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Towards sustainable systems configurations: application to an existing fish and seafood canning industry

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A B S T R A C T

Spain is the first fish and seafood canning producer country in the European Union. Within Spain, the Galician (North-western Spain) canning enterprises dominate the market, being tuna the main species processed in the Spanish fish and seafood canning industries. In this context, this paper analyzes a Galician fish and seafood canning enterprise from the point of view of sustainability. To this end, an existing methodology combining Material and Energy Flow Analysis and Best Available Techniques analysis was enhanced, including for the first time the Exergy Analysis to detect the Improvable Flows of the process and to propose techniques that can minimize the environmental effects of these flows. The final methodology has been applied to a tuna canning process, resulting in the identification of 16 improvable flows, and the selection through best available techniques analysis of 14 alternatives to enhance the process. The application of the methodology developed in this work to an industrial system provides a way to detect material, energy or exergy improvable flows in a process, allowing industrial technicians into selecting the more suitable modifications to implement in their processes, in order to get its optimal alternative.

1. Introduction

Avoiding food spoilage has always been a major concern to humanity, who has developed processes as salting, smoking or canning to preserve it. Nowadays, Spain is the first fish and seafood canning producer country in the EU. In 2014, the Spanish production reached 343,000 tonnes, being its economic value about 1500 million € (FAO, 2014). Within Spain, marine aquaculture is a major industrial sector in the northwest (Barros et al., 2009a), where it has become a strategic sector in Galicia (NW Spain). In fact, they are the Galician canning enterprises who dominate the Spanish market, representing in 2011 the 86% of the Spanish production (AC, 2011).

The main species processed in the Spanish fish and seafood canning industries in 2014 was tuna, constituting two-thirds of the produced volume and half of the economic value (FAO, 2014).

Taking into account the importance of this sector, this paper proposes a methodology to get the optimal alternative of a tuna canning industry from the point of view of sustainability. The proposed methodology lies on the basis of an existing methodology combining Material and Energy Flow Analysis (MEFA) and Best Available Techniques (BAT) analysis (Barros et al., 2007; Torres et al., 2008), adding as a novelty the Exergy Analysis (EA), which will help MEFA identifying the Improvable Flows (IF) of the system. Once identified the IF, the BAT analysis will help providing techniques which will minimize the environmental effects of this IF.

From the concept of Sustainable Development, a number of philosophies had emerged, being the Life Cycle Thinking (LCT) one of the most impactful ones. LCT considers the range of impacts throughout the life of a product (EC, 2012), seeking to identify possible improvements to goods and services in the form of lower environmental impacts and reduced use of resources across all life cycle stages. This philosophy provides a series of tools that ease the complex task of integrating sustainability concepts into the process, such as Life Cycle Analysis (LCA), Environmental Management Systems (EMS), Design for Environment (DfE), or Material and Energy Flow Analysis (MEFA) among others. MEFA comprises a whole family of tools to study the materials and energy flowing through a given system, the storages and flows within this system and the resulting outputs from the considered system to others (Hendriks et al., 2000).

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MEFA has been widely used both in ecology and economy (Suh, 2005), being the scope extensive: to study the metabolism of human settlements (Wolman, 1965; Sundkvist et al., 1999; Alfonso Piña and Pardo Martínez, 2014) or transport systems (Federici et al., 2008), to analyse the input of fossil fuels (Dai and Chen, 2010), to estimate materials demand and environmental impacts of buildings (Huang et al., 2013), to quantify the biomass available for energy purposes and calculate the fossil fuels saved by using this biomass (Kanianska et al., 2011). Within industry, MEFA results have been used quite successfully for optimizing material flows and waste streams in production processes (Binder, 2007). Some examples are the application to the roof tile manufacture industry (Torres et al., 2008; Torres Rodríguez et al., 2011), to a tailoring factory (Herva et al., 2012), or to a steelmaking plant (Zhang et al., 2013).

Exergy Analysis (EA) is a technique based on the determination of exergy flows in the case study using the exergy balances of the components connected by those flows. EA, although less used and more complex than energy analysis, is more useful because it points directly to where energy can be saved. The quantification of the irreversibilities through EA allows detecting where energy quality is lost (where energy can be saved) (EC, 2009). The EA was applied, for example, to the UK iron and steel sector. In that work, Michaellis and Jackson calculated the consumption of exergy associated with the UK steel sector, taking into account: steel production, transport, generation of waste steel, trade and recycling (Michaellis and Jackson, 2000a, 2000b). More recently, it was also applied to a combined heat and power plant with integrated lignocellulosic ethanol production to investigate potential irreversibilities from such integration (Lythcke-Jørgensen et al., 2014).

MEFA and EA results are analysed in order to identify the Improvable Flows (IF) of the system. Being the IF those inputs, outputs or internal flows that are remarkable in comparison with the other flows of the process, and which could be improved if properly managed (Torres et al., 2008). This concept has been successfully applied in various works to date (Torres et al., 2008; Bello Bugallo et al., 2012; Cristóbal Andrade, 2012).

In order to minimize the effects of the improvable flows identified in the system, a Best Available Techniques (BAT) analysis can be made (Barros et al., 2007; Torres et al., 2008). According to the Directive 2010/75/EU on industrial emissions (IPPC Directive), BAT are 'the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for Emission Limit Values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole' (EPCEU, 2010). Following the methodology set by the European IPPC Bureau, BAT analysis evaluates candidate techniques to be BAT. For each technique, this method considers environmental aspects, technical description, benefits, secondary effects, implementation, applicability and economical aspects (Barros et al., 2007).

2. Case study

The selected industrial plant is a fish and seafood canning industry. Particularly, it processes tuna, mussel and cephalopod. This installation is a medium-sized enterprise located at the seaside on the Galician coast. The main consumption data is shown in Table 1.

Tuna represents more than 80% of the raw materials entering the plant, and the tuna line (processing whole frozen tuna) applies the most complete version of the fish and seafood canning process. Therefore, this work was focussed on that line.

Table 1
Main consumption data.

Inputs to the process	Quantity [tonnes per year]
Frozen tuna	901
Empty cans	213
Salt	5
Vegetable oil	302
Water	12.300
Fuel oil	48

3. Methods

An existing methodology (Torres et al., 2008) combining MEFA and BAT analysis was adapted in this paper, adding the EA. The overall methodology includes the following steps:

1. Definition of the system under study. Including the identification of the industrial plant and the qualitative analysis of the selected industrial system.
2. Material and Energy Flow Analysis.
   -Data acquisition.
   -Scenario modelling. It includes software selection, system modelling using the selected software and model running and results of the MEFA.
3. Exergy analysis.
   -Identification of irreversibilities.
   -Data acquisition: identification of the data needed to fill the model.
   -Scenario modelling: as in MEFA, software selection, system modelling using the selected software and model running and results are included in this stage.
4. Selection of the improvable flows. The results obtained from the MEFA and the EA are analysed to identify the IF.
5. Best Available Techniques analysis.
   -Recompilation and inventory of the candidate techniques to be BAT for the selected industrial system. The candidate techniques are inventoried according to the methods proposed in previous works (Barros et al., 2007).
   -Identification of the already implemented BAT.
   -Proposal of alternatives to the process. Candidate techniques to be BAT are selected for each of the identified IF.
6. Optimal alternative identification.

4. Application of the methodology and results

In this section, the above mentioned methodology (Section 3) will be applied to a carefully selected system.

4.1. Definition of the system under study

The considered industrial system is defined in space and time. Qualitative analysis is applied in order to identify the stages involved in the process.

4.1.1. Identification of the industrial plant

The methodology is applied to a tuna canning industry, as seen in the case study (Section 2).

4.1.2. Qualitative analysis of the selected industrial system

The production of canned tuna from whole frozen fish requires a series of activities that can be classified in four main stages (Fig. 1) (Bello Bugallo et al., 2013; Barros et al., 2009b; Casares et al., 2005):