Use of Life Cycle Analysis and Eco-Design, to Improve the Environmental Performance of Processes in Food Industry

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Abstract—Increased competitive pressures and new regulations under the industrial environment require innovation while maintaining its socio-ecological. Several tools were developed to improve its productive performance while meeting environmental obligations, including the analytical method life cycle and eco-design, which integrate the environmental component in the process design. Thus, these two methods were applied to a unit of one of the pioneering fields of food industry in Morocco, the industry of production and bottling of soft drinks., for its participation in major pollutants generated to demonstrate the opportunities offered by these methods.

Index Terms— life cycle analysis, eco-design, IMPACT 2002, environmental impact

I. INTRODUCTION

With the globalization, intensive innovation is a new competition regime. Companies that have a capacity for innovation are those that have a robust process and methodologies for structuring the design process. However, the revolts in favor of the environment are forcing companies to innovate while respecting the socio-ecological environment, the new basic principle is "think global and act local." The analysis of impacts of life cycle and product eco-design process is like the key to meet the current requirements of competitiveness and the green economy. The study EIPRO - Environmental Impact of Products (Tukker et al., 2006), conducted as part of the Integrated Product Policy (European Commission, 2006), food and beverages contribute significantly to the impact environment generated by the consumption of meat and meat products, followed by dairy products, being the main contributors.

Phase of agricultural production of food of animal origin, is considered the greatest impact (Foster et al., 2006), however, it should be noted that there are significant environmental improvement levers, and at all stages of the life cycle of food products (Roy et al., 2009). The evaluation of the adequacy of process life cycle, referring to the use of energy at different stages, from production to consumption of the food shows that the phase of production / processing consumes about two-thirds of the total energy put into play, the rest being for consumption of the product by the consumer and waste management resulting (Uitdenbogerd et al., 1998).

From there, the food industry can act at three levels, to reduce its environmental impact, mainly the phase of production/processing (Jungbluth, 2000). Among the proposed routes for improving the environmental performance of food products, it is recommended to reduce energy consumption at each stage of the life cycle of products, while establishing a system of waste management (liquid, solid) at each stage including production during the industrial processing.

The objective of this paper is to present the two main stages of an effort to improve the environmental performance of a process:

--Assessment of environmental impacts generated by the process.

--Eco-design process by adopting the levers for improvement identified during the environmental impact assessment.

The study design chosen is a production of table water and soft drinks, occupying first place in its sector at the Oriental Region of Morocco.

II. ENVIRONMENTAL IMPACT EVALUATION PROCESSES RELATED TO FOOD INDUSTRY

A. Definition of the environmental evaluation

The environmental evaluation is to make a judgment about an object's relationship with its environment. That is to establish what is known in scientific jargon "its environmental profile." The object in question may be a product, service, institution, project, a production site, a business development plan, etc. (Debouche, 2010). Many tools and methods have been developed to conduct an environmental assessment. They are characterized by the object to be evaluated, and the complete to partial evaluation (Debouche, 2010), and allow, as appropriate, to achieve a quantitative or qualitative
assessment, taking into account one or more impact categories (mono or multi).

We cite as examples: the environmental impact assessment, eco-labeling, eco-auditing, evaluation of environmental performance, footprint, etc. As part of our work, we present the analysis of life cycle environmental assessment method as multicriteria taking into account the whole lifecycle of the process considered.

B. Definition of Life Cycle Analysis LCA

An important first step that led to the concept of eco-design is the realization that a product interacts with the environment during all phases of its life cycle.

Most famous in the scientific literature under his English name, Life Cycle Analysis (LCA), the technique of Life Cycle Analysis (LCA) of a product is thus born in the USA in the 70s after the energy crisis at the time. Initially developed in order to identify the energy requirements of industrial processes, the points on emissions into the atmosphere and the use of raw materials were added later (Ngouna Houe, 2006).

LCA is currently a standardized method by the international ISO standardization system through the series of international standards ISO 14040 (ISO 14040, ISO 14041, ISO 14042, ISO 14043, ISO 14044). ISO 14040 defines LCA as a method which "deals with the environmental aspects and potential environmental impacts throughout the life cycle of a product, from acquisition of raw materials for its production, use, its end of life treatment, recycling and disposal (ie from cradle to grave) "(ISO 14040:2006). This standard specifies the principles and framework applicable to the performance analysis of the life cycle.

Our presentation of the LCA will rely mainly on the content of these two standards. For simplicity, and in accordance with the foregoing standards, we call the "system" means any product, process or service subject to a stroke.

C. Applications of Life Cycle Analysis LCA

Generally, stroke can have different applications. It can for example be used as part of environmental communication made on a system: environmental statement relating to a product, eco-labeling ...

It can also be used to compare the environmental performance of several systems, or to identify which steps are most impactful life cycle of a system. As part of this article, the LCA will be considered a tool for decision support for eco-design, to identify opportunities to improve the environmental performance of the system studied, at each stage of its life cycle (Omont, 2010).

D. Realization of Life Cycle Analysis LCA

The LCA consists of four phases defined by SETAC (Society of Environmental Toxicology and Chemistry) and the two considered standards of ISO 14040:

--Definition of objectives and scope: The objectives and scope of the study determine the rules by which the LCA will be conducted. It is therefore necessary to fix them and describe them at this early stage. The definition of the goals is to secure the future or (s) application (s) of the LCA. The main elements of the scope of the study are as follows: The system studied - product, process or service in the study; system limits - perimeter of the study, the Functional Unit (FU) of the studied system - depending system taken as reference for the study allocation rules - rules for the allocation of impacts between the various co-products of the system, the method of impact assessment - method chosen depending on the system studied and objectives study (Omont, 2010).

--Inventory methodology: The Life Cycle Inventory (LCI) is to identify the set of "elementary streams (energy resource)" exchanged by the system with the environment. This is matter or energy directly extracted from the environment or released into the environment (eg minerals).

To realize this we count the entire inventory of anthropogenic flux (eg electricity consumption) and extracts issued by the system and use of LCA databases and LCA software capable of transcribing the data into an inventory of elementary streams (Omont, 2010).

--Assessment of the environmental impact which is divided into three phases:
- Classification.
- Characterization.
- Comparison of the data.

There are several methods of impact assessment to evaluate different impact categories (eg global warming, aquatic eutrophication ...) from different ways of modeling the impact.

Some methods, known as "endpoint", such aggregate impact categories in the categories of damage on different components of the environment (eg human health, ecosystem quality, resource depletion). The choice of the particular method used must be consistent with the objectives of the LCA and the system studied. In general, these methods use the Life Cycle Inventory system for evaluating the environmental consequences of a system. They classify the elementary streams of the ICV depending on the impact category to which they contribute (eg grouping of emissions Greenhouse Gas (GHG) contributing to the impact of "global warming", such as CO₂, CH₄ ...). Then they calculate the score for each impact category by summing the elementary streams contributors after they have been weighted according to their contribution to the impact category considered (Omont, 2010).

--Interpretation of results, important step that commits the author of the study to draw conclusions and propose actions and at each of the steps mentioned above (Weidenhaupt et al., 2000).

Defining the objectives and scope of application: The objectives and scope of the study determine the rules by which will conduct the LCA. It is therefore necessary to fix and describe the very first stage. The definition of the goals is to determine the future or (s) application (s) of the LCA. The main elements of the scope of the study are as follows: The system studied - product, process or service that the study system boundaries - boundaries of the study, the Functional Unit (FU) of the studied system - function system taken as...
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Methodology of Life Cycle Inventory: The Life Cycle Inventory (LCI) is to identify the set of "elementary streams (energy resource)" exchanged by the system with the environment. This is material or energy extracted directly from the environment or emitted into the environment (eg minerals). To achieve this we count all inventory anthropogenic flows (eg power consumption) and extracts issued by the system, then use databases LCA and LCA software capable of transcribing the data in an inventory elementary stream (Omont, 2010).

Evaluation of environmental impact: There are several methods of impact assessment to assess the different impact categories (eg global warming, aquatic eutrophication ...) from different ways of modeling the impact. Some methods, called "endpoint" aggregate these categories impact categories in damage to various components of the environment (eg human health, ecosystem quality, resource depletion). The choice of the particular method used must be consistent with the objectives of the LCA and the system studied. Generally, these methods use the Life Cycle Inventory system for evaluating the environmental consequences of a system. They classify elementary streams according to the ICV impact category to which they contribute (eg grouping emissions Greenhouse Gas (GHG) contributing to the impact "global warming", such as CO2, CH4 ...). Then they calculate the score for each impact category by summing the elementary streams contributors after they have been weighted according to their degree of contribution to the impact category considered (Omont, 2010).

Interpretation: Interpretation of results should make it possible to identify the main issues of the study and make recommendations for eco-design (Omont, 2010).

III. ANALYSIS OF THE LIFE CYCLE PROCESSES OF A UNIT OF PRODUCTION OF SOFT DRINKS AND WATER TABLE

The study is to develop a production process for the industry considered that takes place in four stages:
1 - Description of the technological choices of a process.
2 - stroke of the initial process to identify its impacts on the environment and define proposals for eco-design.
3 - Eco-design of the process studied.

A. Defining the objectives and scope of their

The objective of this study is to determine the elements that will leverage environmental improvement processes studied. The system analyzed is represented by the whole circuit processing, from raw materials to distribution of finished products (boissons drinks and table water). Thus, the study is extended to all processing operations of the raw material for the analysis of a single process will not allow us to verify that the optimization of the latter causes no modification (s) of the process, upstream or downstream, generator (s) of transfer of pollution, contrary to a full system scan from the inlet to the outlet.

For all unit operations studied, we took into consideration the activities of production, equipment and cleaning, and excluded local production facilities. The geographical scope is the Oriental Region of Morocco. The life of the system is 20 years according to the scale transformation of many manufacturing processes.

Studied the process takes place on a single industrial site and several points of distribution (it was agreed to take an average of 30 distribution points for analysis), separated by 50km (This distance was chosen because more than 85% of the production is intended to supply the outlets of the city location of the industrial site). The unit distributes its own products, which requires transportation under appropriate temperature and insulation. This transport was considered in the study. The comparison between the original process and the process will be carried out eco-designed base defined properties of the finished product: eg microbiological quality, the objective of the project is to study and not a process to evaluate the environmental load generated by the manufacturing product.

The choice was made to use in the first place, a workbook for estimating environmental impacts of products (Bilan Produit_2008_Logiciel) (which we will not present the results). This tool allows you to approach the main environmental impacts of everyday products, taking into account their entire life cycle. It provides a first assessment of environmental impacts, enabling better targeting of stroke and get a first overview of the main impacts. We deepen the analysis of data collected using the method of impact assessment 2002+. It assesses the environmental load of our system on 14 impact categories: human toxicity, respiratory effects, ionizing radiation, depletion of the ozone layer, photochemical oxidation, aquatic ecotoxicity, terrestrial ecotoxicity, acidification aquatic, aquatic eutrophication, acidification land occupation surfaces, global warming, consumption of non-renewable energy and mineral extraction (Humbert S. et al., 2005).

It then proposes an aggregation of impacts into 4 categories of damages: human health, ecosystem quality, climate change and resources. Note that in the absence of scientifically recognized, it has not been established characterization factor of damage to the aquatic acidification and aquatic eutrophication (Jolliet, 2003). These two categories of impact are not taken into account in the assessment of damages on the quality of the ecosystem, including aquatic ecotoxicity however.

Another criticism is to focus on the study method used is that it does not quantify the different types of pollution cause by industrial activity studied. That is why, in this work, we extended the study to the analysis of liquid pollution, which is one of the types of pollution most marked in Morocco.

B. Realization of the life cycle inventory

The life cycle inventory was conducted using data corresponding to specific flow control (full amount consumed 30T/month), which were quantified on the basis of a normal production day. The process was divided into four subsystems.
Subsystem "production": The processing of the process of preparation and bottling of beverages, are conducted according to the simplified diagram of Figure 1.

![Diagram](image)

**Fig. 1.** Diagram production and bottling of soft drinks

Each unit operation completed with a specific mission, all of its objectives are summarized in the table:

<table>
<thead>
<tr>
<th>Unit operations studied</th>
<th>Functions performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>- water treatment</td>
<td>1 - Control of physico-chemical quality and the microbiological safety of products</td>
</tr>
<tr>
<td>- preparation of finished syrup</td>
<td>2 - Preparation and production of soft drinks</td>
</tr>
</tbody>
</table>

Subsystem "cleansing": It represents all unit operations of cleaning equipment online. It requires large amounts of cold and hot water, and the use of alkaline detergents and acids.

On the unit studied, the cleaning is done according to the steps shown in Figure 2:

![Diagram](image)

**Fig. 2.** Diagram showing the stages of sanitation

Subsystem "equipment": It consists of tanks, plate heat exchangers (cooling), a starblender, pumps, piping, and various facilities for packaging of soft drinks. The equipment has been sized for the process studied. Only the nature and mass of material taken into account. Equipments are evaluated by equipment group participating in the same unit operation (eg bottling: a starblender, filler, capper, shrink wrapper, a pump and piping).

Subsystem "Transport": It is represented by the set of trucks and other raw materials to the factory and trucks used for the distribution of finished products.

C. Impact Evaluation

The results of the overall evaluation of the system shows that the subsystems are the greatest impact subsystem "production" and the subsystem "cleaning". Subsystems "equipment" and "transport" have minor impacts and having no meaningful improvement opportunities unlike the first two sub-systems, for it the rest of our study we will focus on these.

Impacts subsystem "production" are due to high energy consumption, the "preparation and production" using hot water at 90 °C and cold water at 10 °C. Lines bottling consume large amounts of electricity.

The subsystem "cleaning" consumes large amounts of electricity and fuel for heating water and cleaning solutions, and produces effluents contaminated with residues of caustic soda and drink soft, and are discharged directly into sewers. As emphasized by Pfister et al (2009), if the sample undergoes a loss of water quality and / or is transferred to another watershed, this corresponds to a decrease of freshwater resources. In addition, although the methodological framework of LCA is suitable for this type of evaluation, impact assessment methods neglect this aspect (Koehler, 2008). IMPACT 2002 + method not counting water resource depletion, environmental load actual cleaning may be underestimated. We did not assess the potential impact of their eventual release into the aquatic environment. Hence, to address this problem, in the context of other studies, we conducted a follow-up on a day of production, the effluents studied. Las physicochemical analysis gave very high values.
of BOD₅ (1141.5 mgO₂/l) and COD (373.27 mgO₂/l) in addition to high alkalinity (pHmedium = 10.3) with an average rate of consumption of 51 l/s and rejection of 20 l/s, against regulatory values of what qualifies these pollutant releases.

### TABLE III

<table>
<thead>
<tr>
<th>Output l/s</th>
<th>DBO₅ mgO₂/l</th>
<th>DOC mgO₂/l</th>
<th>MES mg/l</th>
<th>P mg/l</th>
<th>NTK mg/l</th>
<th>T °C</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averages</td>
<td>20</td>
<td>373.27</td>
<td>1141.5</td>
<td>369.6</td>
<td>0.91</td>
<td>0.77</td>
<td>26.38</td>
</tr>
<tr>
<td>values</td>
<td>100</td>
<td>500</td>
<td>50</td>
<td>10</td>
<td>30</td>
<td>30</td>
<td>6.5-8.5</td>
</tr>
</tbody>
</table>

* Standard values Moroccan direct discharge limits

| l/s: liter per second, mgO₂/l: milligrams of oxygen per liter, mg/l: milligram per liter, °C: degree Celsius, pH: Hydrogen potential |

The values shown in Table III are higher than those permitted by the standard Moroccan limit values for discharges direct what qualifies these releases of pollutants. This data is not provided by the environmental analysis, and to perform a thorough environmental analysis it is advisable to combine several methods.

### D. Interpretation

This analysis was conducted to determine ways of optimizations by using eco-design. The results show that the sources of environmental improvement related subsystems "production" and "clean." These proved to be very resource-intensive and energy (electricity, fuel and water). The main lever for improvement highlighted by this study is the economy of resources: energy, water.

### IV. ECO-DESIGN PROCESSES OF THE FOOD INDUSTRY

#### A. Definition

The knowledge gained from an approach of LCA can be utilized during the design phase of a product in order to better assess the environmental impact (Gungor et al., 1999). This can be particularly useful when the generated impacts beyond the production phase were not taken into account (Reyes et al., 2006).

In the literature, methods and techniques to analyze the environmental impact of a product in order to minimize the effects by acting on the design parameters are known under the name of eco-design, or Design For Environment (DFE), the name most commonly used in the USA. Eco-design is defined as "the systematic consideration of environmental, health and safety performance evaluation in the design of a product (or service) throughout its life cycle." As defined in ISO 14062, the Eco-design aims to propose approaches and principles of design to minimize the same performance, the environmental impact of a product throughout its life cycle (Reyes & al., 2006).

#### B. Realization

The objective of the study is to propose an eco-design simple and easily applicable by the companies of the industry studied in a developing country.

It is currently in development with all project partners. This approach is based on the results of the LCA process, but also take into account the constraints on the company including: socio-political requirements (regulations), the image and the technical and economic feasibility. Note in this respect that the eco-design shall not in any way affect the main function of the process: the control of product safety.

The eco-design includes thinking in terms of functions performed by the process (guarantee of product safety):

1. Definition or function (s) expected (s) of the process to meet the needs of the company.
2. Proposed options or technological improvements to meet those needs with consideration of environmental criteria designers.
3. Environmental assessment of these options follow standardized.

This approach is applied at 2 levels:

1. Eco-design process itself, by improving the existing unit operations or by the choice of technologies to accomplish the same functions.
2. Eco-design industrial site in which the method is implemented (reduction of energy losses, choice of energy sources, development of eco-industrial synergies ...).

In the case of process optimization, validation, environmental changes may be made in a simplified LCA of the entire system is limited to the main flow and impacts previously identified as being paramount. In the case of a disruptive technology, it will be necessary to verify the absence of the appearance of a new impact, a classic LCA. In all cases, it is an iterative process: after several cycles of improvement, it will be necessary to perform a complete LCA of his new method for identifying areas for improvement. This kind of study has provided meaningful results, the study conducted in the project ECOPRM which inspired us (Omont, 2010).

Thus, following the results obtained during the environmental assessment of production processes, ways of improving underway, we have defined are as follows:

1. Reduction of energy consumption:
   - Boiler and steam distribution: the type of boiler used is a steam boiler. Steam is the heat transfer agent preferred in this process. One kg of steam at 3 bar (from 143.6 °) contains 2133 kJ of energy when it is condensed into water, while the usable energy per kg of heated water, for example at 110 0 C and cooled to 120 0 C in the heating process, is only 85.8 kJ. The cost of fuel needed to operate the boiler plant is about 25 to 35% of the total energy bill. Therefore, it is important and profitable to focus on ways to make it more efficient and less costly operation of boilers and steam distribution.
   - Between 23-25% of total energy intake fuel is lost during the operation of a boiler typically 4% in the boiler jacket, 18% in the flue gas and 3% in the form of drain. Between 75 and 77% of the thermal energy is found in the steam produced, and
it represents the thermal efficiency of the boiler.

The importance of heat loss in the combustion gases depends on the excellence of the combustion, so it is possible to control it. The heat loss of the combustion gas can be reduced by the installation, and maintenance of the burner, by obtaining a mixture of air and maximum fuel and the air control and temperature air within variation problems.

Incomplete combustion produces carbon monoxide (CO). Soot can be deposited on the surface exposed to fire the boiler, which further reduces the efficiency. When the oil is not completely burned, the smoke from the chimney.

Another parameter that can be controlled is the heat loss during emptying. Everything depends on the quality of the makeup water, that is to say, mainly solids solution that contains the amount of uncontaminated condensate returned to the boiler and drain the system used. Control of garbage can be done by manually opening a valve for some time intervals, depending on experience and analysis of boiler water, or continuously. This control can also be done with a valve controlled by a timer or, alternatively, from automatically checking solids solution using, for example, a conductivity meter. It is obvious that the latter method, with adequate protection, minimizes heat loss from the drain.

Several parameters also affect the distribution of steam, which is at the origin of large energy losses, such as vapor pressure (low pressure generates heat losses over large areas during distribution and in the equipment used), piping, insulation, leaks, heat transfer, condensate traps, and condensate recovery. To do so would put in place a program to monitor the effectiveness of the facilities and their maintenance (Natural Resources Canada).

2 - Power consumption:

Save up to 20% can be done through a system of organizing schedules and habits of functions. Once identified energy devices, should monitor their consumption unit may request from the utility advice to reduce consumption. New behaviors and changes should be considered as:

• ensure that good habits are established and educate employees first: turn off the lights and put the equipment off when not in use;
• Ask presence sensing devices for managing lighting;
• stagger the switching equipment or retrofit energy production schedule in order to reduce power demand. So, do not turn on all devices in the conditioning unit when the shift starts, rather than running them as needed and stop immediately the task is completed.
• Perform battery charging, filling water tanks, and perform other activities that consume energy less urgent during off-peak periods (Natural Resources Canada).

Finally, we expect the construction of a flow indicator to quantify water consumption after the introduction of water recycling systems and rational management (minimizing water loss during cleaning). It will allow us to track improvements made by the new process.

V. CONCLUSION

LCA and eco-design are adapted to environmental improvement processes food. It is however important to note that the environmental assessment methods are not available to quantify the impact on the environment generated by sampling freshwater. But the food industry takes large amounts of water (Maxime D., 2005).

This parameter can not be neglected and should be checked with other tools (eg indicator flow). Eco-design allows for its help designers to opt for choice technology more environmentally friendly. It is also a teaching tool in the company, in the sense that each player learns the consequences that may have environmental unit operations which he has responsibility, on operations upstream or downstream (eg consequences of cleanups conducted on the treatment of effluents) (Omont, 2010).

Research on the integration of ecodesign in SMEs (small, medium business) in developed countries (Europe) is naturally the intersection of the fields of research on eco-design as part of PLM, and SMEs, as part of the organizations industrial.

The section describing the industrial context, showed that eco-design from the original field of research-action between research institutions and businesses, was now a full-fledged industrial problematic. On this basis, some bibliographic sources used to prepare a summary analysis of all experiments in the field of eco-design company for over ten years.

Authors of a study on the state of the art eco-design in the European Union, Tukker et al. report that eco-design still has a negligible role in business, and especially in SMEs. They even specify that in terms of eco-design activity SMEs are deeply recessed relative to large firms (Tukker et al., 2000a).

The authors believe that one can count a hundred SMEs practicing eco-design in each of the following countries have benefited from government programs ambitious dissemination of eco-design: Denmark, Sweden, the Netherlands and Austria. According to them, the small group of European SMEs developing an eco-design activity corresponds to SMEs identified a potential niche market for "green" products, and took the opportunity to differentiate their product. These SMEs are however exceptions (Tukker et al., 2000b).

The authors conclude that, even in the most advanced countries in the field of eco-design the proportion of SMEs developing an activity of environmental design products is very low (Tukker et al., 2000b). Hillary says, meanwhile, it is generally difficult to mobilize and engage SMEs in an effort to improve its performance environment, whether for production sites or product design (Hillary, 2000). The SME Observatory noted in its report on SMEs and the environment, eco-design is still not accessible to smaller businesses, those with fewer than 50 employees (AGPME).

Finally, Tukker et al. report that, in general, eco-design is not an axis Strategic SME and corporate policies on environmental design products are extremely rare, while in many large enterprises, eco-design is already a strategic (Tukker et al., 2000b).

In summary, environmental concerns play a strategic industry, because of new regulatory and economic challenges they represent. The integration of production methods environmentally represent the advent of a new production area
that fits in the principle of sustainable development adopted by several countries in the developing world.

References