was used to identify case studies, accessible data and data missing for the LCAs:

- Most of the heat required for distillation comes from gas combustion (propane or natural gas). A few sites use fuel oil or biomass;
- Almost all distilleries are equipped with wine heaters, which use the heat from the alcohol vapours to pre-heat the wine before distillation, thereby reducing their energy consumption.

Only data from distilleries equipped with wine heaters and running on gas were taken into account in the LCAs, which were carried out in compliance with the normative framework (ISO 14040 and 14044), ((ISO, 2006; ISO, 2006a)). The ILCD method and the Ecoinvent and Agribalyse libraries® were used. The functional unit was defined as "producing 1 hL of pure alcohol".

4.2 Results

The survey data show differences in fuel consumption between the two populations studied: the vast majority of distilleries operating in a closed circuit are large structures that have undoubtedly worked harder on their energy efficiency (because they have more financial and human resources to devote to it).

During the first 18 months of the project, the LCAs were carried out in SimaPro®, to identify the useful primary data and the main impact contributors (Grémy-Gros *et al.*, 2022). The results of these initial LCAs show that gas consumption makes a significant contribution to most of the impacts. Electricity consumption, due to the operation of the refrigeration units in the open circuits, is not negligible for the production of ionising radiation: this is linked to the characteristics of the French energy mix.

To improve data quality, the surveys have been modified and a distillery observatory has been created. A simplified tool for qualifying operators' distillation equipment, called "Mon parc d'alambics" ("My stills"), has been developed in-house. This tool has been grafted onto the "Déclaration d'après travaux et de fin de travaux" application used by distillers and distillers by profession to declare modifications to the stills. This application, which is essential for those declaring Cognac spirits for customs purposes, enables both the BNIC's departments to collect production data and the distillers to monitor their stills.

5. Implementation of environmental management tools and methods

The first application of the tools and indicators selected and developed in the project involved the organisation of a participatory eco-design workshop on vineyard soil maintenance techniques. The main objective was to contribute to the PDO's strategic thinking on this issue. The workshop also enabled the participants, who were all elected members of PDO committees, to understand and use the LCA results so that they could give their opinion at a subsequent meeting on the continuation of the BNIC's work using this method.

5.1. Methods

A participatory workshop was held to involve elected representatives from the PDO in generating and discussing ideas and solutions for maintaining vineyard soils in Cognac, as well as assessing the environmental benefits of these strategies. More details on this workshop are available in Renaud-Gentié *et al.* (2023).

The methodological framework of Rouault *et al.* (2020) and the serious game Vitigame® (Renaud-Gentié *et al.*, 2020) which provide tools for participatory ecodesign in viticulture, were used and adapted to meet the objectives of the workshop and the time constraints of the participants. The ecodesign workshop was introduced by providing participants with information on LCA and environmental impacts. Participants were divided into three tables, each led by an LCA and viticulture scientist and an PDO agent specialising in viticulture or the environment. The eco-design work was based on the results of the LCA of a real case study of a viticultural technical itinerary representative of the main soil management practices in the PDO, derived from the study of the 55 plots in the maturity network. The ecodesign work focused on soil management, and fertilisation was included because this practice is correlated with soil management choices. The objective given to the participants was to design a low-impact, herbicide-free soil maintenance PTO. A projection to 2030 was imposed in order to limit participants' fixation on currently available practices and encourage innovation (Della Rossa *et al.*, 2022).

The 17 participants were elected members of Cognac PDO committees with a variety of backgrounds: winegrowers, vine nursery managers, individual distillers, environmental or technical managers from large distilleries, winegrowing extension officers, PDO agents. The LCA results of the eco-designed cases were calculated in Vit'LCA® and presented to these people on the same day. The functional unit was "1 ha of vineyard cultivated for 1 year". They were then asked to complete a feedback survey at the end of the day to feed into the reflective analysis.

5.2. Results obtained

The dynamics of exchange and eco-design varied around the three tables, depending on the profiles and personalities of the participants and moderators. When the fixation bias persisted, it resulted in less innovative and less risky proposals, giving a lesser gain in environmental performance. The eco-design levers mobilised by the participants concerned the replacement of fossil fuels and fertilisers, the use of plant cover and green manure, the mowing of grass by sheep or robots, and the combination of tools on the tractor. The impact was reduced by up to 90% in certain environmental impact categories. The average impact of all the impact categories was reduced by between 18% and 51%, depending on the table. The most effective solutions for reducing impact were switching to electric power and reducing organo-mineral fertilisation.

The participatory design generated rich discussions and confrontations of points of view around the tables. This raised new questions for the area, such as the environmental merits of intensive or extensive production, the replacement of fossil fuels in the area, the need to experiment with green manures, the role of fertilisers in the environmental performance of the wine-growing area and the need to add additional indicators to the LCA.

6. Discussion

The project identified the need for tools and data to provide environmental indicators for the Cognac PDO. The development of new functions for the Vit'LCA® viticulture LCA calculation tool that meet the needs of the PDO and were built in consultation with users should encourage its adoption (Renouf *et al.*, 2018b). An initial modelling of electric traction has been carried out and included in the tool, but it needs to be refined, in particular by taking into account electronic components, which are likely to have a significant impact (Pradel *et al.*, 2022). Following the project, the Vit'LCA tool® was transformed into an online tool, making it easier to update and use, and was awarded a Bronze SIVAL at the SIVAL Innovations competition in 2023.

In addition to the LCA criteria, the user committee wanted to see the addition of impacts on biodiversity, a subject that will have to be addressed in a future project.

A first version of DistCO'LCA is now operational and can be used to model various process modulations. However, there are still parts to be developed, and the availability of data from the industry (quantity of wine distilled over the life of a still, composition of water treatment products, etc.) and from generic life cycle inventory libraries such as Ecoinvent or Agribalyse® limits the relevance of part of the results. Possible developments have been identified, such as the integration of water treatment, the spreading of vinasse in vineyards, the use of heat (water, vinasse), new fuels (methane, hydrogen, etc.) and the vinification, ageing and bottling stages of cognac. Lastly, this tool could incorporate the impact of grape production by connecting to or using the results of Vit'LCA®. Further consideration will be given to this in the future, depending on the data available on vinification in the surveys for the different types of distillation site. Ultimately, it could also be used to study the effects of different technical alternatives when making investment choices, and to encourage eco-design of distillation.

The viticultural trial comparing three methods of row soil maintenance was subjected to two frost years out of four. The two usable years showed little difference between the methods for the complete pathway of technical operations. This can be explained by the fact that the differences between methods were limited to the maintenance of the row. Focusing on the results for 2022, it appears that chemical weed control had a lower environmental impact than its alternatives when a diesel tractor is used. On the other hand, if an electric tractor is used, there is a considerable reduction in the impact of fossil fuels. The use of alternatives to chemical weed control then becomes acceptable. However, the modelling of electric tractors still needs to be refined. Pradel *et al*. (2022) have highlighted the significant impact of manufacturing electric vineyard weeding robots, particularly due to the electronic components that have not yet been taken into account in this initial modelling.

With regard to LCAs of distillation, the first LCAs carried out in SimaPro® made it possible to obtain the impacts of distillation for two types of still and to identify the problem of data availability and quality.

Methodological and data issues were identified:

- The impact of the still. The lifespan of a still and the quantity of wine distilled during its lifetime vary greatly from one site to another;
- The quantity, origin and fate of the water used. In the case of closed circuits, given the treatment products used, the water is sent to a treatment plant;
- Quantifying and recovering the heat contained in the cooling water from the alcohol vapours. Some sites reuse it for domestic or agricultural use (greenhouses), but in the absence of this information in the surveys prior to the project, this point could not be addressed in these LCAs;
- The diversity of distillery facilities (burners, type of water used, etc.) and the activities they host, particularly for distillers.

Finally, the use of LCA results for a participatory eco-design workshop succeeded in involving the stakeholders. This approach provided input for defining the PDO's environmental policy. The use of a serious game catalysed discussions and knowledge sharing, as observed in other contexts by Dernat *et al*. (2022). The game also enabled forward-thinking at PDO level. Effective eco-design levers were identified (change of energy, fertilisers and introduction of green manures). The strategies proposed improved environmental performance by orders of magnitude consistent with those observed by Rouault *et al*. (2020). The diversity of the participants' profiles and their position as decision-makers in the WCA provided the right conditions for initiating transformative changes (Hebinck *et al.*, 2018). However, the issue of communicating LCA results to stakeholders for ecodesign and more broadly for decision-making remains a challenge due to their complexity (Guérin-Schneider *et al.*, 2018) and a challenge for the future. More generally, this experience has shown that participatory ecodesign can be used at the PDO level in forward-looking thinking. Such an approach could be imagined in this PDO for a discussion on distillation or other parts of the winegrowing technical itineraries.

7. Conclusion

The DOMECCO project is the foundation for the Cognac sector's environmental approach. The results summarised in this article represent the main operational outputs of this research-action project.

The needs analysis has helped to clarify the requirements of industry players and to propose or build appropriate tools. The work carried out has enabled the industry's stakeholders to become acculturated to life cycle analysis and to the data needed to carry it out. The need for a simplified tool for stakeholders led to the adaptation of an existing wine-growing tool, Vit'LCA®, and the creation of a calculator dedicated to distillation, DistCO'LCA.

The pandemic context slowed down the project and limited the time dedicated to participative eco-design. The participatory workshop based on Vitigame showed that there are different ways of eco-designing soil maintenance. This serious game, initially created for winegrowers and technical advisers, has proved its worth in enabling stakeholders in the industry to discuss changes in practices and environmental impacts.

These initial results will form the basis for future studies, which could lead to the eco-design of the entire wine-growing and distillation process.

Ethics
The authors declare that the experiments were carried out in compliance with the applicable national regulations.

Declaration on the availability of data and models
The data supporting the results presented in this article are available on request from the author of the article.

Declaration on Generative Artificial Intelligence and Artificial Intelligence Assisted Technologies in the Drafting Process.
The authors used artificial intelligence in the translation process from French to English.

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Authors' contributions
Antoine Giudicelli: project coordination, proofreading of the article
Cécile Gremy-Gros: LCA of distillation, drafting of the Distillation section
Séverine Julien: preparing and facilitating the participative eco-design workshop
Christel Renaud-Gentié: Drafting of the needs analysis, soil maintenance and the workshop section

Declaration of interest
The authors declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

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