SIMULATION
http://sim.sagepub.com/

Methodological approach towards sustainability by integration of environmental impact in production system models through life cycle analysis: Application to the Rioja wine sector

Emilio Jiménez, Eduardo Martínez, Julio Blanco, Mercedes Pérez and Charmery Graciano

SIMULATION published online 15 March 2013
DOI: 10.1177/0037549712464409

The online version of this article can be found at:
http://sim.sagepub.com/content/early/2013/03/15/0037549712464409

Published by:
SAGE
http://www.sagepublications.com

On behalf of:

Society for Modeling and Simulation International (SCS)

Simulation

Simulation: Transactions of the Society for Modeling and Simulation International
0(0) 1–19

DOI: 10.1177/0037549712464409
sim.sagepub.com
SAGE SCS

Methodological approach towards sustainability by integration of environmental impact in production system models through life cycle analysis: Application to the Rioja wine sector

Emilio Jiménez[1], Eduardo Martínez[2], Julio Blanco[2], Mercedes Pérez[2] and Charmery Graciano[2]

Abstract

This paper proposes the integration of life cycle analysis within the production system models as a tool for decision making (whether at the strategic, tactical or operational levels) attending not only economic and technical criteria but also the environmental impact. This methodological proposal advances over the traditional approach of calculating the value of the environmental impact of a particular product, by proposing the use of models to determine the environmental impact of the product, according to the decisions made in the production system. That is, it does not provide an impact value of the product, but rather a model to determine the impact in terms of the decisions made in the production process; therefore, it can be used, especially by means of simulation, for the optimization of the production system, based on multiple criteria (including environmental impact).

The methodological approach is exemplified by a case study, which is used to validate the proposal and to expose it more precisely and clearly, although the methodology is equally applicable to any production process, especially processes highly automated or with different alternative production techniques.

This case study, based on the wine production sector of the Rioja Qualified Designation of Origin, in Spain, was made with actual data after several years of research in representative wineries; therefore, besides an application example, it is a support tool for sustainability in wineries, by reducing the environmental impact of wine production (especially in La Rioja and Spain, but generally throughout the world).

Keywords

sustainability, modeling and simulation, environmental impact, life cycle assessment, production systems, decision making

1. Introduction

Production systems, at all levels and in all places, are governed primarily by economic factors when making decisions trying to optimize their results, especially in today's globalized markets[1–3] and principally in times of crisis. However, production models based solely on economic gain at the expense of the exploitation of resources (in its broadest sense) cannot persist longer than a certain time, due to the limited nature of these resources. So it is necessary to aim, sooner or later (preferably sooner), towards a sustainable model, that is, a model in which resources are not consumed faster than their generation.

It is necessary to know both the generation capacity of environmental resources and the consumption of these resources, or equivalently, the environmental impact due to the production activity. Knowledge of resource consumption and environmental impact not only allows comparison with the resource generation, but it is also the first step towards establishing a policy of reducing these

[1]Department of Electrical Engineering, Higher Technical School of Industrial Engineering, University of La Rioja, Spain
[2]Department of Mechanical Engineering, Higher Technical School of Industrial Engineering, University of La Rioja, Spain

Corresponding author:
Emilio Jiménez, Department of Electrical Engineering, University of La Rioja, Higher Technical School of Industrial Engineering, C/ Luis de Ulloa 20, E-26004 Logrono, Spain.
Email: emilio.jimenez@unirioja.es

consumed resources and their impact, in the most appropriate way (i.e. towards their optimization).

Nowadays, the sustainability of the actions or decisions made in order to manage or solve any problem or need that may arise, both in business and society in general,[4–8] is increasingly gaining more force and weight. A growing trend has been observed in recent years related to including ecological and environmental factors[9–11] in production and logistic models used as support for decision making based on simulation.[12–14]

One of the most widespread and powerful techniques to determine the environmental impact is the life cycle analysis (LCA),[15] which is used to determine the full impact of each product based on all consumption of resources "from the cradle to the grave", that is, from the beginning of the most basic productive activities and materials for its production, to its eventual integration into the nature at the end of its useful life (through reuse, recycling or degradation).

This paper proposes the integration of LCA within the production system models as a tool for decision making (whether at the strategic, tactical or operational levels), attending not only to economic and technical criteria, but also to the environment impact. This methodological proposal advances over the traditional approach of calculating the value of the environmental impact of a particular product, by proposing the use of models to determine the environmental impact of the product, according to the decisions made in the production system. That is, it does not provide an impact value of the product, but rather a model to determine the impact in terms of the decisions made in the production process; therefore it can be used, particularly by means of simulation, for the optimization of the production system, based on multiple criteria (including environmental impact).

There exist production processes without important decision making (for example, the production of electricity in a wind farm), which can accurately estimate the impact of the production unit (on average), but there also exist other processes in which decisions are constantly made to adapt production to the arising external factors, such as demand, breakdowns and failures, supplies and raw materials, transportation and logistics, etc. In such processes (such as the automotive sector, or in general any automated manufacturing system or production systems with different alternative production techniques), modeling and simulation are essential tools for the optimization of the production system by taking appropriate decisions each time.[16,17] The integration of environmental impact in these models can determine the impact of the production according to the decisions made, and therefore constitutes a powerful tool for production support, attending to sustainability together with the other criteria.

The proposed integration of LCA into the production process can be used independently of the process modeling formalism. This also facilitates the optimization of multiple sustainability aspects: not only environmental impact, but also the combination with economic, technical or social factors included in the original production system model. The methodology approach is exemplified by a case study, which is used to validate the proposal and also to expose it more precisely and clearly, although the methodology is equally applicable to any production process, especially very automated processes and with different alternative production techniques (such as in the canning industry, mechanization sector, textiles, etc.).

This case study, based on the wine production sector of the Rioja Qualified Designation of Origin (DOCa Rioja), in Spain, was made with actual data after several years of research in representative wineries;[18] therefore, besides an application example, it is a support tool for sustainability in wineries, by reducing the environmental impact of wine production (especially in La Rioja and Spain, but generally throughout the world).

After this introduction, Section 2 presents the proposed methodological approach; in Section 3 the case study of the productive system of Rioja wine is shown; Section 4 presents the results of the case study; Section 5 summarizes the conclusions of the new methodological approach proposed in this research.

2. Methodology

2.1 Life cycle assessment

LCA is a methodology that can be seen as a tool to examine all environmental aspects and potential impacts of a product or service. Unlike other methodologies for assessing environmental impact, the LCA methodology has been developed to consider a wide range of potential resources and environmental impacts that include, among others, the following: global warming, depletion of the ozone layer, eutrophication, acidification, human toxicity and ecosystems, natural resource depletion, energy consumption, land use and water use.[19,20]

In order to get an impression of the overall impact caused by the product or process under study, the analysis should focus on the product life cycle. This philosophy of life cycle approach, also known as ''cradle to grave'', considers that all the stages involved in the life cycle of a product or process have a responsibility on its environmental consequences.[21] LCA methodology is the most widely used tool to consider the systematic environmental impacts along the life cycle of a product, process or activity, and it is also a methodology under the ISO 14040 standard.[22] This makes LCA an appropriate tool for different purposes: to provide product information and associated environmental impacts; to isolate the stages in the life cycle of a product or process to identify which one generates the most significant contribution to its overall environmental impact; and to assess improvements or alternatives, as well as evaluate and compare products, processes or services, etc. Environmental communication tools, such as the environmental product declaration (EPD), can be based on LCA, and can be used as a tool to develop balanced environmentally friendly products, as well as contribute significantly to the marketing strategy.[23]

In the case of the methodology proposed in this article, within the different impact assessment methodologies under the LCA umbrella, the methodology of Eco-Indicator 99 has been chosen. Eco-Indicator99 is an impact evaluation method that models the damage of emissions of the processes by analyzing the fate, exposure, effects and damages. Pursuant to the LCA methodology, the impact assessment method Eco-Indicator99 consists of five phases (after the initial selection of the environmental categories).

- Selection of the environmental categories: there are different methodologies for assessing the impact of the life cycle, each of which provides a number of environmental categories to be analyzed.[24,25] The impact categories established for the Eco-Indicator99 are:
  - carcinogens;
  - respiratory organics;
  - respiratory inorganics;
  - climate change;
  - radiation;
  - ozone layer;
  - ecotoxicity;
  - acidification/eutrophication;
  - land use;
  - minerals;
  - fossil fuels.
- Classification: involves the allocation of the environmental loads of all the inventory data for the various categories previously selected, based on the expected environmental consequences of every environmental load, that is, for each substance consumed or emitted.
- Characterization: involves the application of models to obtain an environmental indicator for each impact category, converting to a single reference unit all substances classified in each category by using weighting factors or equivalency.
- Standardization: consists of evaluating the significance of the environmental profile generated in the previous steps by setting the weight of each category. This stage allows the non-dimensionalization of the categories and the comparison between them. The value obtained in each category can be relativized with respect to a reference quantity, which can be, for example, the value of that category in question for all global activity of the country or region where the study is conducted.
- Grouping: this is the assignment of the impact categories on one or more sets in hierarchical order.
- Validation and weighting: this is the conversion of the results of the characterized values to a common and summable unit, multiplying by their weighting factor, that is, the normalized results. Then, all of them are added up to score a single total environmental impact of the system.

The Eco-Indicator99 methodology allows weighted analysis from three perspectives or different models: hierarchical, individualistic and egalitarian. For this study, the egalitarian version has been chosen, which analyzes all possible effects from a long-term point of view. The use of Eco-Indicator99 provides unique values of environmental impacts, combining in different impact categories as may the effect on climate change or carcinogenic effects of the used substances. This will facilitate the methodological approach by the incorporation of the results obtained at this stage in the decision-making process proposed throughout the paper.

2.2 Modeling and analysis of the production process

Modeling and analysis of the production process involve the collection of data and calculation procedures to quantify the inputs and outputs of a product system. It is an iterative process that must be repeated or modified, if necessary, for the emergence of information during its execution. It is likely that at this stage the need for modifying the objectives or scope of the study arises.

The system under study should be modeled as a complete sequence of unit operations that communicate with each other via inputs and outputs. It is necessary to build up a model of reality that is able to represent as accurately as possible all the changes between individual operations belonging to the product system studied. The compilation of inventory data for each individual process quantifies the inputs and outputs associated with the reference flow of proceeds derived from the functional unit.

For this modeling phase the following steps are defined.

- Construction of the flow diagram in accordance with the system boundaries established in the definition of the objectives and the scope of the study. A general model of a flow chart is shown in Figure 1.
- Data collection of all the activities in the production system. It is necessary to establish the origin of these data: bibliographic and/or in situ measurements; in the latter case, the methodology used should be specified (measurements, surveys, interviews, reports).
- Calculation of environmental loads related to the functional unit.

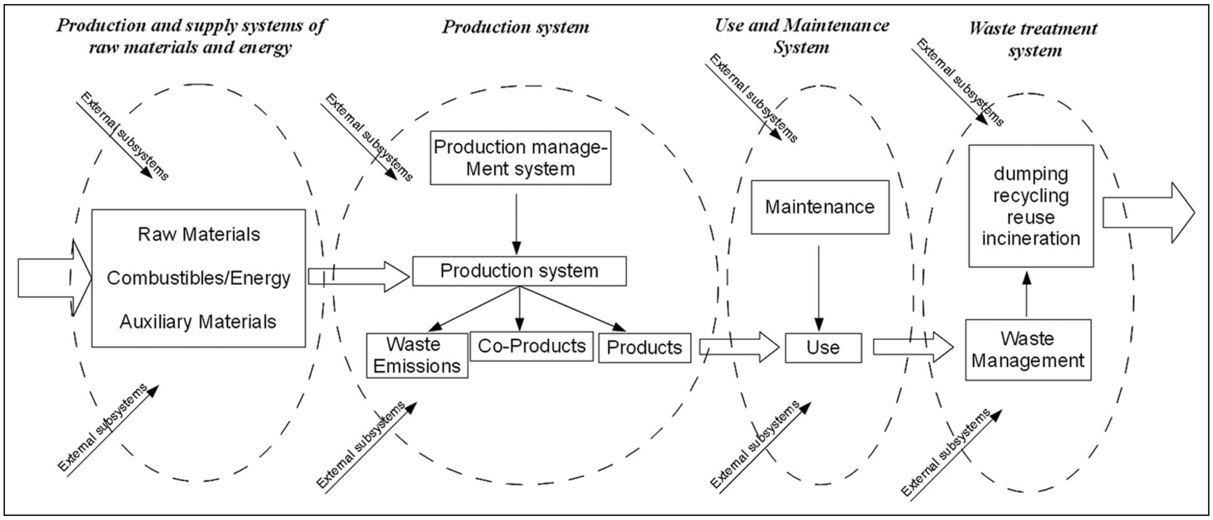

Figure 1. General diagram of process flow.

- Standardization of data in terms of units.
- Mass balance that allows interrelating the inputs and outputs between the different subsystems.
- Quantification of system outflows to the nature or technosphere.
- Global inventory.

2.3 Integration of LCA in the production system model

Let us analyze some examples showing the purpose of the proposal. On the one hand, imagine the production of electricity from a wind turbine. The production system has almost no leeway in deciding the production process: the generation, maintenance, repairs, etc. are basically variables that cannot be controlled internally. So the LCA can be useful to find the environmental impact of each unit produced (in this case, each KW · h of wind energy produced in a given wind farm).[26–28]

On the other hand, imagine a productive system of an automated factory in which the production manager can decide when to order materials, when to start each process, the batch sizes, production routes in the factory or between factories of the company, etc.[29] In this case, every one of these decisions affects the total environmental impact of the whole production system, and therefore also the impact of each element (e.g., every brick, every car, etc.). In this case, it is of no interest to find the average impact of each brick, but to have a model showing the impact value according to the decisions made. Usually, the models of the systems are used to optimize production processes, frequently by simulation, making decisions that optimize production depending on the state of the system. However, by using the proposed methodology, which includes every part of the process model its environmental impact, decisions can be made while knowing the environmental impact of the real process (which depends on the decision made).

Analyzing this environmental impact (together with other factors, such as economic, productive, technical or social), decisions can be made aimed at optimizing a multicriteria objective. That is, the proposal of integration of LCA into the production process model can be used independently of the formalism used to model the process. This facilitates the optimization of multiple sustainability factors: not only environmental impact, but also the combination with economic, technical or social elements that may be included in the model of the production system.

Thus, the methodology consists basically of determining all the possible alternative production techniques, representing them in a model that provides all possible methods of production (according to the decision made on the alternative production techniques) and analyzing with LCA the environmental impact of any of the individual possibilities; in this way, given any production system, the model can provide the real environmental impact, as well as the processes in which the impact is the highest, or those in which there exists alternative production techniques that allow reduction of the environmental impact.

3. Case study: DOCa Rioja wine sector

3.1 Modeling and analysis of the generic production process of the DOCa Rioja wine sector

One of the first items to be considered is the correct definition of the objectives and limits of the system. This step is essential in order to evaluate the final results, since it is necessary to know, together with the assessed impact, the scope of the study and the stages of the process that have been taken into account. In the present case, the main objective of this study is to obtain a complete environmental vision of the process by identifying and analyzing the inputs and outputs of materials and energy associated with all the different ways of developing each one of the activities involved in the process of production of red wine in DOCa Rioja. Therefore, every stage of the life cycle will be considered, from assessment of the land for cultivation to waste disposal after wine consumption, in order to identify critical activities and propose improvements to the production system, by determining the optimal method of production according to the developed model.

Regarding the system limits established for all processes, the following activities are outside these limits:

- the production, purchase and maintenance of capital assets, due to the lack of existing data, the low contribution of these elements to the functional unit and the exclusion of these activities in previous studies;[30,31]
- CO_2 emissions during fermentation: these represent carbon that was only temporarily isolated from the natural carbon cycle;[30,32]
- emissions from the application of herbicides and pesticides, due to lack of data concerning weather conditions at the time of application[31,33,34] and the absence of specific dispersion models of the area to estimate the behavior of these emissions in air, water and soil;[35]
- production of organic fertilizer, due to the lack of data;[36]
- pulling up the old vineyard: these activities are included in the implementation of a new vineyard;
- installation and dismantling of the processing plant, due to the lack of existing data, the low contribution of these elements to the functional unit and the exclusion of these activities in previous studies;[30,31]
- collection, treatment and transport of process water.

The following activities have been included within the limits of the system:

- fuel consumption in agricultural operations;
- electricity consumption in winery equipment;
- production and transport of herbicides and pesticides;
- production of inorganic fertilizer;
- transportation of fertilizers;
- emissions from fertilizer application;
- wastewater treatment;
- production and transport of barrels;
- production and transport of bottling and packaging;
- production and transport of clarifiers and other oenological compounds.

Once the breadth and scope of the study is clearly defined, the next step in modeling the production process is to divide it into individual activities to facilitate the subsequent analysis and evaluation process. In this case four major activities have been determined.

- Agricultural phase: includes the different methods of carrying out all the operations related to the cultivation of grapes, from assessment of the land for cultivation to harvesting and transporting the grapes to the winery.
- Phase of industrial transformation in the winery: includes all operations performed in the winery for processing grapes into wine, from receipt of the harvest to bottling wine ready for trade.
- Distribution and commercialization phase: includes the distribution of bottled wine to wholesalers within and outside Spain.
- Waste consumption and management: includes wine consumption and waste management of the container, and also the management of waste produced in the previous phases. Data corresponding to packaging waste and urban waste management, in Spain and the rest of Europe, are used.

Some schemes of the production possibilities in the different parts of the whole process are represented in the subsequent figures, in which what is important is not the name of any individual task but the possibility to follow different methods by simulation of the model, that is, the representation of all the alternatives in the productions (and so the possibilities in the decision making).

For instance, analyzing the scheme of Figure 2, the different alternative possibilities can be observed at every stage, providing as a global result 5,971,968 possible alternatives just for the activities of the agricultural phase (and much more if it is considered that some of the stages could be avoided). The combination of these possibilities with the possibilities of the other phases (for instance those in Figure 3) provides the real options of wine production, with more than 10^{20} different possibilities.

3.1.1 Activities of the agricultural phase. In this study it is considered that the vineyard has a useful life of 50 years;[31] from this period, some assessments and site preparation should be performed again. The activities studied in this phase are shown in Figure 2.

The inventory data used in this phase was provided by growers of various production zones in the region, previous studies, agricultural machinery manufacturers and manufacturers of products such as fertilizers, herbicides and other substances used.

All data is based on 1 hectare of irrigated vineyard area, with an annual production of 6500 kg of Tempranillo

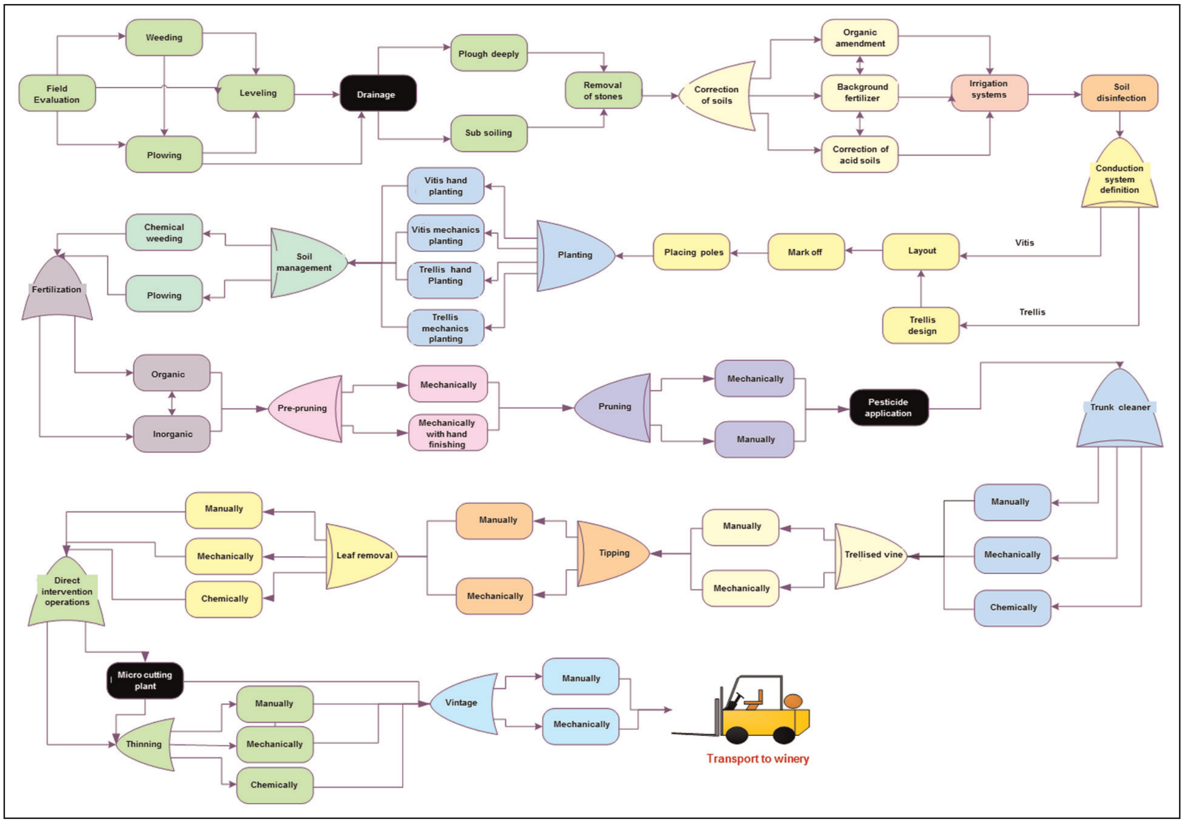

Figure 2. Activities of the agricultural phase. Generic process of classic production of red wine in DOCa Rioja.

grape, which is the maximum production allowable by the Corporation DOCa Rioja for red grapes.

It is considered that the workers live within 11 kilometers of the winery on average and that a moving individual car consumes 4.95 l/100 km of diesel.[37] They make two trips per day (of 8 hours working). The number of workers varies according to the activity.

Most agricultural compounds and materials are purchased in the area of La Rioja. The transport distance from the supplier warehouse to the studied winery is taken into account for each product.

The organic amendment is carried out using a dose of 45 tons of sheep manure. It was considered a background mineral fertilizer at 600 kg superphosphate 18% and 600 kg of potassium sulfate 50%. For the correction of acid soils, 2750 kg of calcium oxide has been used on the ground.

Annual water requirements of 11,000 hl/ha for each irrigation system studied have been considered in the vineyards. The water comes from the local distribution network. Uptake, treatment and transport values of water used for irrigation of the inventory correspond to the inventory of the database. All the possible irrigation systems have been evaluated: tended, borders, furrow, sprinkler, micro sprinkler, drip and superficial. The installation of the irrigation system has not been taken into account.

Soil disinfection was carried out with the use of nematicides Telone II and Temik 10G, in doses of 500 l and 200 kg, respectively.

The Corporation DOCa Rioja sets the minimum and maximum allowable number of plants per hectare of vineyard allowed depending on the conduction system utilized. In this work a planting of 3,100 plants per hectare in all the systems has been considered. For the planting on trellis systems, the use of pine poles, pole markers, anchors and galvanized steel wire, which are the most commonly used materials in the area, have been taken into consideration.

Soil management is done by tillage or chemical weeding. The realization of three tillage activities per year has been considered. Chemical weeding is done by applying 1.5 kg of glyphosate 36% diluted in 150 liters of water.

For emissions associated with the production of grapes, a significant percentage of the total impact of agricultural systems corresponds to the emissions associated with the application of amendments and organic and inorganic fertilizers.[34,35,38] In the current study, organic vineyard fertilization was developed by applying 3000 kg of sheep manure, and inorganic fertilization with 500 kg of NPK fertilizer. The data on the composition of the latter have been supplied by the manufacturer (Fertiberia).

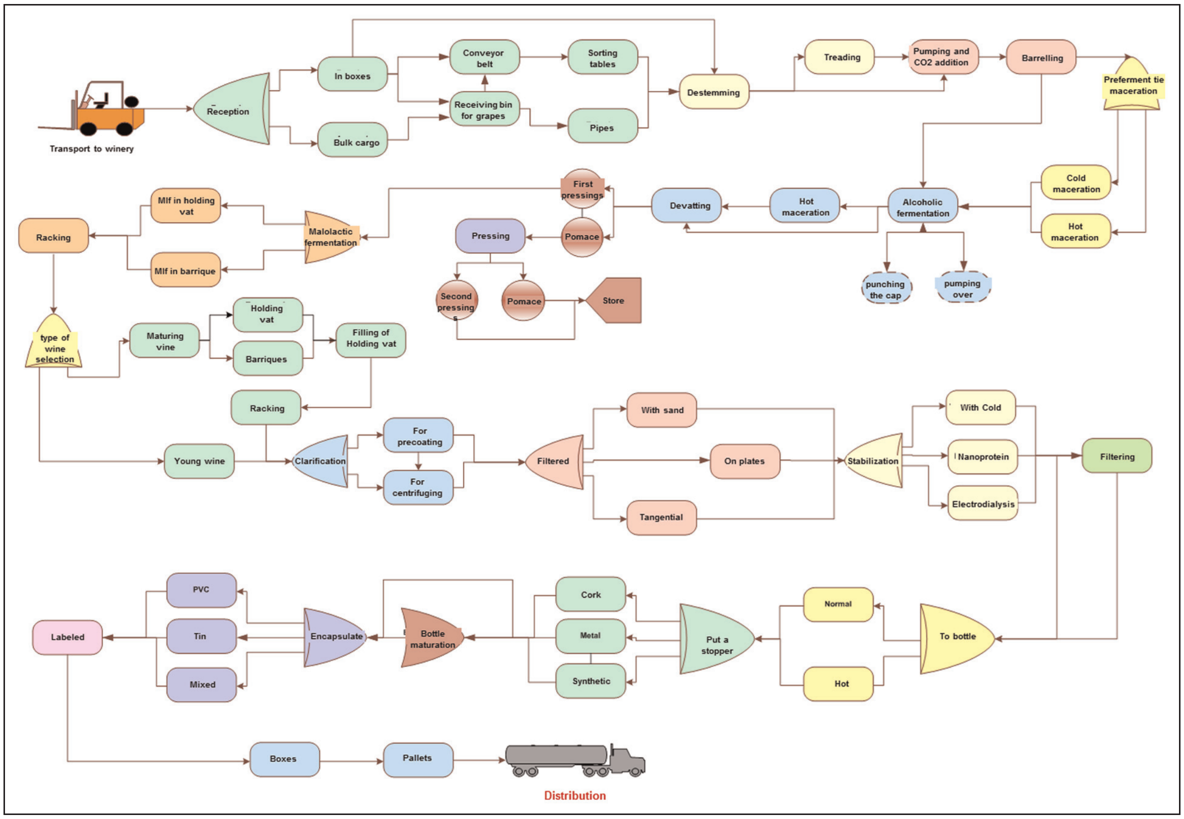

Figure 3. Activities of the industrial transformation phase. Generic process of classic production of red wine in DOCa Rioja.

The methodology used to calculate the emissions associated with the fertilizer application corresponds to a proper distribution model[35] based on an average retention factor on the floor of 60% for inorganic fertilizer and 40% for organic.[36] However, it is noteworthy that the analysis does not take into consideration important factors to study the behavior of fertilizer at the time of application, such as weather, soil characteristics and climatic conditions.[39–41]

The vine shoots produced in the pre-pruning and the pruning are crushed by a machine and then scattered on the ground. The CO_2 emissions from the breakdown of the branches are also considered, since it is estimated that the amount of CO_2 released is equivalent to the amount fixed by the plant during its growth.

The branches, tips and clusters produced from the trunk cleaner, heading and thinning operations are collected and transported to a composting plant. To apply the chemical trunk cleaner, 370 l of a solution composed of Paraquat herbicide and oil Agral 90 is applied. The chemical thinning was carried out with the application of chemical thinner Sierra (Ethephon) using a backpack sprayer at a dose of 2 l/ha.

Table 1 shows a small example of the inputs and outputs associated with the specific activity of organic

Table 1. Inputs and outputs associated with the activity of organic amendment.

Activity	Process	Input	Unit	Quantity	Output	Unit	Quantity
Correction of soil	Organic amendment	Workers transport diesel	l	0.27	Ammonia (atmosphere)	kg	80.9166
		Tractor diesel	l	19.00	Nitrate (groundwater)	kg	1405.67
		Organic fertilizer	kg	45,000	Dinitrogen oxide (atmosphere)	kg	59.75
		Fertilizer transport	km	10	Oxides of nitrogen (atmosphere)	kg	4.073
					Phosphates (groundwater)	kg	1806.51

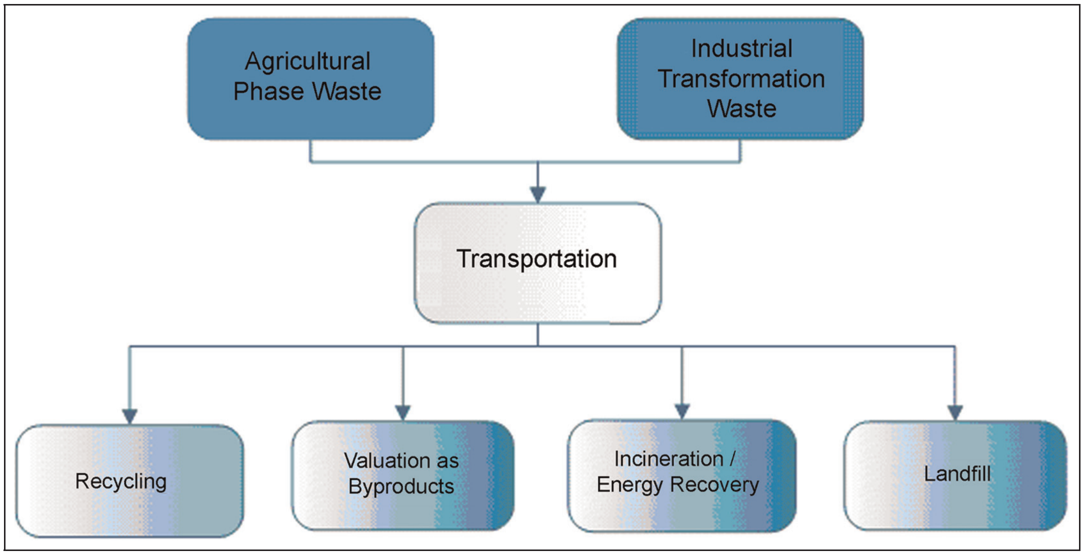

Figure 4. Process waste management. Generic process of classic production of red wine in DOCa Rioja.

amendment. For brevity other activities are omitted, which is not a problem since what is most important is the methodology.

3.1.2 Phase of industrial transformation in the winery. This section discusses in detail the various activities involved in processing of grapes to produce 1 TN bottles of red wine by the Bordeaux method, from receipt of the vintage in the winery to the departure of wine ready for bottling and marketing, analyzing all the possible alternatives in the study area to carry out each activity. The activities in this phase are presented in Figure 3. At this stage of industrial transformation, the possible alternative production systems of the model are 139,968, which, combined only with the possibilities of the agricultural phase, provide 835,884,417,024 analyzed possibilities (not all the models of all the phases have been included, due to lack of the space).

3.1.3 Phase of distribution and disposal, and phase of waste consumption and management. The phase of distribution and disposal assesses in parallel the impact of distribution associated with the process of wine in Spain and exports to Europe and the Americas.

The phase of waste consumption and management analyzes separately the waste management process of wine production and the management of post-consumer waste for both domestic consumption and for exports (see Figure 4).

3.2 Modeling and analysis results for the generic production process of the DOCa Rioja wine sector

The results of the inventory analysis assigned to the different categories taken into account in the Eco-Indicator99 methodology for each of the activities studied are presented. For brevity, just some specific examples of the performed work are presented, but they are enough to show the methodology and its main results. Figure 5 shows the total ecopoints for all impact categories evaluated in each activity of the agricultural phase.

In the specific case of the activities of the agricultural phase, in general, the main impact categories affected are the following:

- fossil fuels;
- respiratory organic;
- potential for acidification, eutrophication.

As an example, the results of the ground preparation activities are presented, although due to their low impact compared to the total impact of the growth phase of the grapes, their total contribution can be considered negligible (see Figure 6).

In the same way that the pooled results of the agricultural phase and the results by impact categories of the specific activities of the ground preparation activity have been calculated and presented, the rest of the results of all activities within the fixed system boundaries have been calculated.

From the analysis of all results and alternatives studied, a minimum and a maximum range of environmental impacts associated with the work could be defined, ranging from 13.4 to 484.0 ecopoints in the agricultural phase and from 91.2 to 293.6 ecopoints in the industrial phase, as can be calculated from the values in the figures. Any selected path in the model should have an added factor inside these bounds, when integrating the factors of any process (therefore, the bounds correspond to the particular cases of minimum and maximum factor in every decision taken).

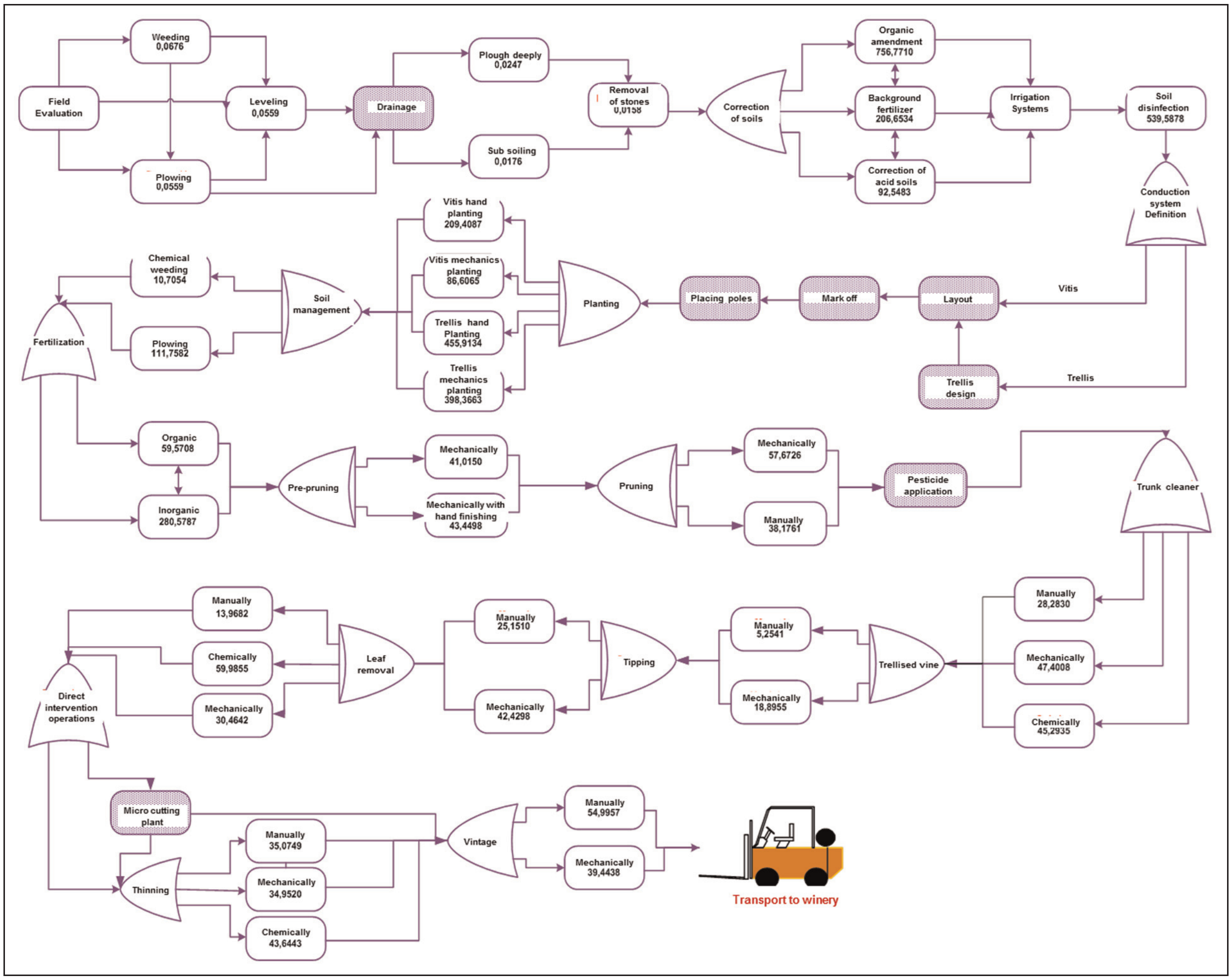

Figure 5. Environmental impacts associated with each activity in the agricultural phase. Generic process of classic production of red wine in DOCa Rioja (ecopoints).

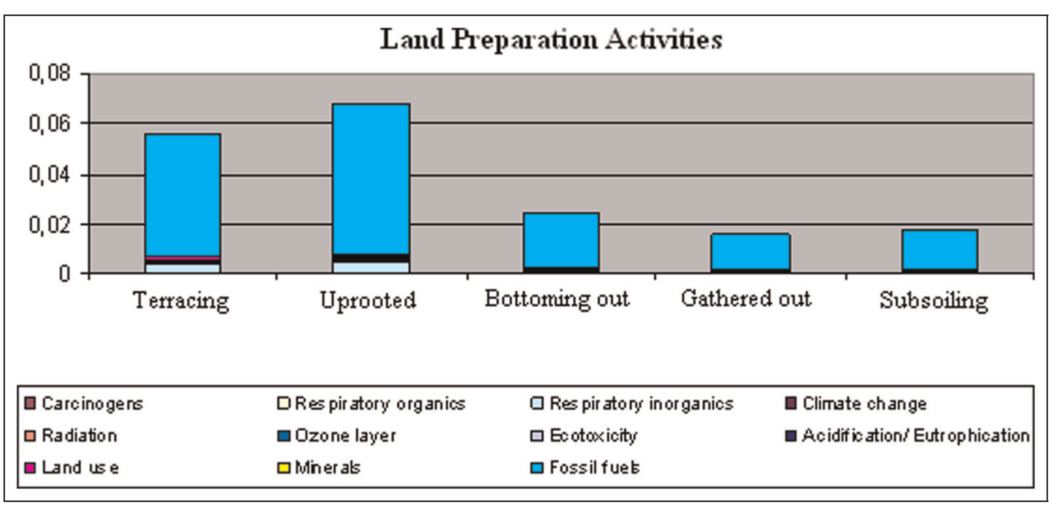

Figure 6. Environmental impacts associated with the activities of land preparation. Generic process of classic production of red wine in DOCa Rioja (ecopoints).

3.2.1 Model implementation for simulation. The models of the different stages should be implemented in order to be analyzed and simulated. The proposed methodology could be easily adapted to continuous or hybrid systems, but as it has been defined (and used in this case study), it corresponds to discrete models, and so any discrete simulator could be used, as well as coded in any high-level language. In fact, the methodology can be applied to different levels, since it can be used for an optimal design (taking into account the environmental impact) of the system or for its application at different levels; that is, it could be used at the strategic, tactical or operational levels and, depending on the complexity of the model, different implementations could present advantages.

In this case study, general purpose discrete event applications have been used for the initial approaches and, when the optimization has been applied at operational levels, Petri net simulators have been used (commercial and specifically developed simulators, since any Petri net simulator is valid for this methodology, as well as other discrete event systems (DESs) simulators). This has permitted a much more complex simulation, allowing, for instance, the combination of different models under the Petri net family of formalisms,[29] as well as the simulation of production options based on several paths simultaneously (dividing the whole production into different parts that could follow different paths depending on the resources and the dynamical evolution of the system).

It is necessary to take into account that the environmental impact is only one factor or criterion in the assessment and optimization of the real process, since the real process corresponds to a multicriteria problem, in which multiple conflicting criteria need to be evaluated in making the decisions (such as economical, environmental or social criteria). This paper is centered in the environmental impact criterion, but the whole problem should be based on multicriteria decision-making techniques, such as the Promethee method, amongst others.[42,43]

3.3 Evaluation of alternatives

Once the generic process of producing red wine in the DOCa Rioja is finished, including the different activities involved and the different options available for each of these activities, it is possible to analyze concrete alternatives. The alternatives analyzed are usually those of particular relevance in the production process that is being analyzed, whether because it is an alternative that is currently in operation in the plant or company, or because it is being used by competitors.

3.3.1 Bordeaux method. One of the alternatives studied in this case study is the entire process used for the production of red wine by the Bordeaux method, breeding from 1000 kg of grapes. Figure 7 shows the unit processes with elementary flows and product flows, which allow modeling of the process.

As an example, the summary of the different inputs and outputs used in the agriculture stage process of DOCa wine production by the Bordeaux method is shown in Table 2.

Table 3 shows the results of the environmental impact of the process of production of Crianza red wine by the Bordeaux method for each of the impact categories considered in the methodology of Eco-Indicator99. The table shows the values in ecopoints for each of the phases studied.

Figure 8 shows graphically the results obtained for each stage of the process. The categories Respiratory Organic, Radiation and Ozone Layer were discarded for representation in Figure 8 because of their low incidence in the total impact.

3.3.2 Carbonic maceration method. Another alternative that is analyzed in this case study is the entire process used for the preparation of young red wine by the carbonic maceration method in a traditional winery of DOCa Rioja. Figure 9 shows unit processes with elementary flows and product flows, which allow modeling of the process.

As an example, a summary of the different inputs and outputs of the phase of industrial transformation used in the preparation of young red wine by the carbonic maceration method is shown in Table 4.

Table 5 shows the results of the environmental impact of the process of young red wine production by the carbonic maceration method for each of the impact categories considered in the methodology of Eco-Indicator99. The table shows the values in ecopoints for each of the phases studied.

Figure 10 shows graphically the results obtained for each stage of the process. The categories Respiratory Organic, Radiation and Ozone Layer were discarded for representation in Figure 10 because of their low incidence in the total impact.

3.4 Analysis of sensitivity

In addition to analyzing different alternatives in the process under study, it is also interesting to perform a sensitivity analysis of the different activities that are involved in the production process. Based on the data studied in the generic process of production of DOCa Rioja red wine, the critical activities of the process system are studied in the phase of industrial transformation, mainly due to the bottling and packaging operations in the marketing stage, and in the growing season. Consequently, some scenarios have been proposed based on the results of the classical generic red wine production in order to evaluate the possible effect of changes in these specific activities.

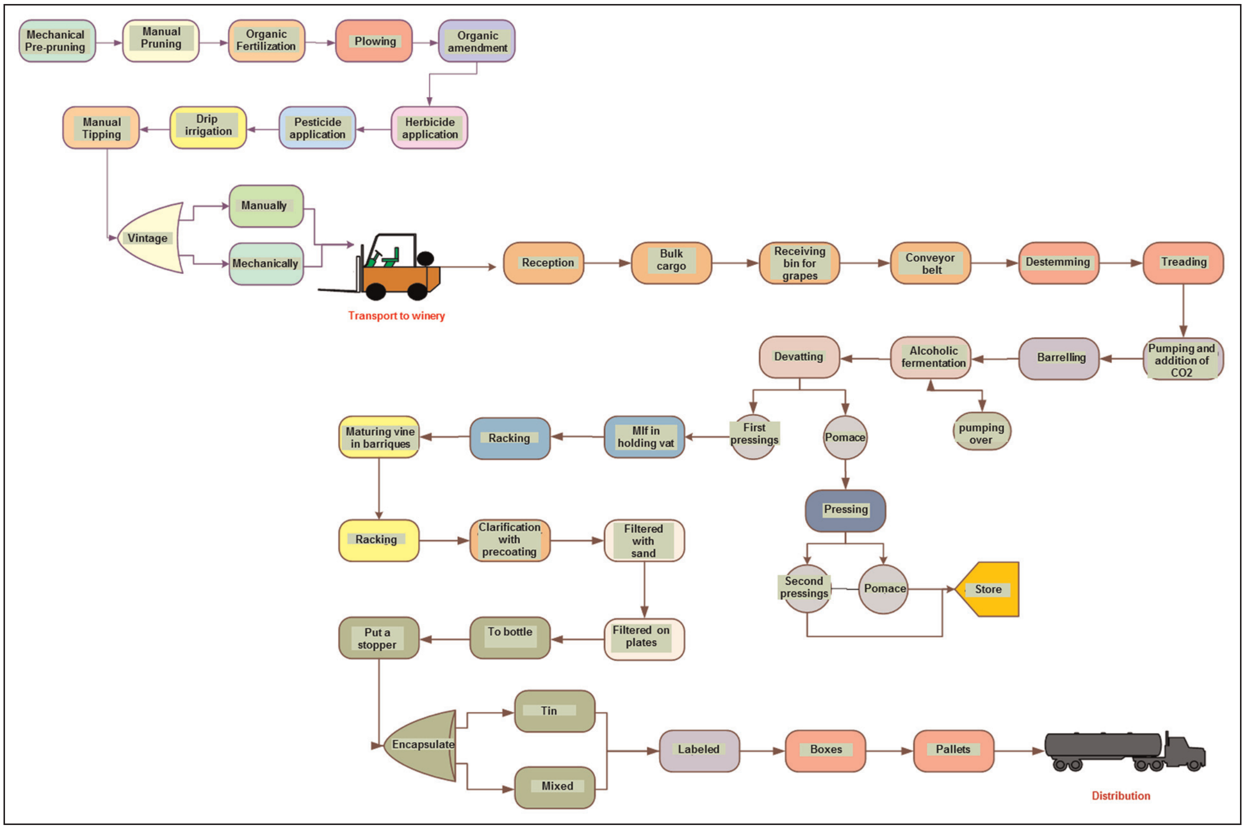

Figure 7. Production process of Crianza red wine in the DOCa Rioja: Bordeaux method.

The alternative scenarios that have been proposed are not unique, but they have been selected to be an example to show how any action taken on the critical activities positively improves the environmental impact of the system without the need to generate cultural changes in the market.

For the sensitivity analysis, five alternative scenarios were studied as follows.

1- A watering schedule optimization has been considered, reducing water intake by 50% under drip irrigation.
2- The total elimination of irrigation has been considered.
3- Consideration has been given to performing a mechanized harvest.
4- Bottles of 400 grams of weight have been replaced by lighter bottles, of 250 g, known as the ''lean + green'' type. The percentage of recycled glass has been increased to 82%, which is the present value in Germany (ecovidrio).
5- Tin capsules have been replaced with aluminum complex capsules.

The results show that the impact associated with the agricultural phase is reduced by 4.6% by the removal of 50% of the water supply to the vineyards. If the water supply is completely abolished, the reduction percentage is doubled. However, the Corporation DOCa Rioja regulates the productions and establishes that at least 600 l water per year have to be supplied; so, the total withdrawal of artificial irrigation is not permitted.

The harvest has been found to be another important cause of the impacts associated with the agricultural phase, because fuel consumption is associated with the transport of a large number of workers needed to carry it out manually. The results show that if harvesting is done mechanically, the reduction of the impacts associated with the agricultural stage is 29%.

It has been shown in previous studies[24] that the use of lightweight containers produces a substantial reduction in the environmental impact of bottling. In this case, the use of a bottle such as ''lean + green'', which is equivalent to 62.5% of the weight of a traditional Bordeaux bottle, has been evaluated. It has also been considered that the percentage of recycled glass increases equal to the rate of glass recycling in Germany. The result is a reduction of

Table 2. Summary of inputs and outputs of the activities of the agricultural phase. Production process of crianza red wine: Bordeaux method.

Agricultural phase					
Input	Unit	Quantity	Output	Unit	Quantity
Abamectin 1.8% p/v EC	l	0.0090	Ammonia (atmosphere)	kg	5.3900
Organic fertilizer	kg	3000.0000	Phosphates (groundwater)	kg	120.4400
Water	l	1,250,325.0000	Nitrates (groundwater)	kg	93.7000
Sulfur 72% p/v SC	kg	1.4400	Dinitrogen oxide (atmosphere)	kg	3.9800
Sulfur 80% WG	kg	1.0000	Nitrogen oxides (atmosphere)	kg	0.2700
Sulfur 99% DP	kg	79.2000	Grape bunches	kg	375.0000
Copper 19% p/v SC	kg	0.9500	Tips	kg	1500.0000
Copper 37.5% WG	kg	0.1900	Grape branches	kg	5600.0000
Deltamethrin 1.5% p/v EW	l	0.0045	Transportation waste (collection point)	km	20.0000
Diesel (tractor)	l	122.5115	Grape	kg	6000.0000
Diesel (worker transportation)	l	18.8103			
Glyphosate 36%	l	0.3600			
Mancozeb 64%	kg	0.2240			
Metiram 80% WG	kg	0.1200			
Pyriproxyfen 10% p/v EC	l	0.0500			
Tebuconazole 25% p/v EW	l	0.1000			
Triadimenol 25% p/v EC	l	0.0630			
Purchase and transportation of products	km	9.0000			

Table 3. Quantification of results of environmental impact by impact categories. Life cycle analysis of production of crianza red wine: Bordeaux method (ecopoints).

Impact category	Unit	Agricultural phase	Industrial transformation	Sales	Consumption	Total
Carcinogens	Pt	0.860618406	1.780715609	0.464088996	–0.200007492	2.905416
Respiratory organics	Pt	0.00804173	0.049406167	0.042426716	0.003027895	0.102903
Respiratory inorganics	Pt	8.286921044	25.63583672	14.16222727	–2.704875217	45.38011
Climate change	Pt	1.043424215	3.956386481	2.600344267	–0.400273308	7.199882
Radiation	Pt	0.045812047	0.093486835	0.029276125	–0.005421427	0.163154
Ozone layer	Pt	0.000553529	0.005777191	0.001548024	–2.35477E-05	0.007855
Ecotoxicity	Pt	3.292436486	4.997412237	1.607599211	–0.54469359	9.352754
Acidification/ eutrophication	Pt	2.627881575	3.126812952	2.280691257	–0.099139387	7.936246
Land use	Pt	1.186705544	2.360438207	0.254915988	–0.156973697	3.645086
Minerals	Pt	0.703524078	43.18213562	0.558261421	0.01278159	44.4567
Fossil fuels	Pt	8.892249626	32.35117309	23.40893711	0.06523999	64.7176
Total	**Pt**	**26.94816828**	**117.5395811**	**45.41031638**	**– 4.030358191**	**185.8677**

27% of the impact associated with the bottling process, which results in a reduction of 7% of the impact associated with the phase of industrial transformation.

The impact associated with the package is reduced by 92% when replacing tin capsules with capsules of aluminum complex. This leads to a reduction of 61% of the total impact associated with the phase of industrial transformation.

If the changes proposed in scenarios 1, 3, 4 and 5 are applied, that is, the flow of irrigation water decreases 50%; harvesting is done mechanically; 37.5% weight of the bottles is reduced, increasing the recycling rate to 82%; and also tin capsules are replaced with aluminum complex capsules, a reduction of 50% of the total impact of the system is obtained.

4. General results

According to the total impacts caused by the processing system, it is shown that the Bordeaux method produces less impact than the carbonic maceration method, with an associated load of 185.87 ecopoints, while the carbonic maceration method has a load of 227.05 ecopoints, that is, it presents 18% more associated environmental impact. This difference is due fundamentally to two aspects as follows.

- In the agricultural phase, the harvest for winemaking by carbonic maceration is carried out manually, increasing the impact of that phase, as shown in the sensitivity analysis.

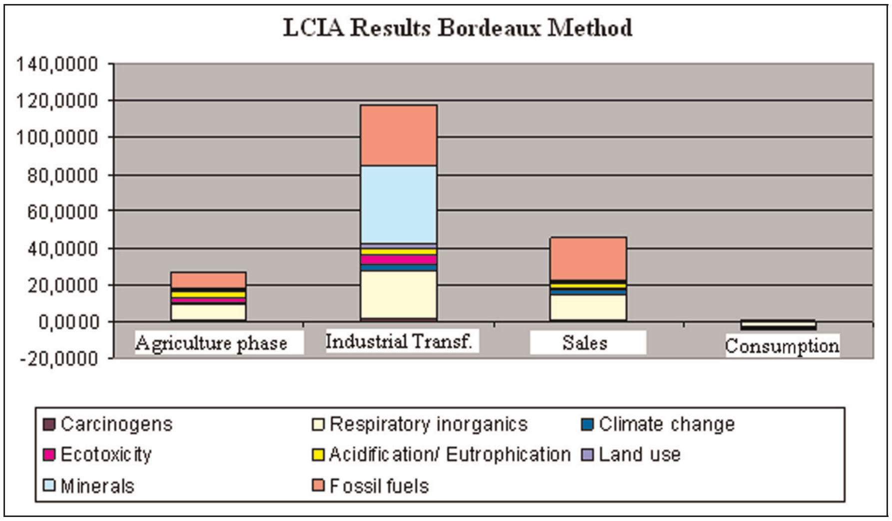

Figure 8. Results of the live cycle impact assessment (LCIA) by phases of the process. LCA of production of Crianza red wine: Bordeaux method (ecopoints).

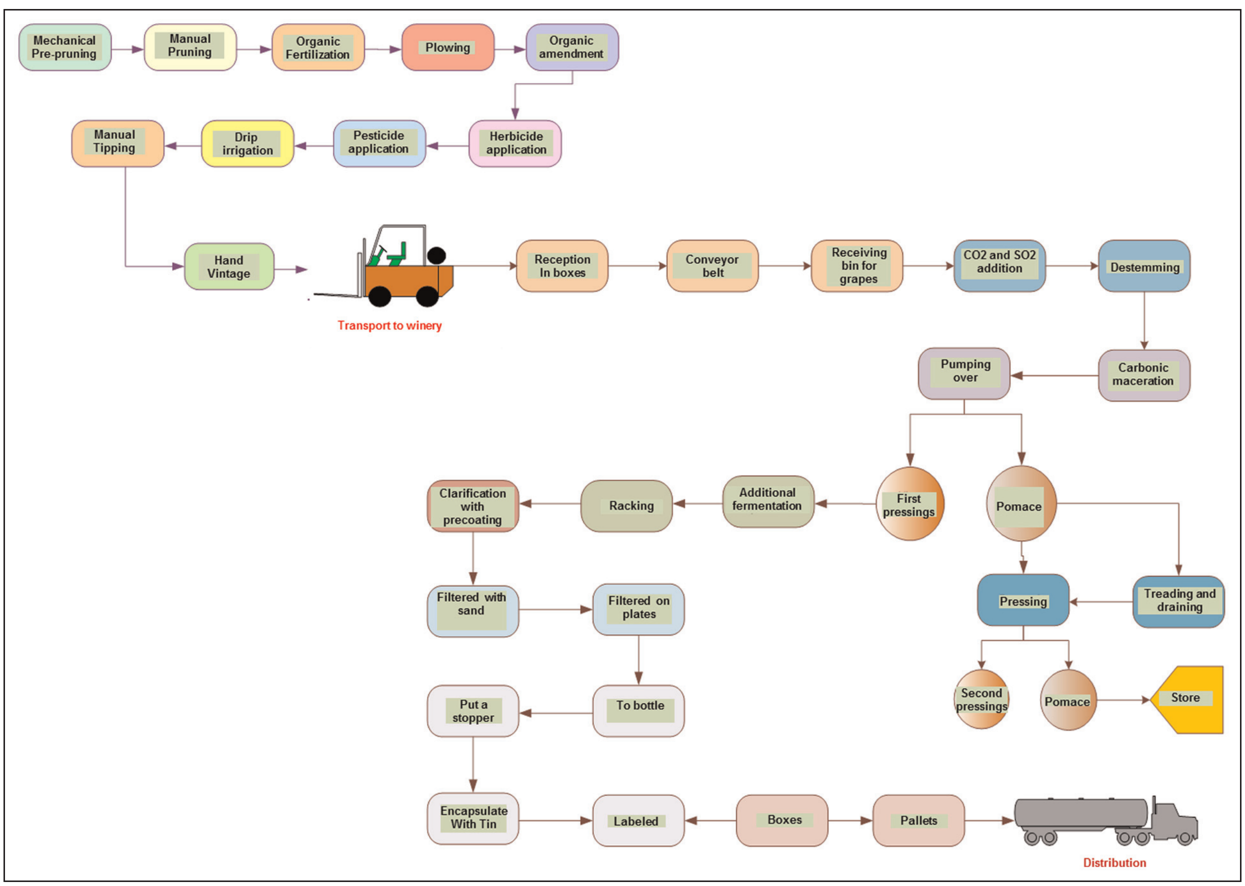

Figure 9. Production process of young red wine in DOCa Rioja: carbonic maceration method.

Table 4. Summary of inputs and outputs of the activities of the industrial transformation phase. Production process of young red wine: Carbonic maceration method.

Industrial transformation phase					
Input	Unit	Quantity	Output	Unit	Quantity
Citric acid (cleaning)	kg	0.0152	Water (residual)	l	668.1485
Water (clean)	l	82.6515	Cartridge filter	un	0.0282
Albumin	kg	0.0459	Lias	l	23.1003
Bentonite	kg	0.2872	Free grape juice	kg	190.0661
Cardboard	kg	25.6571	Marc	kg	200.0800
25 kg baskets of grapes	un	40.0000	Pallet of wine[a]	un	1.3037
CO_2	kg	0.2380	Scratch	kg	30.0000
Cork	kg	2.4781	Glass recycling	kg	0.2523
Electricity	MJ	56.8791	Diatomaceous dirt	kg	1.4080
Tin	kg	3.4543	Waste transportation	km	265.0000
Filter (cartridge)	un	0.0282	Pouring glass	kg	0.1682
Isinglass	kg	0.0040			
Wood	kg	26.0743			
Self-adhesive paper	kg	1.3141			
Polyethylene	kg	0.6519			
SO_2	kg	0.1276			
Caustic soda (cleaning)	l	0.0052			
Diatomaceous dirt	kg	1.4080			
Transportation products	km	945.0000			
Glass	kg	300.7968			

[a]Equals 750.9408 bottles of wine

Table 5. Quantification of results of the Life Cycle Inventory by impact categories. Life cycle analysis of the production of young red wine: carbonic maceration method (ecopoints).

Impact category	Unit	Agricultural phase	Industrial transformation	Sales	Consumption	Total
Carcinogens	Pt	0.993267794	1.662631195	0.434652102	–0.129065407	**2.961485685**
Respiratory organics	Pt	0.012406156	0.042893	0.04027329	0.003043605	**0.09861605**
Respiratory inorganics	Pt	9.735584717	25.80443579	13.46003588	–2.548112241	**46.45194415**
Climate change	Pt	1.521390609	3.424610307	2.463572336	–0.377406503	**7.032166748**
Radiation	Pt	0.057912536	0.074714107	0.026823529	–0.005126502	**0.154323671**
Ozone layer	Pt	0.0006822	0.005471601	0.001467708	–1.75322E-05	**0.007603977**
Ecotoxicity	Pt	3.639638558	4.230722645	1.492960383	–0.508532263	**8.854789324**
Acidification/ eutrophication	Pt	2.84960636	2.872461097	2.176220312	–0.087328445	**7.810959324**
Land use	Pt	1.344949062	1.916292785	0.210993796	–0.146594347	**3.325641296**
Minerals	Pt	0.883747714	82.22918461	0.501715106	0.013497717	**83.62814515**
Fossil fuels	Pt	17.14312779	27.31493817	22.13690681	0.137058154	**66.73203093**
Total	**Pt**	**38.1823135**	**149.5783553**	**42.94562126**	**– 3.648583763**	**227.0577063**

- In the phase of industrial transformation, the winery using the carbonic maceration method uses tin in all of their capsules, while the winery using the Bordeaux method only uses tin in 50% of them. The sensitivity analysis showed the incidence of using or not tin capsules in the process.

On the other hand, the results of the comparative analysis provided data to model the system process that is associated with lower environmental impacts. The following actions are recommended by stages.

- Agricultural phase
  1. In the ground preparation activities, clearing and subsoiling are recommended before the uprooting and bottoming out, if ground conditions permit it.
  2. Although they are not perfect substitutes, it is recommended to use basal dressing before organic amendment, provided that the field's needs can be satisfied with the former.
  3. Disinfection of soil has a fairly high impact, so it is recommended to evaluate less aggressive ways to develop it.

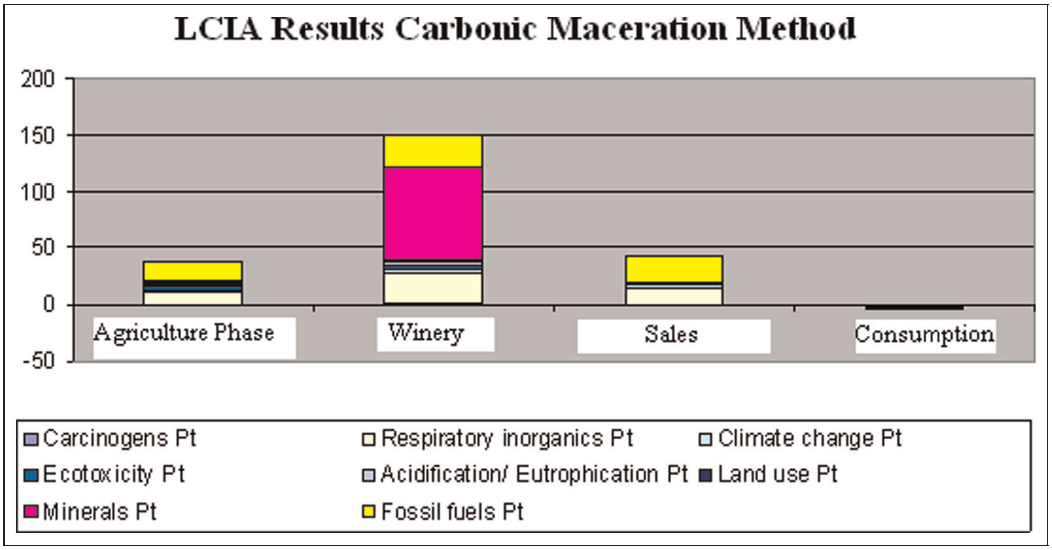

Figure 10. Results of the live cycle impact assessment (LCIA) by phases of the process. LCA of production of young red wine: carbonic maceration method (ecopoints).

4. Amongst the activities of establishment of the vineyard, vessel driving and manual planting is the combination of operations with lower environmental impact, and is also traditional in the area of study. Therefore, its implementation not only helps the environment but is also a source of cultural enrichment.
5. According to the results of the study, chemical weeding is the ground maintenance operation with the lowest impact. However, this result has a high level of uncertainty in the absence of data for emissions from the application of herbicides used.
6. Organic fertilization is recommended whenever possible, because of the high impact associated with inorganic fertilization.
7. It is recommended to perform pruning, trunk cleaning, fencing, breaks, and defoliation manually. By contrast, the pre-pruning, thinning and harvesting are recommended to be performed mechanically, this being the process with fewer associated environmental impacts.

Figure 11 shows graphically the general form of grape cultivation with less environmental impact associated. The processing activities that have not been evaluated are represented in black.

- Industrial transformation phase

1. Although it does not correspond to the form of vintage, the recommended reception in plastic baskets with conveyors and sorting tables is the form of lowest environmental impact.
2. The hot maceration operation is the most recommended process of maceration.
3. The malolactic fermentation developed in conventional stainless steel tanks has a lower associated impact than if used barrels are utilized, even if the barrels are not suitable for Crianza wine. The former is most recommended and the common practice in the Rioja wine sector.
4. Barrel aging has a considerably larger environmental impact than aging carried out in stainless steel tanks in the presence of oak chips; so it is recommended that the latter method is used, whenever wine characteristics permit. In DOCa Rioja it is not allowable to replace the utilization of barrels with oak chips in the aging of wines; however, oak chips constitute a viable alternative for young wines to provide the characteristics of the wood, instead of the typical practice of using barrels for short time.
5. Whenever the characteristics of wine permit, using clarification by centrifugation, tangential filtration and tartaric stabilization with mannoproteins is recommended, since these are the processes with less associated environmental impact amongst all the techniques evaluated.
6. In the bottling line, which is the part of the industrial transformation phase with higher impacts, the following is recommended: filling under normal conditions, packaging in lightweight bottles, preferably of the lean + green type, and positioning and use of corks and polyvinyl chloride (PVC) or aluminum complex capsules.

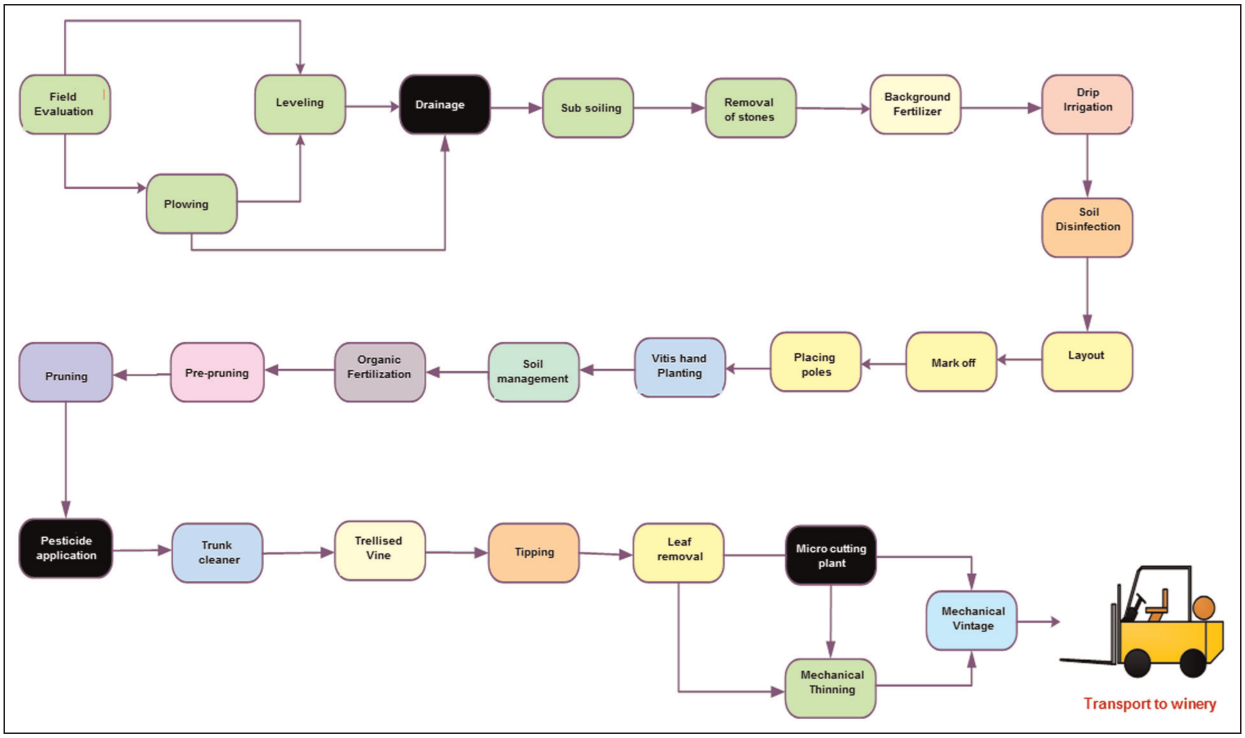

Figure 11. Proposed activities of the agricultural phase.

7. In addition, incorporating the nearest suppliers for the purchase of materials used both on the farm and in the winery is recommended, in order to obtain a reduction of the impact associated with the consumption of fuel for this item.

Figure 12 shows graphically the wine production system with a lower associated impact for the Bordeaux method.

5. Conclusions

Throughout this paper, a methodology approach that allows incorporation of aspects of environmental impact in the industrial process modeling is presented, exemplifying the methodology in a case study of the traditional process of red wine in the DOCa Rioja.

The methodology consists basically of determining all the possible alternative production techniques, representing them in a model that provide all the possible methods of production (according to the decision made on the alternative production techniques) and analyzing the environmental impact of any of the individual possibilities by LCA; in this way, given any production system, the model can provide a real environmental impact, as well as the processes in which the impact is highest, or those in which there exists alternative production techniques that allow reduction of the environmental impact. In this way, the result does not provided an impact value of the product, but rather a model to determine the impact in terms of the decisions made in the production process; therefore, it can be used, especially by means of simulation, for the optimization of the production system, based on multiple criteria (including environmental impact).

The case study has been developed with real data of the main and more representative wineries of the region, which allows considerable improvement of the impact factor of any winery, as well as determination of the bottlenecks, from a sustainability point of view, and to present the different alternatives and the impact of any of them. In addition, the information of the impact of any alternative individual process that has been used in the developed model can also be integrated in any other model developed with a different modeling formalism (for instance Petri nets) or in simulation applications.

Funding

This work was partially supported by University of La Rioja and Banco Santander (grant number API12-11), under project 'Sustainable production and productivity in industrial processes: integration of energy efficiency and environmental impact in the production model for integrated simulation and optimization'.

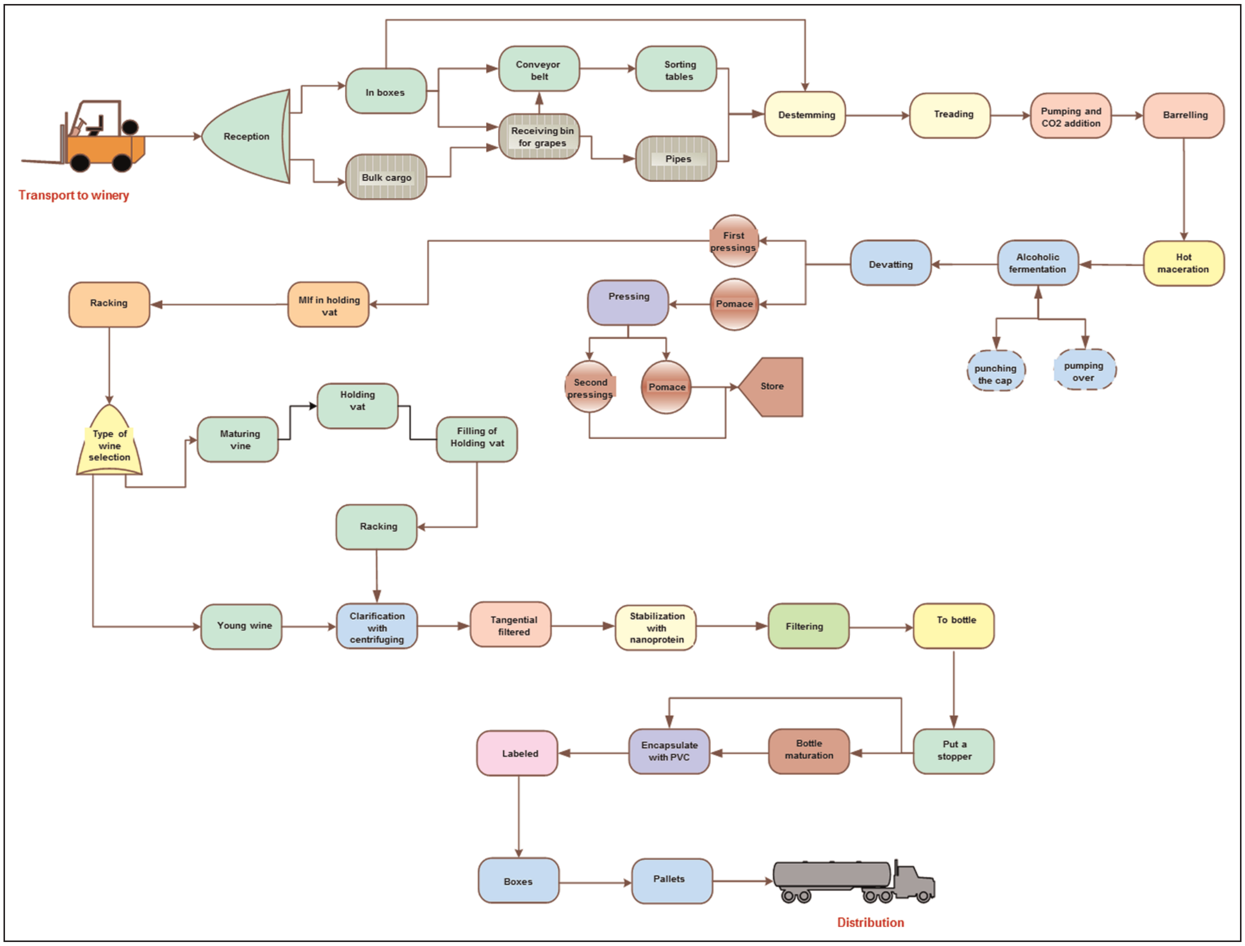

Figure 12. Proposed activities of the industrial transformation phase.

References

1. Fullana P, Gazulla C, Clavijo MJ, et al. *Análisis del ciclo de vida del vino crianza D.O.C. Rioja*/(translated as *Life cycle analysis of DOC Rioja wine*). Dirección General de Calidad Ambiental, Consejería de Turismo, Medio Ambiente y Política Territorial del Gobierno de La Rioja, 2005.
2. Johnstone N, Haščič I, Poirier J, et al. Environmental policy stringency and technological innovation: evidence from survey data and patent counts. *Appl Econ* 2012; 44: 2157–2170.
3. Wainer G. Applying cell-DEVS methodology for modeling the environment. *Simulation* 2006; 82: 635–660.
4. Valkering P, Rotmans J, Krywkow J, et al. Simulating stakeholder support in a policy process: an application to river management. *Simulation* 2005; 81: 701–718.
5. Schweimer GW, et al. *Life cycle inventory for the Golf A4*. Research, Environment and Transport, Volkswagen AG, Wolfsburg, 2000.
6. Serieux JE, Munthali S, Sepehri A, et al. The impact of the global economic crisis on HIV and AIDS programs in a high prevalence country: the case of Malawi. *World Dev* 2012; 40: 501–515.
7. Frischknecht R and Jungbluth N. Implementation of life cycle impact assessment methods. Final report, Ecoinvent Report, no. 3. Dübendorf, 2003.
8. Brentrup F, Kusters J, Kuhlmann H, et al. Application of the life cycle assessment methodology to agricultural production: an example of sugar beet production with different forms of nitrogen fertilizers. *Eur J Agron* 2001; 14: 221–233.
9. Behzadian M, Kazemadeh RB, Albadvi A, et al. PROMETHEE: A comprehensive literature review on methodologies and applications. *Eur J Oper Res* 2010; 200: 198–215.
10. Sonnemann GW. *Environmental damage estimations in industrial process chains. Methodology development with a case study on waste incineration and special focus on human health*. PhD Thesis, Departamento de Ingeniería Química, Universidad Rovira Virgili, Tarragona, 2002.
11. De Soto JH. Economic recessions, banking reform and the future of capitalism. *Econ Aff* 2011; 31: 76–84.
12. Ihobe SA. *Análisis de ciclo de vida y Huella de carbono: Dos maneras de medir el impacto ambiental de un producto*. Sociedad Pública de Gestión Ambiental, 2009.

13. Schmidt JH. *Life cycle assessment of rapeseed oil and palm oil. Part 3: life cycle inventory of rapeseed oil and palm oil*. PhD Thesis, Department of Development and Planning, Aalborg University, 2007.
14. Notarnicola B, et al. Life cycle assessment (LCA) of wine production. In: Mattson B and Sonesson U (eds) *Environmentally-friendly food processing*. Cambridge: Woodhead Publishing Limited, 2003, pp.306–326.
15. Brans JP and Vincke PH. A preference ranking organization method - (the Promethee method for multiple criteria decision-making). *Manag Sci* 1985; 31: 647–656.
16. Hill DRC and Komatsu T. Introduction to the special issue: ecological and environmental simulation. *Simulation* 2006; 82: 425–426.
17. Gorobets A. The global systemic crisis and a new vision of sustainable human development. *Environ Dev Sustain* 2011; 13: 759–771.
18. Potts T. The natural advantage of regions: linking sustainability, innovation, and regional development in Australia. *J Cleaner Prod* 2010; 18: 713–725.
19. Fassó A and Cameletti M. A unified statistical approach for simulation, modeling, analysis and mapping of environmental data. *Simulation* 2010; 86: 139–154.
20. Longo F. Advances of modeling and simulation in supply chain and industry. *Simulation* 2011; 87: 651–656.
21. Jiménez E, Tejeda AS, Pérez M, et al. Applicability of lean production with VSM to the Rioja wine sector. *Int J Prod Res* 2011; 50: 1890–1904.
22. Milà i Canals L, et al. Sources of site- dependency and importance of energy consumption in agricultural LCA: apple production in New Zealand. In: *Life cycle assessment in the agri-foods sector, DIAS report: proceedings from the 4th international conference*, 6–8 October 2003, Bygholm, Denmark.
23. Hauschild M. *Estimating pesticide emissions for LCA of agricultural products. Agricultural data for life cycle assessments*. Vol. 1. The Hague: Agricultural Economics Research Institute (LEI), 2000.
24. Chiriac SE. Economic and environmental interdependencies at a global level: how does the financial crisis influence the environmental crisis. *Qual Access Success* 2011; 12 (suppl.1): 416–421.
25. Guinée JB, Heijungs R, Huppes G, et al. Life cycle assessment: past, present, and future. *Environ Sci Technol* 2011; 45: 90–96.
26. Martínez E, Jiménez E, Blanco J, et al. LCA sensitivity analysis of a multi-megawatt wind turbine. *Appl Energy* 2010; 87: 2293–2303.
27. Martínez E, Sanz F, Jiménez E, et al. Life cycle assessment of a multi-megawatt wind turbine. *Renewable Energy* 2009; 34: 667–673.
28. Martínez E, Sanz F, Jiménez E, et al. Life-cycle assessment of a 2-MW rated power wind turbine: CML method. *Int J Life Cycle Assess* 2009; 14: 52–63.
29. Sanchez-Ramirez C, Gastón Cedillo-Campos M, Perez-Villanueva P, et al. Global economic crisis and Mexican automotive suppliers: impacts on the labor capital. *Simulation* 2011; 87: 711–725.
30. Guinée JB, et al. An operational guide to the ISO standards. Final report, Ministry of Housing, Spatial Planning and the Environment (VROM) and the Centre for Environmental Studies, Leiden University, The Netherlands, 2001.
31. Narciso M, Piera MA and Guasch A. A methodology for solving logistic optimization problems through simulation. *Simulation* 2010; 86: 369–389.
32. Point E. *Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada*. Nova Scotia: Dalhousie University Halifax, 2008.
33. Brentrup F, Kusters J, Lammel J, et al. Methods to estimate on-field nitrogen emissions from crop production as an input to LCA studies in the agricultural sector. *Int J Life Cycle Assess* 2000; 5: 349–357.
34. UNEP. *Life cycle impact assessment definition study: background document III. Analysis of midpoint categories*. Paris: United Nations Environmental Programme, Life Cycle Initiative, 2003.
35. Amann M, Bertok I, Borken-Kleefeld J, et al. Cost-effective control of air quality and greenhouse gases in Europe: modeling and policy applications. *Environ Modell Softw* 2011; 26: 1489–1501.
36. Powers S. Nutrient loads to surface water from row crop production. *Int J Life Cycle Assess* 2007; 12: 399–407.
37. Bruzzone AG and Longo F. An advanced system for supporting the decision process within large-scale retail stores. *Simulation* 2010; 86: 742–762.
38. Schneider F, Kallis G and Martinez-Alier J. Crisis or opportunity? Economic degrowth for social equity and ecological sustainability. Introduction to this special issue. *J Cleaner Prod* 2010; 18: 511–518.
39. Aranda A, et al. *El Análisis del Ciclo de Vida como herramienta de gestión medioambiental*/translated as *Life cycle assessment as a tool for environmental management*. Madrid: FC Editorial, 2006.
40. Jiménez E and Pérez M. Simulation and optimization of logistic and production systems using discrete and continuous PN. *Simulation* 2004; 80: 131–142.
41. ISO 2006. ISO 14040 Environmental management. Life cycle assessment. Principles and framework. Geneva, Switzerland.
42. Gazulla C, Raugei M and Fullana-I-Palmer P. Taking a life cycle look at crianza wine production in Spain: where are the bottlenecks? *Int J Life Cycle Assess* 2010; 15: 330–337.
43. Erisman J. *Key factors necessary to determine the impact on the nitrogen cycle and the resulting environmental effects as part of LCA for agricultural products. Agricultural data for life cycle assessments*. Vol. 1. The Hague: Agricultural Economics Research Institute (LEI), 2000.

Author biographies

Dr Emilio Jiménez is a Professor at the University of La Rioja, in the Electrical Engineering Department, where he leads the modeling, simulation and optimization group. His main research interests include DESs, factory automation, modeling and simulation of industrial processes, formal methodologies to solve decision problems based on DESs, and renewable energy and environmental impact.

Dr Eduardo Martínez is a full-time researcher in an enterprise devoted to energy production and a lecturer at the University of La Rioja, in the Mechanical Engineering Department. His main research interests include renewable energy, energy production and environmental impact.

Dr Julio Blanco is a Professor at the University of La Rioja, in the Mechanical Engineering Department, where she leads the integral design group. Her main research interests include engineering of fabrication processes and environmental impact.

Dr Mercedes Pérez is a professor at the University of La Rioja, in the Mechanical Engineering Department, where she leads a national research project about optimization of welding processes by artificial intelligence. Her main research interests include factory automation and modeling and simulation of industrial processes.

Dr Charmery Graciano developed her PhD studies at the University of La Rioja, and she returned to the Dominican Republic as a university professor. Her main research interests include wine production and environmental impact.