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Computer Aided Process Engineering for Sustainability Analysis of Food Production

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We propose a dedicated tool that permits the evaluation of food production process sustainability, in particular virgin olive oil process. It is based on an integrated process-product-enterprise (P²E) approach that allows systematically taking into account sustainable issues within food production process design. The domain specific tool “&cOlive” is implemented as an Excel application. This CAPE based tool assesses sustainability of a future or an existing system of virgin olive oil production. In the first case, 28 configurations of the system may be chosen based on 7 agricultural scenarios and 4 industrial scenarios (extraction).These scenarios were built with field data directly collected through questionnaires and visits of olive oil producers in France, in the context of the European OiLCA project. Complementary data were provided by French experts from the *Centre Technique de l'Olivier*. They completed and reinforced the relevance and the quality of the model. Finally, commercial databases such as Ecoinvent for environmental LCA were used. The tool offers the opportunity to simulate a lot of scenarios and to study the influence of different extraction technologies and different operating parameters on sustainability.

1. Introduction

Process system engineering (PSE) discipline was initially based on matter and energy balance calculation in order to simulate and optimize chemical processes (Jacquemin, 2012). Since the beginning of the twenty first century, the need for sustainability has led PSE to consider economic, environmental and social issues (Azapagic, 2006). In doing so, life cycle thinking (LCT) seems to be one of the most relevant approaches to take into account impacts on economy, environment and society of a process. LCT is applied through the methods of life cycle costing (LCC), environmental life cycle assessment (ELCA) and social life cycle assessment (SLCA) respectively. Historically oriented to environmental impacts of a product, ELCA has naturally extended its field of investigation to social and economic aspects. The integration of LCC, ELCA and SLCA is under development to lead to life cycle sustainability assessment (LCSA) of systems (Guinée et al., 2011).

On the other hand, process design tools usually applied to chemical processes are more and more used in other domains such as food production (Busset et al., 2013).

In parallel, enterprise (considered as a system of systems) strategy constantly changes to adapts to a rapidly changing world. To meet this need, business process management (BPM) discipline has emerged and proposed formalization for enterprise process modelling. As Heintz (2014) showed, the trend is now to integrate different models for different granulometry level of the enterprise such as process level, product level or enterprise level.

In Europe, olive oil represents a strategic sector with about 2.5 Millions of producers. However, the sector has to deal with a large quantity of wastes that leads to environmental problems. The composition of the waste

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products may lead to phytotoxic chemical compounds, particularly in wastewater (Roig et al., 2006). As a consequence, environmental life cycle assessment (ELCA) has been applied to olive oil for more than ten years. The objective was to identify environmental hotspots and to propose recommendations to limit environmental impact (Salomone et al., 2010). Up to now, no LCSA has been undertaken. As far socio-economic context, European sector faces to emergent competition with new producers countries such as Australia, Argentina or South Africa. In this context, the European project OiLCA, funded by the "European Regional Development Fund" under the Innovation European Interreg IV program, has been realized (OiLCA, 2011).
The present work proposes a CAPE based approach for life cycle sustainability assessment of food production. The two main objectives of such a study are (i) to present a tool that illustrates the sustainability assessment approach and (ii) to apply it to virgin olive oil production life cycle for design or re-design it.

2. Conceptual framework

The dedicated tool for sustainability assessment is based on the process-product-enterprise (P²E) approach. It consists in coupling product model, process model and enterprise model. Product model represents product life cycle and it is made with elementary processes that are "black boxes". Therefore, the causal relationship between inputs and outputs is not explicit. The process model is based on the determination of a relation between inputs and outputs. Finally, the enterprise model permits to complete the product model by the inclusion of business processes and rules. Indeed, product model only represents the operational system of the enterprise seen as a system of systems.
This approach completes the previous work of Gillani (2013) who proposed a CAPE based tool as the application of a process-product approach for environmental assessment of processes. The interest of the P²E approach is the integration of three levels of a system of systems in order to formalize their interactions. Such integration is supported by the sustainability evaluation of process-product-enterprise system. Indeed, environmental, social and economic impacts of the enterprise are held at all levels of design (molecule, process, product, enterprise) (Figure 1). This approach is part of a decision making process in the context of the system design or re-design guided by evaluation. It permits the user to (i) make a technologic choice of agro-industrial process, (ii) to make a choice of supply chain and (iii) to make a choice of input.

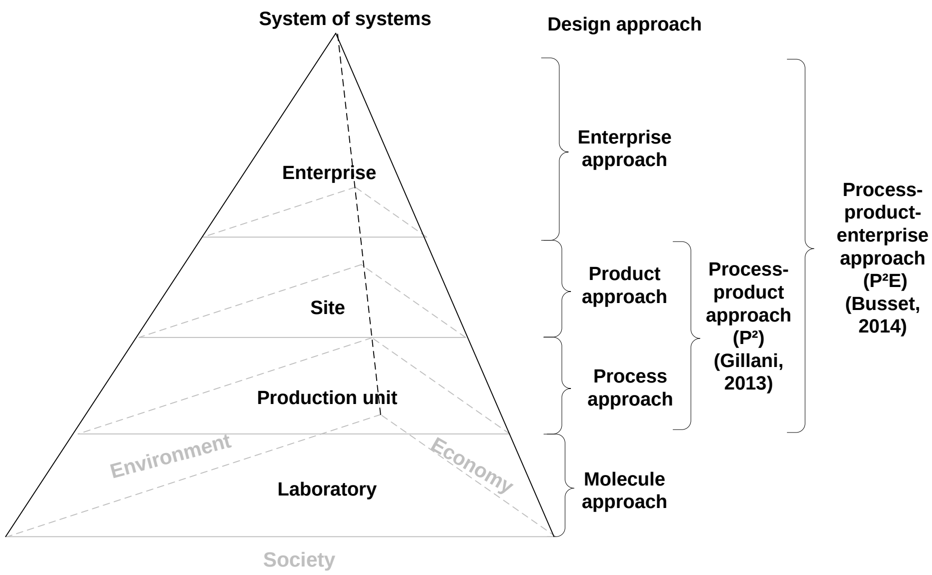

Figure 1: Approaches for system of systems design

Since the P²E approach for sustainability is based on environmental life cycle assessment, its structure is inspired from the ELCA standards (ISO 14040, 2006) (Figure 2).

- Two steps remains similar ("goal and scope definition" and "interpretation and validation of results");
- Two steps are modified ("data inventory" and "multicriteria analysis") that are a generalization of the life cycle inventory and the impact assessment phases;
- Two steps are added ("process, product and enterprise modelling" and "choice").

The new steps were needed because of the complexity of the system modelling and because of the importance of the choice step.

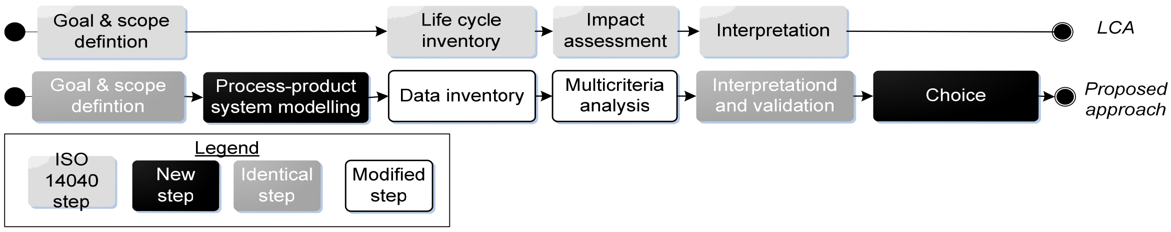

Figure 2: Process Product Enterprise (P²E) approach structure

This conceptual framework constitutes the basis on which the dedicated tool for sustainability of virgin olive oil production relies.

3. Virgin olive oil case study

3.1 Preliminaries

The objectives of “&cOlive” tool is to offer the opportunity to evaluate sustainability of virgin olive oil production. As mentioned before, “&cOlive” may be used for design or re-design phase or during operational phase. It can be seen as a tool for the simulation of a future system or for the evaluation of an existing system. For the simulation of a future system, “&cOlive” proposes several system configurations based on real case studies. For the evaluation of an existing system, real data can be used directly.

In theory, the genericity of the tool makes it usable by any professional of the virgin olive oil sector and it can be extended for any food production. Two modes are possible: simple or expert. The first mode is advisable for professionals of the sector, whereas the second mode is required for experts of sustainability evaluation.

In order to normalize the results, a functional unit is defined as in environmental LCA. It corresponds here to the production of 1 Litre of virgin olive oil. However, it may be noted that the functional unit is only applicable to environmental and economic aspects. Indeed, social data are qualitative or semi-quantitative. Therefore, it is not meaningful to divide this kind of indicators by the functional unit. This justifies the use of multicriteria analysis in order to help decision making during the choice step. On the other hand, the study also evaluates the quality of data and some values of technical parameters.

Before describing the structure of “&cOlive”, the next paragraph presents virgin olive oil production system as the core of the tool.

3.2 Virgin olive oil production system

The “&cOlive” tool includes all the elements of the sustainability evaluation of virgin olive oil production system. The figure 3 shows the system of systems of virgin olive oil production. Virgin olive oil life cycle (product model) is composed of 7 phases namely, nursery, olive production, virgin olive oil extraction pomace treatment, wastewater treatment, bottling and bottles end-of-life. These processes correspond to the main operational processes of two enterprises represented by orchards and mills. “Orchards” is the generic name for the agricultural company that produces olives and “mills” is the one for the company that extracts virgin olive oil and treats wastes. No end-of-life enterprise was modelled. Finally, the extraction process is modelled as a flowsheet.

The hypotheses of the study are the inclusion of infrastructures raw material and distribution of virgin olive oil. On the contrary, workers transportation, use phase, emission due to fertilizers degradation and carbon storage are not included.

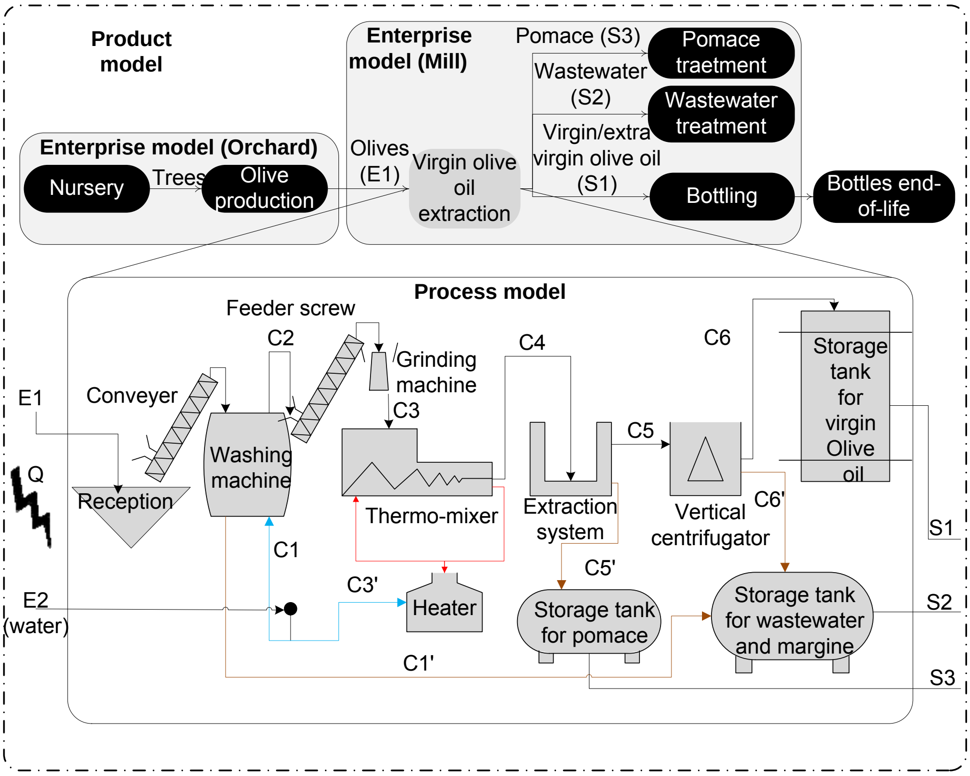

Figure 3: Olive oil production system

3.3 Inventory data collection, scenarios and system configuration

For the simulation of a future system, “&cOlive” necessitates the definition of different scenarios for orchards and for mills. To this end, direct data collected through the OiLCA project provides the basis of mass, energy and currency inputs/ouputs of different case studies. In total, 6 scenarios for orchards are defined based on the type of irrigation, the type of culture (organic or conventional) and the intensity of the culture (traditional, intensive of super intensive). For industrial phase represented by mills, 3 scenarios are identified depending on the extraction technology: press, 2-phases centrifugation system and 3-phases centrifugation system. Two additional average scenarios are finally defined respectively for orchards and mills. As a consequence, 28 system configurations are possible. This constitutes the first database of the tool.

4. Results and discussion

4.1 General structure of “&cOlive”

“&cOlive” tool is an in-house VBA-type tool composed of 21 objects that are in line with the six steps of P²E approach (Figure 4). It is dedicated to virgin olive oil production but may be modified by an expert user quite simply. When user starts “&cOlive”, he is directed to the home page containing three buttons: “about”, “instructions” and “starts”. “About” and “instruction” bring up respectively a sheet with general information about the tool and a sheet with the instructions about how to use the tool. Finally, the “starts” button redirects the user to the data entry sheets divided into 6 tabs. The mode (simple or expert) is chosen in tabs “presentation”. Then, data entry may be realized on the other tabs divided into economic, environmental, technical and social aspects. The last tabs “simulation” contains a button that finishes data entry and starts simulation. In simple mode, user is directly sent to the results of sustainability analysis, without any access to calculation details. On the contrary, expert user accesses all the “&cOlive” objects, especially the different databases (raw data about orchards, raw data about mills and weighting factors used for impact assessment and multicriteria analysis). Weighting factors database include all the selection of indicators for sustainability assessment. Environmental factors rely on Ecoinvent 2.2 inventory database and Hauschild (2012) impact categories selection method. Social qualitative and semi-quantitative data are converted into quantitative data through factors described in this “Weighting factors” sheet, following the UNEP-SETAC (2009) guidelines. In terms of level of granulometry, “process simulation sheets” only concerns the process approach, whereas

“Raw data orchards”, “Raw data mills”, “LCSA calculation” and “weighting factors” concern product and enterprise approaches. This choice has been made due to the strong link between product model and enterprise model.

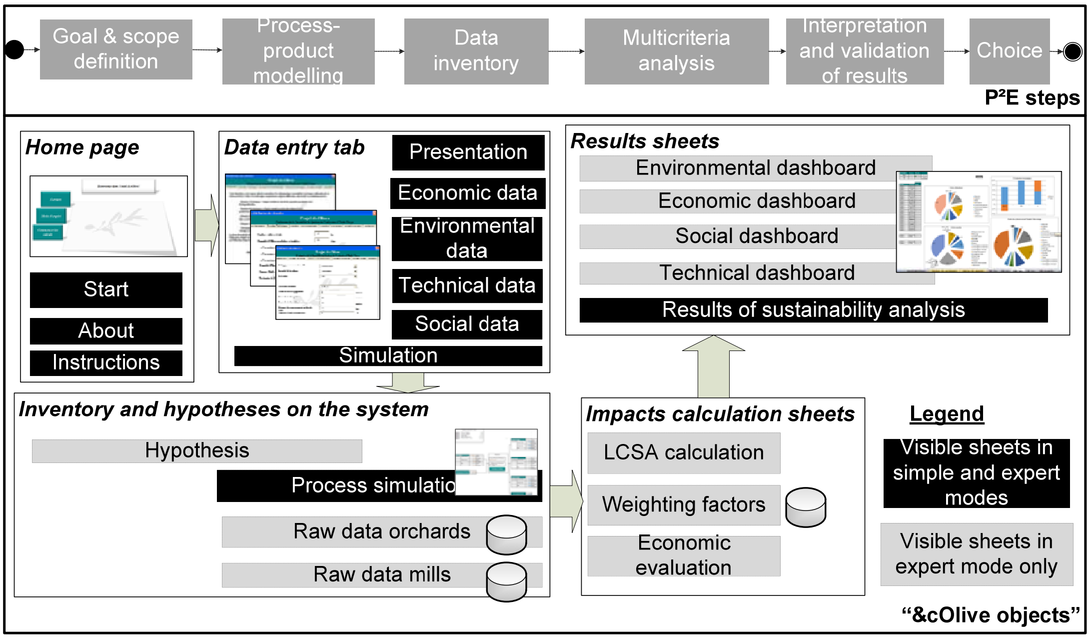

Figure 4: “&cOlive” objects and P²E steps

Figure 4 shows the complex and multilevel interaction between system elements and their external environment (environmental, economic and social dimensions). It also illustrates the complex but feasible applicability of P²E approach through this CAPE based tool.

4.2 Opportunities

As an application to the generic process-product-enterprise (P²E) approach, “&cOlive” offers a lot of opportunities for users. It tackles sustainability issues of any virgin olive oil production system. Thirty indicators characterise economic, technical, environmental and social impacts of the system.

Table 1: Indicators for sustainability assessment

Environmental indicators	Social indicators	Economic indicators	Technical indicators
Climate Change, Human toxicity (cancer), Human toxicity (non-cancer), Photochemical Oxidant Formation, Acidification, Eutrophication, terrestrial, FreshWater eutrophication, Marine eutrophication, Ecotoxicity, Abiotic depletion, Resource depletion, Water, Ozone Layer Depletion, Ionizing radiation, human health, Particulate matter/respiratory inorganic, Ionizing radiation, ecosystems, Agricultural land occupation, Urban land occupation, Natural land transformation	Health and Safety at work, Health & Safety of consumer, Technology development, Local employment, Promoting social responsibility	Cost per functional unit, Discount rate, Discounted benefit, Return on investment	Process yield, Mass balance, Average uncertainty on raw data,

The P²E approach formalizes two axes for interpretation of results: one oriented to sustainability pillars, the other oriented to levels of granulometry of the system.
Concerning virgin olive oil case study, “&cOlive” deals with a lot of scenarios based on real data. The results of sustainability assessment of these scenarios converge with literature results (Busset, 2014). Finally, this specific tool might be transferable “easily” to another food system by an expert of sustainability assessment.

4.3 Limits & perspectives

“&cOlive” have some limits that open up opportunities. Energy analysis have not been yet included within process simulation. However, the specificity of virgin olive oil extraction process (only mechanical) justifies this choice. Based on P²E decision making approach, the complete formalization of “goal and scope” and “choice” steps could reinforce “&cOlive”, for instance using requirements and constraints modelling and a decision making process. Uncertainty analysis is partially proposed by “&cOlive” and should be deepened. As discussed in the system description, some elements are excluded from the study, such as carbon storage or worker transportation. Their inclusion could reinforce the robustness and the completeness of results on sustainability assessment.

5. Conclusions

We proposed a process-product-enterprise approach for sustainability assessment of system in the context of system design or re-design. The real integration of social issue to technical, environmental and economic issues is one of the key points of the approach for sustainability. The CAPE based tool for food production sustainability assessment constitutes an advanced example of the relevance of such an approach. The double axes interpretation of the method permits to make more understandable the complexity of a complex system such as virgin olive oil production system. “&cOlive” tool gives to stakeholder the opportunity to better understand the system production face to sustainability issues and to optimize existing or new processes.

Acknowledgements

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