Participatory ecodesign of crop management based on Life Cycle Assessment: an approach to inform the strategy of a Protected Denomination of Origin. A case study in viticulture

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Highlights

- *A framework for game-based participatory ecodesign of crop technical management to inform a protected denomination of origin (PDO) environmental strategy is proposed.*
- *The framework was tested in Cognac PDO by engaging a diverse group of members to design herbicide-free solutions for vineyard management by 2030.*
- *The ecodesign workshop used the serious game Vitigame, tailored for viticulture ecodesign, specifically adapted here to focus on soil management.*
- *The environmental impacts of both the initial and ecodesigned pathways of technical operations were evaluated through life cycle assessment.*
- *The workshop yielded solutions that resulted in a reduction of environmental impacts ranging from 18% to 51% and raised issues for the PDO's future strategy and applied research.*

Abstract

Since the context on environmental issues is challenging, the Cognac protected denomination of origin (PDO) adopted life cycle assessment (LCA) to inform its environmental strategy, initially focusing on vineyard soil management. This study developed a participatory eco-design approach involving stakeholders to inform the PDOs' strategy for transitioning to less impactful crop management practices. It did this by drawing on literature that emphasises the use of participatory design, serious games, and LCA to foster knowledge sharing, engagement, and sustainability assessment. The approach that was put to the test in the Cognac PDO involved 17 elected officials with varying levels of experience. The participants used the serious game known as Vitigame (a game done for participatory ecodesign in viticulture) to ecodesign a soil management and fertilisation pathway for 2030, with the process guided by the results of the LCA. Exchange dynamics, LCA results, and participant feedback were analysed. The study revealed diverse dynamics and efficient ecodesign strategies among the participant groups, which resulted in a reduction of environmental impacts by up to 51% and raised new questions for the territory. The diversity of participants presented challenges, highlighting the need to improve LCA knowledge sharing. The workshop's results could inform the PDO's strategic planning. The interest of this innovative process including a serious game was confirmed, suggesting potential applications to other viticultural PDOs and adaptability to diverse sectors.

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Introduction

An increasing number of citizens are voicing their opinions on agricultural practices (Zollet and Maharjan, 2021) and public authorities like the European Union (Pomarici and Sardone, 2020) or national authorities are keen to impose new standards to develop environmental progress in agriculture, for production under quality and origin labels (Raffray, 2019). In this context, territorial bodies in viticulture such as protected designations of origin (PDO) develop environmental policies and initiatives. The Cognac PDO interprofessional body known as BNIC, has, through the *Développement d'outils de management environnemental de la filière Charente Cognac* (DOMECCO) project, opted for the implementation of life cycle assessment (LCA) and participatory ecodesign in collaboration with researchers. This initiative aims to identify environmental burdens and best practices in grape production and processing to support the Cognac PDO's environmental transition policy. The first practice given priority status and selected as a case study for viticulture within the project is vineyard soil management, as the adoption of herbicide-free strategies presents challenges.

Soil management is indeed a crucial component of technical strategies in viticulture. Weeds can diminish grape yield by competing for water and nitrogen, create a humid microclimate in the area of the bunch that is favourable to grape mould (*Botrytis cinerea*) and be a nuisance for workers carrying out manual operations in the vineyard. In all wine regions, prior to the 1970s, weed control involved soil tillage, both under and between the vine rows. Subsequently, it was predominantly replaced by herbicides until the 1990s (Fried *et al.*, 2019). In Europe, regulatory changes in the use of herbicides gradually reduced the number of authorised active substances (Tataridas *et al.*, 2022). In viticulture today, this practice is primarily confined to the vine row. The remaining soil is either covered by mowed spontaneous or sown covers, or it is mechanically tilled several times throughout the vine growing season. An increasing number of wine growers, particularly those on organic farms, are opting to replace herbicides under the vines with mechanical tillage. Substituting herbicides with vine-row soil tillage may lead to a temporary decrease in yield if vine roots are inadvertently cut during tillage. Moreover, tillage of rows and/or inter-rows presents additional challenges for winegrowers. It raises the demand for labour in the farm (Merot and Wery, 2017); thereby, increasing the costs associated with working time, energy, and the acquisition of new tools (Dumas-Lattaque *et al.*, 2018). In parallel, it demands new competences with the technical mastery of soil tillage techniques, which must be tailored to specific soil types. Last, the limited availability of labour in many wine regions (Villain, 2021) is an important factor limiting adoption of agroecological practices (Ghali *et al.*, 2022). Replacing the use of herbicides by sown or spontaneous cover in the vineyard offers the advantage of limiting soil erosion (Capello *et al.*, 2020) decreasing the incidence of major fungal diseases as well as enhancing soil organic matter content, water infiltration, aggregate stability, and biodiversity. Nevertheless, due to increased competition for water and nitrogen (Delpuech and Metay, 2018), the grass covers tend to diminish vine vegetative growth and yield when compared to bare soils (Abad *et al.*, 2021b; 2021a), which is a significant concern for winegrowers (Payen *et al.*, 2023). Research is still facing challenges in identifying cover crop species that are minimally competitive with vines yet effective in covering the soil to inhibit weed growth.

The Cognac PDO has already moved forward in implementing new rules in its PDO specifications by prohibiting the use of herbicides in the headlands and in vine inter-rows (République-Française, 2022). The organisation aimed to engage a wide range of its members in the generation and discussion of ideas, questions, and solutions for future low-impact vineyard soil management in the production area. In such a situation, participatory design could be applied. Participatory design, facilitated through design workshops, "in which a collective of actors explores and builds *in abstracto* disruptive solutions to reach ambitious goals" (Jeuffroy *et al.*, 2022), enables stakeholder empowerment, collective learning and knowledge sharing around a common object for the researchers, farmers, and other relevant stakeholders involved (Meynard *et al.*, 2012; Dogliotti *et al.*, 2014; Fieldsend *et al.*, 2021). A foresight perspective can be given to the workshops by three potential key roles of the process in transformative change: pre-conceptualising change, promoting the creation of new actor networks, or creating strategies with a high likelihood of implementation (Cadiou *et al.*, 2023).

One means of promoting participatory design involves the application of serious games. Dernat *et al.* (2022) found that serious games used for knowledge sharing facilitate farmers' engagement in collective decision-making, and serve as a suitable tool for building a shared vision of the future among participants that value local knowledge. Several authors have designed and effectively used serious games to facilitate collaborative thinking, bringing together different actors to address territorial issues. Lardon *et al.* (2008; 2013) and Bletterie and Lardon (2021) used the game '*Jeu de Territoire*' in different regions to foster collaboration between different actors to develop a shared diagnosis of their territorial resources and dynamics. The game facilitated the development of foresight scenarios and the joint formulation of proposed actions. This approach is particularly suitable to involve a variety of actors in different, as yet undefined, actions for their territory, which need to be jointly elaborated on the basis of a common diagnosis. It has proved to be effective way of building a shared vision of development challenges and generating ideas and innovation. However, it requires substantial preparatory work, including field surveys and is not designed to focus on a specific agricultural production type. Hossard *et al.* (2021) developed the CAPPIP game through a participatory process more focused on agricultural practice change. It explores opportunities for practice change to mitigate the impacts of pesticide use by wine growers on a watershed scale. The game is coupled with a simple calculator to evaluate the proposed solutions. Through the game, local stakeholders adjusted their practices on their virtual farms, although their proposed changes were less ambitious than those suggested by experts. The lack of economic evaluation of practice changes is seen as a limitation by both the players and the game designers. In the same context of viticulture, the serious game Vitigame (formerly known as Vitipoly), also aims to promote practice change among wine growers, but with a broader approach than the reduction of pesticide impact. It addresses a wide range of impacts generated by all the annual viticultural practices of a plot by incorporating environmental assessment through LCA in the participatory eco-design of vineyard management (Renaud-Gentié *et al.*, 2020b). However, it is not designed to address territorial issues. It is linked to an LCA calculator, Vit'LCA®. Although the combination of computational modelling and participatory approaches is sometimes considered challenging because of the potential difficulties for farmers to adopt the results, this approach is gaining ground in agriculture (Becu *et al.*, 2008). It is the case for serious games (Martin *et al.*, 2012; Jouan *et al.*, 2021) and especially concerning environmental assessment as in CAPPIP and Vitigame. Sustainability assessment plays a crucial role in the development of innovative solutions to promote more sustainable agriculture. It is essential to clearly define its place in the innovation process, and to establish well-defined criteria and indicators (Perrin *et al.*, 2023). The integration of LCA into participatory design provides a solid basis for identifying design objectives with stakeholders (Kulak *et al.*, 2016). It also provides comprehensive information for identifying critical areas for improvement and key levers for reducing environmental impacts, as well as for assessing the outcome of the eco-design process.

The LCA method calculates the potential environmental impacts of a product or a service. Based on life cycle thinking, this comprehensive method considers impacts from the extraction of raw materials to the end of life and recycling of the product (Mouron *et al.*, 2006). LCA has been used for several decades to assess the environmental impact of agricultural products (Audsley *et al.*, 1997) and has highlighted the substantial contribution of the agricultural phase to the overall impact of food and beverage products, including wine (Bessou *et al.*, 2013; Vázquez-Rowe *et al.*, 2013). In viticulture, Rouault (2019) reviewed different published LCAs of a bottle of wine and found that the contribution is highly variable depending on the impact category, the viticultural practices and the limits of the system considered by the authors. In studies that included grape production up to wine transport, the agricultural phase accounted for between 13 and 69% of the global warming potential impact of the bottle of wine and between 61 and 90% of the eutrophication potential impact. In agricultural applications, LCA is often applied "from the cradle to the field gate", covering the entire life cycle of the inputs and consumables used on a plot or a farm.

Methodological frameworks have been proposed to comprehensively assess wine-growing pathways of technical operations (PTO)[1] through LCA (Bellon-Maurel *et al.*, 2015; Renaud-Gentié, 2015; Rouault *et al.*, 2016). This allows for the comparison of strategies or informs winegrowers practice choices at field level (Renaud-Gentié *et al.*, 2020a) and can be used as a useful basis for ecodesign (Rouault *et al.*, 2020). A framework for applying LCA at the territorial scale in agriculture has been proposed by Nitschelm *et al*. (2016) and adapted for viticulture by Baillet *et al*. (2020). This up-scaling represents a methodological challenge because of the need to take into account the diversity of vine-growing practices and the influence of soil characteristics on pollutant emissions. The use of typologies allowed the authors to translate the diversity of the territory into the major types to calculate a reasonable number of LCAs. To date, however, LCA has not been used to accompany agricultural design on that scale. Although LCA is not an ecodesign tool *per se*, it is considered the most effective method to inform eco-design (Navajas *et al.*, 2017). Ecodesign solutions should be derived from LCA results, either by identifying and optimising the most impactful parameters through calculation (Duran Quintero *et al.*, 2021), expertise (Navajas *et al.*, 2017), or participatory ecodesign processes. The latter is particularly advantageous as it involves participants in the transformation process, and generates solutions that make use of their professional knowledge and creativity (Kulak *et al.*, 2016).

The combined use of LCA and co-design is an emerging practice that is not yet widely implemented due to the potential requirements for tool development. An LCA calculator has been developed to support the co-design of infrastructures, improve stakeholders' understanding and facilitate informed and collective decision-making among the three proposals considered (Borrion *et al.*, 2019). In the field of elderly care, the double-diamond method has been used alongside LCA to formulate a strategic plan aimed at minimising environmental impacts while ensuring financial feasibility for healthcare institutions (Clune and Lockrey, 2014). In agriculture, co-design based on LCA results has been less documented. Kulak *et al.* (2016) engaged diverse expert stakeholders from the bread sector in an LCA-based ecodesign workshop to generate impact reduction scenarios across the supply chain. The process resulted in a substantial potential reduction in the overall impact of the bread supply chain, with a 40% reduction in global warming potential. In viticulture, Rouault *et al.* (2020) proposed and tested a framework and tools for participatory eco-design of vineyard management at the field scale, involving collaboration with winegrowers and their extension officers. The process comprised three workshops per session, involving knowledge transfer to participants on LCA and the environmental impacts of grape growing. Growers then generated a list of alternative practices to enhance the environmental impact of a specific real PTO, followed by a collective redesign of this PTO using the least impactful practices. The authors reported an average decrease of environmental impact of 27% for sessions conducted with five distinct groups. The same process was completed by a farm-scale approach of PTO ecodesign complemented by an economic assessment (Perrin *et al.*, 2022). It enabled the participants to assess the applicability of ecodesigned PTOs derived from a field scale ecodesign process to the entire farm. This involved identifying the barriers and levers at the farm scale. The serious game Vitigame was developed based on Rouault *et al.* (2020)'s work, offering all the necessary tools to facilitate participatory ecodesign workshops in viticulture at the field level (Renaud-Gentié *et al.*, 2020b). An LCA calculator customised for viticulture, Vit'LCA®(Renouf *et al.*, 2018b), is associated with the game for LCA calculation. However, to date, no participatory ecodesign process of crop management has been conducted for reflection at the PDO scale, involving actors beyond farmers and extension officers.

The aim of this study was to develop a participatory eco-design approach involving PDO stakeholders to inform the environmental PDO strategy for transitioning to less impactful crop management practices. The paper presents and discusses this approach, its process, constraints, and results based on a participatory ecodesign workshop organised with members of the Cognac PDO on vineyard soil management in the Cognac PDO.

After detailing the elements and process of the workshop and its analysis, we will present the results in terms of the dynamics of exchange, the choices made by the groups, environmental performance achieved, and feedback from the participants. We will then discuss the achievement of the study's objectives, identify potential improvements and outline future perspectives.

Materials and Methods

The participatory ecodesign for protected designations of origin approach

The ecodesign approach proposed and tested in this study is illustrated in Figure 1. On the left and the top of the figure are the elements necessary for the ecodesign workshop, on the right the outputs of the workshop and at the bottom reflective analysis and evaluation of the process.

The ecodesign process mobilises elements of the framework proposed by Rouault *et al.* (2020). It involves collaborative design work based on the LCA results of the PTO of a selected case study. This case is hereafter referred to as the "initial case". A comprehensive Life Cycle Inventory of this case's agricultural practices allows LCA calculations in order to determine impact results from cradle to field gate, and identify environmental hotspots to be presented to the workshop participants. Prior to the ecodesign work, a knowledge transfer on environmental impacts addressed by the LCA, the LCA methodology and results is necessary to facilitate

[1]A pathway of technical operations is a logically ordered chain of technical operations towards a given production objective according to Sébillotte (1974).

the participants' understanding of the LCA results and the ecodesign process. The participants then play the ecodesign serious game in small groups under the guidance of a facilitator. This ecodesign process consists of jointly designing a PTO with less impact, in the same context as the initial case, in terms of field characteristics and of weather conditions and disease pressure during the year. A documentation of the case characteristics, its impacts, available ecodesign levers and artefacts that allow modalities of crop management practices manipulation to represent the PTO are necessary to inform and facilitate the ecodesign process (Rouault *et al.*, 2020). A preliminary session where the participants propose alternative practices should be planned if such a pool of alternative practices is not already available in the game. Once the ecodesigned PTO is ready, a reflective exchange is initiated by the game master followed by a visit of the group to the other groups to share what each group has decided and proposed. The ecodesigned PTOs produced by the participants undergo LCA assessment, and the results are presented to all participants for discussion.

However, additional steps and adaptations of the framework are specific to this PDO scale approach. The initial case is selected from a typology of farming practices within the territory (Figure 1 on the left), determined through the first step of the Typ-iti method (Renaud-Gentié *et al.*, 2014). This method involves a multi-component analysis of data describing the practices on a representative sample of the area followed by a hierarchical ascending classification, consolidated by the K-means method. In the case of a PDO, the selection and enrolment of participants for the workshop is aimed at representing the diversity of the stakeholders that make up the PDO actors. It should ensure the representation of the main potential actors of practice change and the presence of agronomic, practical and, if possible, environmental knowledge. The latter is less important as a knowledge transfer on this topic is made for all at the beginning of the workshop. The aim given to the participants for the ecodesign process is also specific to the PDO scale: to "jointly choose an eco-design strategy and design a new PTO for application at large scale in the PDO, with lower environmental impacts compared to the initial case". At this stage, certain constraints can be imposed on the participants, *e.g.*, "avoid the use of fossil energy in the ecodesigned PTO". They have to be defined during the preparation of the workshop between the researchers and the PDO agents, in line with the objectives of the PDO, and after checking they won't increase the risk of fixation (Jeuffroy *et al.*, 2022). The fixation is the reluctance to propose innovations that are too different from what is already known (Jansson and Smith, 1991). Suggesting a long time horizon can help limit fixation bias, and other strategies can be used to limit it as reported by Jeuffroy *et al*. (2022). Issues and questions raised during the workshop, along with the ecodesigned PTOs and their environmental results, are delivered to the PDO agents to contribute to shaping the environmental policy of the PDO. In the field of viticulture, the serious game Vitigame (Renaud-Gentié *et al.*, 2020b), which provides tools and rules for participatory eco-design in viticulture, can cover this process from the LCA of the initial case to the discussion of the ecodesign results, with some adaptations.

Application of the ecodesign approach to the Cognac case

The application of the approach under study occurred on November 23rd, 2021, at the *Bureau National Interprofessionnel du Cognac* (BNIC) offices in Cognac, France.

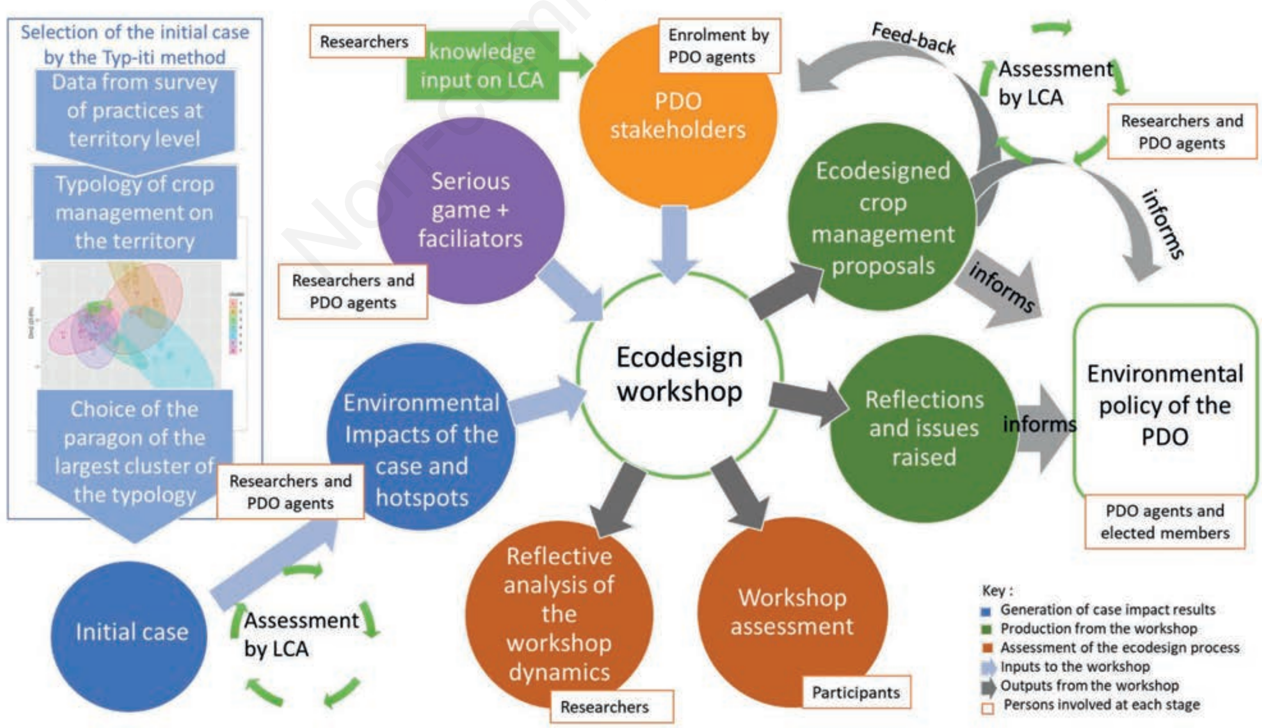

Figure 1. Process of participatory ecodesign of crop management to inform a protected designations of origin environmental policy.

Specific objectives

This workshop had the following specific objectives in line with and in addition to the scientific aim of the study: i) to foster the emergence of ideas and proposals for the evolution of soil management practices in the PDO for the next decade by proposing to elected PDO members a forward-thinking exercise using the LCA results; ii) for the researchers, to explore the feasibility and interest of applying LCA-based participatory eco-design process of PTOs with the Vitigame serious game to a forward-looking thinking at a wide PDO scale and implying a variety of stakeholders; iii) for the PDO agents, a third objective was to share with elected stakeholders of the PDO the work done by the PDO with the researchers with LCA and its results. This work focused on characterisation of soil management practices in the appellation by LCA. Their aim was also to share the interests of LCA for the appellation in order to validate with the members the decision of going on using and developing LCA in their PDO.

Selection and characteristics of the initial case

As of 2022, according to data from the BNIC, the Cognac PDO encompasses 83,140 hectares of vineyards, yielding approximately 1.018 billion hectolitres of grape must, primarily destined to produce *eau de vie* through the distillation of white wine. The Cognac *eau de vie* sector comprises 4,290 winegrowers, 265 *eau de vie* merchants, and 118 professional distillers. Out of the 212.5 million bottles of Cognac *eau de vie* produced, 97% were exported.

The initial case was selected based on a typology of soil management practices within the PDO, with the first step of the Typ-iti method, determined from a sample of 55 vineyard plots considered to be representative of the PDO by the PDO agents. The typology determined seven clusters from the sample. The case selected for the workshop is a paragon of the largest cluster in this typology.

The grape variety cultivated was Ugni Blanc, the primary local grape variety, planted at a density of 3,333 vines/ha. The reference year for vineyard management operations and climatic data was 2019. The soil, with a loamy and clayey texture (50% clay), underwent tillage twice during the vine's vegetative period every two inter-rows, using a cultivator and a rotary harrow.

The other inter-rows were grassed and mowed four times with a blade mulcher. Chemical weeding was utilised under the vines. Both organo-mineral and synthetic fertilisation were applied (80N, 56P and 3K), the wine grower was aiming a yield of 110hL/ha of base wine intended to produce Cognac *eau de vie* through distillation. The use of a thermal tractor for all the operations consumed 170L of gasoil. The primary environmental hotspots in the complete PTO LCA (Figure 2) are fertiliser manufacturing and emissions, pesticide manufacturing and emissions, and fuel combustion emissions from machine use. Soil management and fertilisation (SM&F on the chart) account for 8% to 93% of the impacts of the total PTO, depending on the impact category.

Profile of the participants and facilitators

The 17 participants in the workshop were all members of the Cognac PDO committees, who as elected representatives contribute to the management of the PDO. They represented the main stakeholder profiles of the PDO, including winegrowers, distillers, Cognac *eau de vie* merchants together with two viticulture advisors and a vine nurseryman, as shown in Table 1. The participants were divided into three groups for the ecodesign process: each group with assigned facilitators (Table 1). The distribution of participants was predetermined by the organisers to ensure a diverse representation of profiles at each table. Although the participants were experts in their respective fields, they did not all have expertise in both environmental and viticultural issues. The aim of inviting experts from different backgrounds was to generate proposals for environmentally and agronomically sound practices and assess the practical feasibility of their implementation, as well as to involve a diversity of stakeholders in the definition of the PDO policy. A 'game master' from the research team led the activities at each table. They were three LCA and ecodesign practitioners, two of whom specialised in viticulture and one in food science. They were each assisted by a PDO agent with expertise in viticulture and/or the environment (Table 1).

The role of the PDO agents was to prepare for the workshop with the researchers, collect data on the initial case, carry out the initial case LCA, distribute the participants to different tables to ensure a balanced mix of profiles, contribute to the facilitation of the ecodesign process, collect feedback from participants, and share the detailed results of the workshop with PDO stakeholders in a subsequent meeting. After the workshop, the PDO agents would be responsible for fostering further discussions and actions based on the outcomes of the workshop.

Table 1. Detailed composition of the three groups.

	Group 1	Group 2	Group 3
Winegrowers	2	1	2
Vine nursery manager	0	1	0
Individual distillers	2 (same persons as the winegrowers)	2 (same persons as the winegrower and the nursery manager)	2 (1 same person as 1 winegrower)
Environmental or technical managers of Cognac merchants	3	3	3
Viticulture extension officers	1	1	0
Total participants	6	5	6
Facilitators profiles	Manager of the environment department of the PDO + LCA and viticulture practitioner (research team)	Agent of the viticulture department of the PDO + LCA and viticulture researcher (research team)	Agent of the environment department of the PDO + LCA expert from the research team

PDO, protected designation of origin; LCA, life cycle assessment.

Prior to the workshop, the researchers were tasked with providing the LCA calculator, training the PDO agents on LCA calculations, providing the serious game, training facilitators, and working with PDO agents to prepare for the workshop. On the day of the workshop, the researchers' tasks included sharing relevant knowledge before the ecodesign process, facilitating the ecodesign process as game masters, performing LCA calculations, interpreting the results after the workshop, giving an initial presentation of the results to the participants, and finally conducting a post-workshop, in-depth interpretation of the LCAs and a reflective analysis of the workshop.

Participatory ecodesign tools and their adaptation to fit the workshop's conditions

The serious game Vitigame was used and adapted to meet the objectives of the approach. The use of this game made it possible to skip the step of generating alternative practices by the participants included in the framework of Rouault *et al*. (2020). Indeed, the game box already proposes a wide variety of alternatives generated in previous workshops, thus limiting the process to a single workshop. Vitigame is a serious game designed to facilitate ecodesign by groups of 3 to 8 winegrowers or viticulture students. The aim given to the players for the ecodesign process is to redesign the

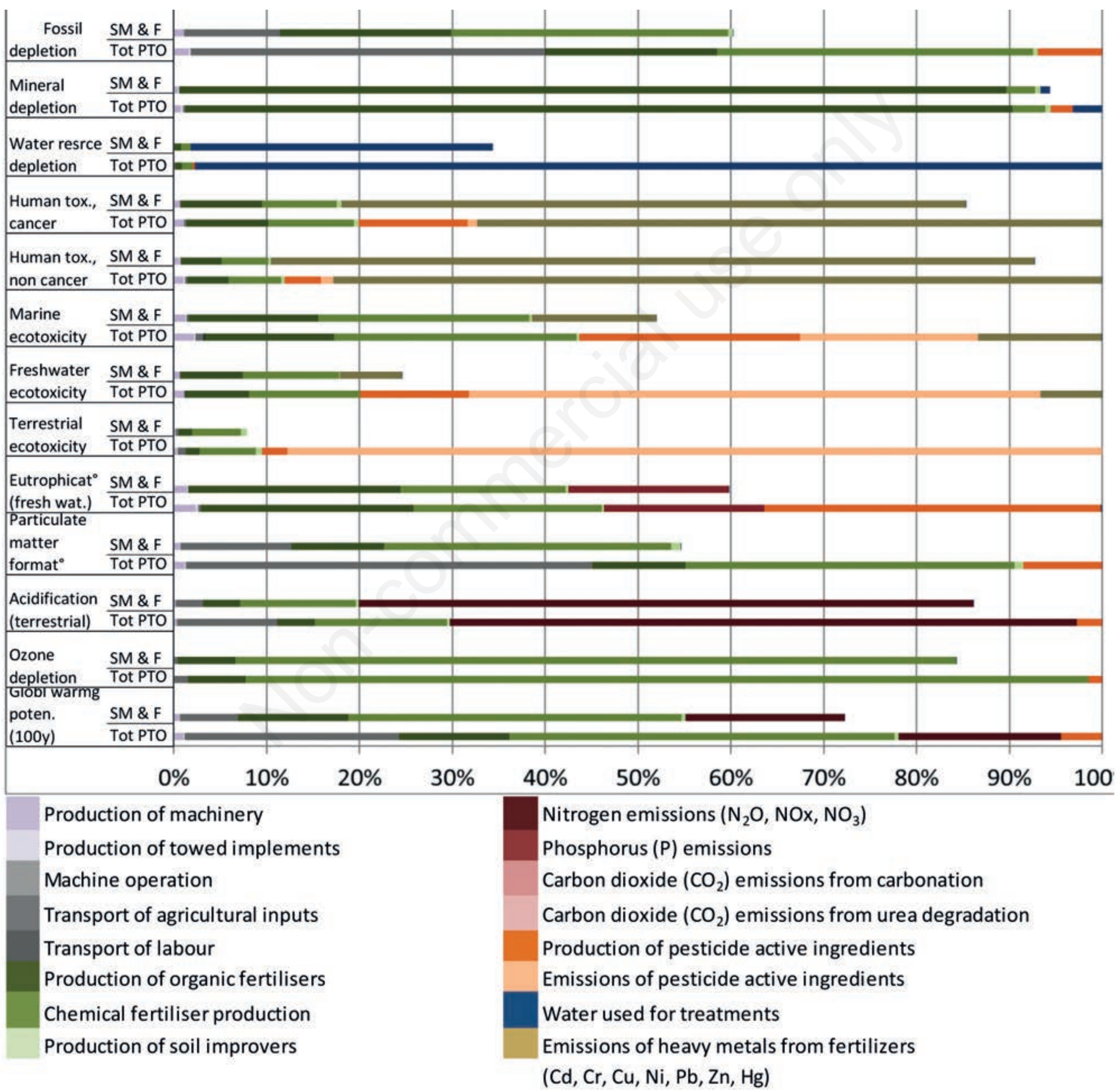

Figure 2. Life cycle assessment contribution chart shown (in French) to the participants for the initial case, comparing soil management + fertilisation practices to the full pathways of technical operation. Characterisation method, recipe midpoint (H); FU, 1ha of vineyard cultivated for one year; SM&F, annual soil management and fertilisation pathway; Tot PTO, total annual pathway of technical operations for the vineyard.

PTO of a real case of vineyard management considering its LCA results, to reduce its environmental impact. It requires technical knowledge of viticulture. The game box contains: i) a game board; ii) operations and treatments cards representing each technical operation that can be carried out in the vineyard by the winegrower or his team and each phytosanitary product that can be used on the vine; iii) weather cards showing the weather forecast and actual rainfalls per half week, and the main fungal disease pressure during the budding to veraison period; iv) a technical sheet describing the initial case, including the agronomic information, operations carried out, and fuel and pesticides consumed; v) an environmental sheet containing the LCA results of one year's cultivation of the initial case; vi) two leaflets informing the players about the causes of environmental impact, the levers and strategies for ecodesign, the characteristics and impacts of pesticides; vii) a guide for the facilitator; viii) the access to the Vit'LCA® online calculator to assess the ecodesigned PTO at the end of the game. Life cycle assessment plays, indeed, a key role in the ecodesign process. The main steps of the game are: i) knowledge transfer: introduction to LCA and ecodesign; ii) around the game table: discovery of the case and its LCA results by the participants, collective choice of an ecodesign strategy; iii) construction of the detailed ecodesigned PTO operation by operation, considering weather and fungal disease pressure; iv) debriefing on the choices made and their effects; v) presentation of the LCA results of the ecodesigned PTOs to the participants.

A complete PTO ecodesign game takes three hours, accompanied by one hour of knowledge transfer on LCA and ecodesign in viticulture and one hour of debriefing.

The Vitigame had been adapted to the objectives of the workshop. The game covers several technical topics, including soil management, fertilisation, plant protection, and operations such as pruning and harvesting. As the focus of the workshop was on soil management, the game was adapted to minimise the need for in-depth viticultural knowledge, and to ensure the active participation of non-experts. The game focused on soil management and fertilisation practices, which have a strong correlation with soil management decisions. As a result, the eco-design time was reduced to 1h30 without diluting the interest of the workshop. This duration and the reduction in the scope of the game were validated in a preliminary workshop held a month earlier in another PDO. The game was thus played on the assumption that the other elements of the initial PTO would remain unchanged (plant protection programme, manual and mechanised operations for pruning, canopy management and harvesting).

A number of adjustments were made to the game, including the creation of specific technical and environmental sheets containing the Cognac's initial case data and information not previously available in the game box. These sheets included details such as total fuel consumption per hectare per year, the contribution of each mechanised operation to fuel consumption, and the treatment frequency index. The weather cards were replaced by a temperature and rainfall timeline derived from regional meteorological data. (Figure 3a). Finally, the environmental sheet, which presents the LCA results in histogram format, was enriched with specific results related to soil management and fertilisation operations. This involved presenting the contributions of SM&F to the impacts relative to the complete PTO (tot PTO) across 13 selected impact categories that were considered to be most relevant (Figure 2).

Life cycle assessment calculation

The LCA results used in (Figure 2) and derived from the workshop have been calculated from cradle to field gate and include all materials and inputs (including energy and water) as well as pollutant emissions, from raw material extraction to the end of life of the equipment or input. The operations included in the system are those that take place in the vineyard throughout the production year. Impacts were calculated using the Recipe 2016 (H) midpoint characterisation method (Huijbregts *et al.*, 2016), facilitated by the Vit'LCA® Excel calculator (Renouf *et al.*, 2018a) which includes Life Cycle Inventory (LCI) calculations as well as LCA calcula-

Figure 3. On the left, a view of the Vitigame eco-design serious game used here for eco-design of vineyard soil management and fertilisation with, in the centre, the meteorological timeline added for this workshop; on the right, one of the three groups where participants were distributed with facilitators.

tions based on practice parameters and pre-calculated embodied impact factors. The functional unit used to express impacts, was "1 ha of vineyard cultivated for 1 year". Primary data were obtained from the field survey while secondary data originated from Ecoinvent® 3 and Agribalyse® 3 databases.

Process of the workshop

The participatory ecodesign workshop was proposed to the participants after a presentation by the PDO agents and the researchers of the agronomic and LCA results obtained in the DOMECCO project on soil management practices in the Cognac PDO. The introductory 1-hour knowledge input to the participants was given by a researcher in LCA and viticulture from the research team. It covered LCA, environmental phenomena related to the main environmental impact categories addressed by the method, the presentation of the game and the initial case and its LCA results. The participants were then divided into 3 groups (Figure 3b). The main fixation bias identified by the research team based on the experience of previous PTO eco-design workshops with winegrowers, was related to the fact that when the eco-designed PTO was considered for contemporaneous implementation, some participants resist introducing very innovative solutions that they may consider impossible to implement immediately in the vineyard. By making the workshop also a foresight exercise, in line with the objectives of the PDO, the aim was to limit this fixation bias; the participants to this workshop had to design a PTO for the year 2030. The game process unfolded in three phases at each table: i) the technical and environmental sheets describing the agronomic and technical characteristics of the case together with the LCA results for both the complete PTO and the soil management and fertilisation practices, were provided to the players and explained by the game masters. The objective given to the players was to design a PTO for the Cognac PDO with a low impact on the soil and without the use of herbicides; ii) the participants discussed options before reaching a consensus on the primary ecodesign direction for their PTO and selected the key levers to activate; iii) they constructed the PTO using playing cards, adjusting operations according to the weather conditions provided by the meteorological timeline. At the end of the ecodesign work, a discussion took place at each table about the choices made and their consequences. The participants at each table presented their ecodesigned PTO to the other participants explaining the reasons for their choices. An additional activity was then proposed to participants after the ecodesign workshop, to allow the research team to enter data into the calculator. This facilitated the presentation of LCA results and initial interpretations to participants before they left.

The facilitators observed the interactions during the ecodesign, and the researchers conducted an analysis of both the interactions and the ecodesign decisions to identify fixation biases and discern the logic behind the development of the ecodesigned PTO.

Feedback from the participants

At the end of the day, the participants were asked to complete a 25-question feedback survey on their interest in this participatory ecodesign process and tools to inform the reflective analysis of the workshop, as recommended by Lardon (2019). After the workshop, a detailed interpretation of the LCA results was carried out by the researchers and shared with the participants by the PDO representatives at a subsequent commission meeting within the framework of the PDO.

Table 2. Main characteristics of the ecodesigned cases from the three groups of players compared to the initial one.

	Initial case	Group 1	Group 2	Group 3
Traction motorisation	Thermal 100hp	Thermal 100hp with Vario+ eco-drive (-20% diesel consumption) + diesel robot for grass management	Thermal 100hp, Biodiesel from waste cooking oil	Electric tractor for soil management thermal tractor 100hp for the other operations
Energy for machinery (ha/year)	Diesel 170 L	Diesel 171.5 L	Biodiesel 149.9 L	Electric 24kwh + diesel 110 L
Maintenance of the inter-row	1 inter-row row tilled (2 passes)/1 inter-row grassed	1 inter-row green manure (faba beans)/1 inter-row natural grass	1 inter-row green manure (faba beans + crucifers) rolled/1 inter-row natural grass	1 inter-row green manure (faba beans) rolled/1 inter-row tilled once + natural grass mowed
Under the row	Chemical weeding	Grassed with a non-competitive species (not existing yet)	Mechanical weeding	Mechanical weeding
Grass management	4 mowing	Interrow mowed with the robot (5 passes) + green manure rolled (5 passes coupled with under row mowing)	2 rolling on the green manure; 2 mowing on the permanent grass	7 rolling coupled with row mechanical weeding on the green manure inter-row + 6 mowing coupled with trimming on 1 interrow
Fertilisation (N/P/K)	Synthetic + Organo Mineral	Organic	Organic	Organic
Other			Sheep eco-grazing in winter and coupled operations	

Results

Interactions between the participants, and eco-design choices

The participatory ecodesign activity started with a time period of getting to know the case and understanding the causes of the impacts calculated by the LCA. The dynamics of exchange and ecodesign along the workshop were different in the three groups according to the profiles and personalities of the participants and facilitators. The participatory design generated rich discussions and confrontations of points of view around the tables. The eco-design levers mobilised by the participants in response to the identified sources of impact concerned the replacement of fossil energy for machinery by electricity or biofuel, the change of fertiliser, the introduction of grass cover and green manure, the use of grass mowing by sheep or robots, and the combination of tools on the tractor (Table 2).

In group 1, the decision was made not to worry about the yield of the vineyard and the participants decided to cover the whole soil with green manure [faba beans (*Vicia faba*)] and permanent natural grass in the alleys (1 every two rows) and non-competitive plants (still to be found by research) under the vine row; however, the expected competition from grass made it necessary to add organic fertiliser to limit the yield reduction. The choice of green manure was made after careful consideration and discussion of the poor match between the availability of nitrogen from green manure and the needs of the vines. An autonomous diesel-powered robot, lighter than a tractor, was used to mow under the rows. The solutions adopted to save diesel for the other operations were stepless transmission technology, eco-driving and reducing the number of passes by combining tools on the tractor. The group imagined tools and grass varieties that do not yet exist, particularly for soil maintenance under the vine row.

In group 2, we noticed a fixation, a participant with a high technical knowledge in viticulture, imposed on the group the necessity of a high technical feasibility of the strategies based on the solutions available today. Some members of the group with less knowledge in viticulture proposed more disruptive and sometimes not technically sound solutions. However, the group proposed a well optimised PTO in terms of machine use with tool combinations on the tractor to reduce fuel consumption. They looked for the best solutions for weed control under the vine row and decided to cultivate it. For the inter-row, they decided to sow faba beans and cruciferous plants every two inter-rows and leaving permanent grass on the other one to limit tillage operations and reduce fertiliser use. Several important questions were discussed in the group: i) yield: "Should we fertilise and maintain it at today's level, or should we let it decrease to reduce the impact of fertilisation?" This led to the question to be investigated in further studies for their PDO: "Is it better for the environment to produce more on a smaller area or less and with fewer inputs, especially fertilisers, on a larger area?"; ii) Energy: "What energy sources will be available for vineyard machinery in the future and what should we promote in our territory?"; iii) Incompatibility between "green practices" such as green manure and sheep grazing or mowing robots and the protection of hedgehogs. Another element of fixation was observed in group 3, where one of the participants insisted on maintaining production at a high yield, even though this would limit the reduction of impacts due to the need for high fertilisation. A long discussion on yield followed and the high yield objective was maintained. A further discussion took place on the possibility of using wood chips as mulch, in relation to the C/N ratio of the wood and the risk of nitrogen starvation that could result. This solution was not retained. A discussion on the most appropriate green manure management (rolling or burying) also preceded the construction of the PTO. They decided to reduce their impact by: i) replacing 100% of fossil fuels for soil management with electricity and synthetic fertilisers with organic ones; ii) replacing herbicide by sowing green manure and rolling it later to create a mulch on half the surface and tillage on the other half; and iii) combining tools on the tractor. However, competition from grass made it necessary to add fertiliser to maintain the desired yield.

Life cycle assessment results of eco-designed pathways of technical operations

For all the groups, the replacement of the synthetic and organo-mineral fertilisers of the original case by organic fertilisers allowed significant reductions in impacts (Figure 4), related to their production, for categories such as mineral depletion (-94%), fossil depletion (-35 to -68%), ozone depletion (-48 to -90%), or related to their emissions of N or heavy metals for categories such as human toxicity and ecotoxicity. The reductions in impact were more limited in group 2, due to the amount of organic fertiliser used (*e.g.*, three times more than in group 1) and the introduction of sheep grazing, which causes water consumption and emissions of CH_4 and N compounds. Group 1, with low organic fertilisation, achieved the best results. The replacement or reduction of fossil energy use was the main driver for the reduction in contribution to climate change, particulate matter formation, fossil resource depletion and acidification. Group 3, with 100% electric machinery, achieved the best results overall, but even more in these last impact categories.

The ecodesign actions of each group that had the greatest effect on the different impact categories are listed in Table 3. The most effective actions are highlighted by a colour scale. The most effective levers for reducing fossil resource consumption, particulate matter formation, terrestrial acidification and global warming potential impacts were the suppression of diesel use by replacing it with electricity (group 3) or biodiesel (group 2), or to a lesser extent their reduction by a combination of tools on the tractor. The elimination or substitution of organo-mineral fertilisers also had an important influence on reducing the potential impacts of fossil and mineral depletion, ozone depletion, human toxicity and ecotoxicity. Some technical choices led to an increase in impacts, such as the use of organic fertilisers (groups 1 and 3) for human toxicity impacts.

Feedback from the participants

Thirteen out of 17 participants completed the feedback form. Most participants (85%) felt that the session had enabled them to gain a better knowledge and understanding of the contribution of practices to environmental impacts and that the LCA methodology had been useful in clarifying technical choices in the Cognac PDO from an environmental point of view. One hundred percent of respondents said that the session provided useful elements for reflection on the Cognac PDO; 85% felt that it enabled them to have a better knowledge and understanding of the impact of practices on the environment; the same proportion said that LCA was a useful method to help clarify technical choices in the PDO from an environmental point of view; and 62% felt that the discussions helped them to reflect on soil management practices. Several mentioned that it would be interesting to repeat this experience with a complete PTO in viticulture or to apply this exercise to the distillation process. They mentioned that the initial knowledge transfer on LCA and impacts succeeded in giving some participants the basic knowledge to understand the environmental issues addressed by LCA and the levers they could use in the workshop (54%). Other participants found the knowledge transfer too complex, others found it too general or with concepts they already knew. Suggestions for improvement were made: i) to have more information on the soil type of the case; ii) to allow more time for the eco-design process and also for the subsequent discussion of the eco-designed PTOs, as more than 50% of respondents found the workshop too short; iii) to include more participants with technical expertise in each group, as some members lacked technical skills;

Table 3. Origin of the impact reduction. Impacts reduced by more than 75% (dark green); impacts reduced between 50% and 74% (green); impacts reduced between 25% and 49% (light green).

	Group 1	Group 2	Group 3
Fossil depletion	+ Machinery impact (higher number of passes for mowing or sowing) - Suppression of chemical and organo-mineral fertilisers and nitrogen emissions reduction due to a lower dose of fertiliser (now organic)	- Replacement of fuel by biofuel on soil maintenance operations - Suppression of chemical and organo-mineral fertilisers	- Suppression of the chemical and organo-mineral fertilisers replaced by organic fertilisers (reduction of nitrogenous emissions) - Replacement of diesel by electric power for soil maintenance operations
Mineral depletion	- Suppression of chemical and organo-mineral fertilisers	- Suppression of chemical and organo-mineral fertilisers	- Suppression of chemical and organo-mineral fertilisers
Water resource depletion	- Suppression of herbicide treatments (water from sprayers)		- Suppression of herbicide treatments (water from sprayers)
Human toxicity, cancer	- Elimination of initial organo-mineral fertiliser + Organic fertiliser		- Elimination of initial organo-mineral fertiliser + Organic fertiliser
Human toxicity, non-cancer		- Elimination of chemical and organo mineral fertilisers (heavy metals) + Organic fertilisers	- Elimination of chemical and organo mineral fertilisers (heavy metals) + Organic fertilisers
Marine ecotoxicity	- Suppression of the chemical fertiliser	- Elimination of chemical and organo mineral fertilisers	- Suppression of chemical and organo-mineral fertilisers.
Freshwater ecotoxicity	- Suppression of chemical and organo-mineral fertilisers manufacturing		
Terrestrial ecotoxicity	- Suppression of chemical and organo-mineral fertilisers manufacturing		
Freshwater eutrophication	- Suppression of chemical fertiliser		- Decrease in fertilisation - Suppression of herbicides (decrease in manufacturing impacts)
Particulate matter formation	+ Machinery impact (higher number of passes for mowing or sowing...) - Suppression of chemical and organo-mineral fertilisers and nitrogen emissions reduction due to a lower dose of fertiliser (now organic)	- Suppression of chemical and organo-mineral fertilisers - Reduction of nitrogenous emissions linked to organic fertilisers + Methane emissions from the eco-pasture sheep (4 sheep/ha over 3 months).	- Suppression of the chemical and organo-mineral fertilisers replaced by organic fertilisers (reduction of nitrogenous emissions) - Replacement of diesel by electric power for soil maintenance operations
Terrestrial acidification	- Elimination of chemical and organo-mineral fertilisers (manufacturing) - Reduction in the dose of fertilisers (decrease in nitrogenous emissions ammonia and nitrous oxide) into the air		- Suppression of the chemical and organo-mineral fertilisers (manufacture) - Replacement of diesel by electric power for soil maintenance operations
Ozone depletion	- Suppression of chemical and organo-mineral fertilisers	- Idem fossil depletion + manufacture of organic fertiliser + enteric emissions from eco-pasture sheep (4 sheep/ha over 3 months)	- Suppression of chemical and organo-mineral fertilisers
Global warming potential (100y)	Idem fossil depletion	Idem particulate matter formation	Idem fossil depletion

iv) to add other dimensions or indicators such as biodiversity or economic ones. Some facilitators and participants pointed out the complexity of the LCA result charts for the participants.

Discussion

We have proposed and tested a participatory ecodesign approach to crop management to inform the PDO's environmental strategy. Its application to the case of soil management in Cognac vineyards helped to address several issues: i) the relevance and operationality of this approach adapted from the framework proposed by Rouault *et al.* (2020); ii) the validation of the feasibility and interest of an LCA-based ecodesign workshop of a viticulture PTO by an association of different stakeholder profiles and with a foresight dimension; iii) the relevance of using the Vitigame serious game at the PDO level; iv) the exploration of future herbicide-free PTOs for vineyard soil management and their environmental performance to inform the environmental strategy of the Cognac PDO; and v) the interest of the participants in LCA as a tool for assessment and ecodesign.

Relevance and operationality of the participatory ecodesign approach at protected designations of origin scale

The initial case was uncritically accepted as the ecodesign basis by all the participants. The design objective was "an annual PTO of soil and fertiliser management with less impact than the initial case" and the framework of constraints was "herbicide-free" and "designed for 2030". They were precisely defined by the organisers. This may have limited the creativity of some participants, as observed by Jeuffroy *et al.* (2022) in different agricultural design situations, who also mention that the constraints may either increase fixation in certain situations, or stimulate the exploration of solutions in the case of unusual constraints. In the present situation, orienting the participatory process towards 2030 catalysed discussions and forward thinking at the PDO scale. It limited fixation in two groups out of three. As experienced by other authors, it raised questions that can feed further thinking at the territorial level, such as the environmental benefits of a more extensive viticulture, *i.e.*, using lower input quantities, but also the question of replacing fossil fuels in the Cognac vineyard, which implies identifying the other energies available in the territory and developing a strategy for the future on this issue with other actors in the territory. Other participatory methods could be mobilised to promote this type of thinking involving stakeholders of the territory outside of the PDO and the wine and spirits sector, such as the "*jeu de territoire*" which helps to build a shared vision of a territory and its stakes and involves actors capable of taking part in collective action for their territory (Lardon, 2013).

Additionally, the workshop gathered several good conditions to prepare for transformative change (Hebinck *et al.*, 2018). Firstly, the presence of agents of change as participants, as all the participants were involved in strategic decisions for the PDO, and represented different professions involved in the Cognac *eau de vie* production chain, secondly, institutional support, as the workshop was organised by the BNIC, the main territorial institution in the wine and spirits sector, which manages and promotes the PDO. The implementation of the changes will then depend on the next steps decided by the BNIC in this process. Indeed, these collective innovation processes need to be followed by complementary actions to increase their usefulness. Jeuffroy *et al.* (2022) advise to first inform the participants about the results and outcomes of the workshop. In the present case, a detailed analysis of the ecodesign choices and their calculated impacts as presented in the results part of this paper was given back to the participants during a meeting with an oral presentation given by the agent of the PDO in charge

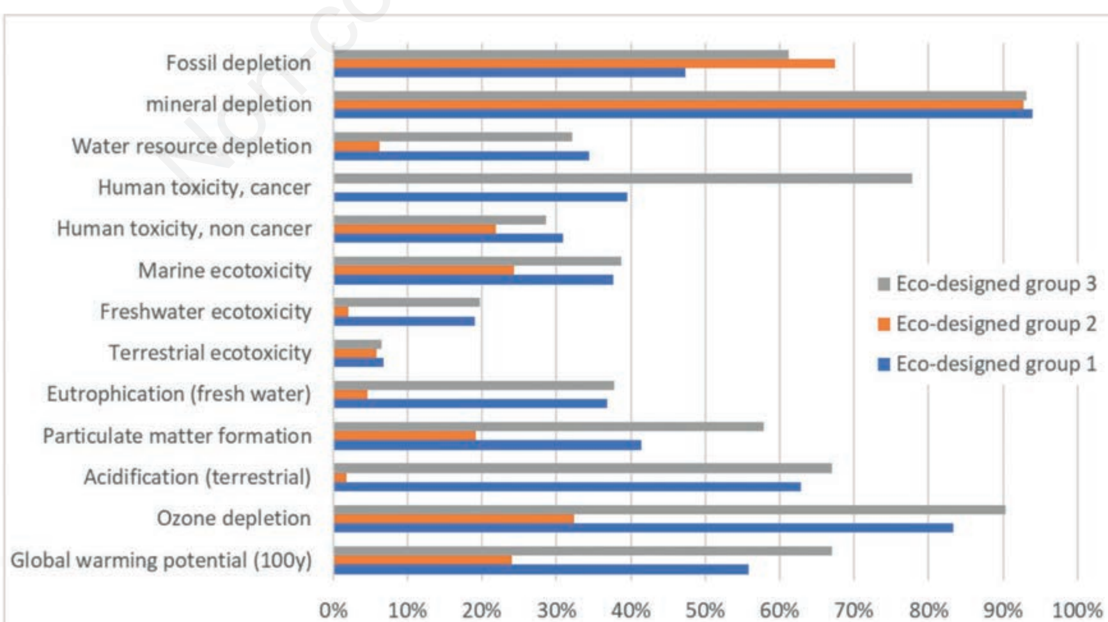

Figure 4. Percentage decrease in environmental impacts, obtained by the three groups (1 to 3) of stakeholders, related to the initial case (identical initial case for all the groups). Functional unit: 1ha vineyard cultivated for 1 year.

of environmental issues. The authors also advise capitalising on what the participants have produced and on the knowledge gaps they have identified. In the present case, the workshop produced pre-concepts for innovative or optimised PTOs, and participants identified knowledge gaps on green manures and grass species that are not highly competitive with vines for covering the vineyard under the row. The role of fertilisers in the environmental performance of the wine territory was also an issue raised. Future applied research programmes conducted or sponsored by the BNIC could be based on the identification of these knowledge gaps to provide PDO members with technical references that allow practice change.

The environmental assessment of the practices is the starting point and the result of the eco-design work. For this reason, special attention must be paid to achieving an understanding of the assessment results by all the participants, whatever their profile. Nevertheless, the communication of LCA results to stakeholders for eco-design and more broadly for decision-making remains a challenge (Guérin-Schneider *et al.*, 2018). This was confirmed by the experience of some facilitators and participants in the workshop, who highlighted the complexity of the LCA results as a difficult point. This should be addressed and tested in such a context in the future, with improvement of visualisation of LCA results, and efforts to better explain the link between impacts and their causes (Rio *et al.*, 2019). Finally, the complexity of the LCA method can hinder quick communication of results to participants, but the Vit'LCA® calculator enabled same-day feedback during the design process, which was appreciated and should be applied in ecodesign workshops.

Feasibility of a life cycle assessment-based ecodesign workshop of a viticulture pathways of technical operations involving different stakeholder profiles

The choice of the participants is crucial for the success of the workshop (Jeuffroy *et al.*, 2022). To ensure an efficient pre-conceptualisation of transformative change, they must represent the diversity of the stakeholders affected by the change to be established (Hebinck *et al.*, 2018). At the PDO level, this can represent a variety of profiles. The wide range of professionals involved in the Cognac workshop were thus able to 'mobilise collective and distributed intelligence', as pointed out by Lançon *et al.* (2008).

However, this led to a heterogeneity in the profiles of the participants in terms of their level of knowledge of the technical aspects of viticulture and the environment.

The participatory ecodesign process based on the serious game was successful in involving these different profiles of participants, in making them understand and manipulate the LCA results and eco-design, and in designing together a sound vineyard soil management PTO. There were good exchange dynamics in all the groups. Nevertheless, the initial knowledge transfer on LCA and environmental impacts produced contrasting reactions from the participants in the feedback questionnaire, which translates the diversity of profiles and underlines the difficulty of adapting knowledge transfer to stakeholders with contrasting backgrounds. In future similar experiences, different pedagogical tools could be mobilised for the initial knowledge transfer on LCA and environmental impact phenomena to better reach this heterogeneous audience. For example, some cards inspired by the Climate Fresk® experience (Ringenbach and Sirot, 2020) could favour the involvement of participants already skilled in environmental issues to transfer their knowledge to others; another option, although less straightforward, is to use mixed reality to convey these complex concepts (Jacquet *et al.*, 2022). The diversity of the participants' profiles also brought richness to the debates, but could also have increased the power of fixation of certain participants with a better technical knowledge who could impose their views thanks to the authority conferred by their expertise. Nevertheless, some participants advised to include more people with technical knowledge in the panel of participants to strengthen the technical soundness of the decisions.

Relevance of using a serious game for an ecodesign workshop

The serious game approach and tools proved to be a good means to generate collective thinking as experienced by Dernat *et al.,* (2022), and enabled the materialisation of reality to create a designed common object. As the participatory work lasted 1h30, knowledge sharing may have been limited compared to longer processes organised with different meetings and workshops (Masson *et al.*, 2021; Della Rossa *et al.*, 2022; Dernat *et al.*, 2022). Nonetheless, the work could generate innovative proposals of PTOs, especially thanks to a projection to 2030 which managed to elicit creativity in two groups out of three. The facilitators mentioned a rich exchange between the players, as dialogue and social interactions were present in the serious game as recommended by Foko and Amory (2008) and encouraged by the facilitators.

The Vitigame rules helped to guide the process with successive steps of co-design: *i.e.*, discovering and understanding LCA results, identifying and selecting the levers, and building the PTO step by step on a weekly basis. Already providing a pool of ecodesign levers and a set of usable practices, as well as white cards to add other practices if needed, it allowed participants to obtain PTOs in a rather short time (1h30) compared to other reported design processes that required more than one workshop (Reau *et al.*, 2012; Rouault *et al.*, 2020)

This role of facilitation is key in the design workshop process (Jeuffroy *et al.*, 2022), and the game artefacts were crucial as intermediate objects for facilitation of the design process. Hebinck *et al.* (2018) highlight the role of the researchers in a researcher-led foresight process. The future-oriented discussions took place during the ecodesign process, in relation to the foresight dimension of the exercise. However, the facilitators had never run foresight workshops before and had not received specific training to do so; they were trained to facilitate ecodesign workshops. The discussions might have been deeper or richer if the facilitators had been given specific training or a framework to encourage foresight thinking during the ecodesign exercise.

Exploring possible future herbicide-free pathways of technical operations for vineyard soil management and their environmental performance

The process produced three quite different vineyard soil management strategies with innovative proposals in two of them. This confirmed the interest of this ecodesign approach to stimulate "collective creativity in agriculture" (Jeuffroy *et al.*, 2022). In terms of LCA, fertilisation was the main hotspot of the PTO of the initial viticulture case, making it a priority for ecodesign, followed by diesel combustion. The participants, helped by the facilitators and the initial presentation, clearly identified the ecodesign objectives and levers, despite the complexity of the LCA histograms. They mobilised different solutions according to the groups, resulting in average improvement rates of the environmental impacts compared to the initial case (38%, 18% and 51% respectively for the three groups) comparable to previous experiences made by

Rouault *et al.* (2020) who reported an improvement rate of 27% in average on complete PTOs. The ecodesign process was a step-by-step design (Meynard *et al.*, 2012), and only concerned the annual PTO. Grapevine is a perennial, and a *de novo* redesign approach (Reau *et al.*, 2012) could be complementary to allow the use of other levers such as switching to a more vigorous grapevine rootstock to increase tolerance to grass competition. A complete redesign of the cultural system has been experimented in field for perennials as in viticulture (Thiollet-Scholtus *et al.*, 2021) or in orchards (Ricard *et al.*, 2022). Such innovative design in these sectors is not yet documented in terms of LCA results, making it difficult to estimate the potential gain in terms of environmental impact of *de novo* design.

The players could also observe that some LCA results are not in line with general thinking, as in the case of sheep grazing in the vineyard (in the case of sheep dedicated to grazing only) or the use of biodiesel from used cooking oil, which, according to modelling (Can, 2014; Ogunkunle and Ahmed, 2021), increased some impacts. The most efficient levers mobilised were the use of electricity instead of fossil fuels, the reduction of fertilisation, and the use of permanent or temporary grass cover such as green manure, which reduced the intensity of use of the machinery for soil tillage. Green manure also contributed to the reduction of fertilisation. Some pre-concepts included solutions that still need to be developed through research or development such as hydrogen tractors and non-competitive grass for the vine row. The process did not aim to reach a consensus on a single ideal PTO for the Cognac PDO as other approaches aimed (Reau *et al.*, 2012). It rather aimed to encourage the emergence of ideas and proposals for the evolution of soil management practices in the PDO, and an exploration of possibilities. Further exploration of these pre-conceptualisation proposals by the PDO agents and members can be a building block of the future strategy of the PDO.

Participants' interest in life cycle assessment as a tool for assessment and ecodesign

The high level of involvement of the participants observed by the facilitators and the positive feedback on the ecodesign process confirm the interest of the participants in such a workshop. The feedback survey also showed their confidence and interest in the LCA methodology for the assessment of technical solutions by the BNIC to inform the PDO strategy and provide references to its members.

This was confirmed by the official decision to continue the use and development of LCA by the BNIC environment department during the subsequent committee meeting.

Complementary dimensions could be added to the LCA evaluation to increase the interest of the participants, such as an economic assessment of the practice change using, for example, the IPE2Vit tool (Ben Jaballah *et al.*, 2019). The addition of biodiversity indicators was suggested by some participants; however we lack sufficiently sensitive biodiversity indicators for application to practice change in viticulture, that could be used in an eco-design process, such as those recently developed for vegetable production (Pépin *et al.*, 2023).

Conclusions

This research proposed a new development of LCA-based participatory ecodesign, to inform the environmental strategies of PDOs. It was tested in the context of viticulture with the Cognac PDO. It confirmed that participatory ecodesign of PTOs facilitated by a serious game and based on LCA can be successfully applied at the PDO level. The involvement of stakeholders with different profiles and elected representatives of the PDO was useful to open the field of creativity and provide good conditions for the future implementation of the proposed solutions in the PDO strategy. Nevertheless, this diversity was a challenge to adapt the knowledge transfer to the needs of the audience and to provide the minimum skills in viticulture necessary to design PTOs in each group. It is therefore important to manage the composition of the working groups to represent the diversity of stakeholders in the sector, and to ensure a sufficient presence of technical expertise, but also to minimise cognitive bias. Most participants found the workshop useful and interesting from a future perspective. They suggested improvements to the ecodesign process. They found LCA to be a relevant tool to be further used and developed in their PDO.

Vitigame was an interesting tool for the ecodesign of vineyard soil management PTOs. The participatory ecodesign exercise with three tables of players gave a variety of new PTOs by mobilising different ecodesign levers and giving different levels of efficiency in terms of reducing environmental impacts. The proposal to design a PTO for 2030 limited fixation bias and raised interesting questions to be addressed for the future of the PDO. The initial knowledge transfer on LCA should be further improved to meet the different needs of a variety of stakeholders. The workshop should then be followed up by incorporating its results into the future actions and thinking of the PDO. This work opens up possibilities for future research to improve this process i) to make LCA results more widely understood and efficiently used by all profiles of stakeholders; ii) to complete the assessment of the ecodesigned solutions by including economic indicators; and iii) to define indicators of the impact of practices on biodiversity; iv) to include such workshops in a wider accompanying path. This could ensure a follow-up of the results up to the implementation of the changes. This path could include different assessment tools and other serious games to address other issues such as *de novo* design of the vineyard.

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