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Marco A. Miranda-Ackerman, Catherine Azzaro-Pantel. Extending the scope of eco-labelling in the food industry to drive change beyond sustainable agriculture practices. *Journal of Environmental Management*, 2017, 204, pp.814-824. 10.1016/j.jenvman.2017.05.027 . hal-01886810

HAL Id: hal-01886810

<https://hal.science/hal-01886810>

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To cite this version:

Miranda-Ackerman, Marco A. and Azzaro-Pantel, Catherine  *Extending the scope of eco-labelling in the food industry to drive change beyond sustainable agriculture practices.* (2017) *Journal of Environmental Management*, 204. 814-824. ISSN 0301-4797

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Research article

Extending the scope of eco-labelling in the food industry to drive change beyond sustainable agriculture practices

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A B S T R A C T

New consumer awareness is shifting industry towards more sustainable practices, creating a virtuous cycle between producers and consumers enabled by eco-labelling. Eco-labelling informs consumers of specific characteristics of products and has been used to market greener products. Eco-labelling in the food industry has yet been mostly focused on promoting organic farming, limiting the scope to the agricultural stage of the supply chain, while carbon labelling informs on the carbon footprint throughout the life cycle of the product. These labelling strategies help value products in the eyes of the consumer. Because of this, decision makers are motivated to adopt more sustainable models. In the food industry, this has led to important environmental impact improvements at the agricultural stage, while most other stages in the Food Supply Chain (FSC) have continued to be designed inefficiently. The objective of this work is to define a framework showing how carbon labelling can be integrated into the design process of the FSC. For this purpose, the concept of Green Supply Chain Network Design (GSCND) focusing on the strategic decision making for location and allocation of resources and production capacity is developed considering operational, financial and environmental (CO₂ emissions) issues along key stages in the product life cycle. A multi-objective optimization strategy implemented by use of a genetic algorithm is applied to a case study on orange juice production. The results show that the consideration of CO₂ emission minimization as an objective function during the GSCND process together with techno-economic criteria produces improved FSC environmental performance compared to both organic and conventional orange juice production. Typical results thus highlight the importance that carbon emissions optimization and labelling may have to improve FSC beyond organic labelling. Finally, CO₂ emission-oriented labelling could be an important tool to improve the effects eco-labelling has on food product environmental impact going forward.

1. Introduction

New consumer awareness and behaviour favouring *greener* products and services is shifting industry towards more environmentally sustainable production systems. Eco-labelling influences the market force of consumer by incentivizing the producer to provide greener products that consumers value differently than conventional ones. Eco-labelling is a means to inform consumers of specific characteristics of products and has been used to target how client preferences for greener products change the value of a product based on the *green* attribute. It has somewhat recently

been used to introduce information on environmental performance of products and the production systems they come from in more detail. Depending on the product and key environmental damage, product eco-labels inform the consumer on measures taken by the producers to minimize environmental impact. One example of a product would be paper coming from a managed forest, in the case of a service, airlines market carbon emissions offsetting services as an added service to transport (i.e. planting a tree with your flight). One type of eco-label that has gain traction is the *organic* eco-labels for food products. This type of labelling focuses on promoting *organic* farming, mainly targeting the agricultural stage of the food supply chain. A second one is *carbon labelling* that is used to inform consumer of the carbon footprint produced due to the production and consumption of products and services. These two labelling strategies help consumers and producers set the value of the

products in a different way than that adopted for conventional products. By using this strategy, producers are incentivized to adopt innovative and more sustainable practices in order to gain access to these consumer markets. The effects on overall performance of supply chains have just started to be studied (Beske et al., 2014; Brindley and Oxborrow, 2014).

Agrofood supply chains have all the stages and characteristics of any consumer product supply chain. It is made up of suppliers, focal companies, clients, distribution routes and centres. Key differences are that the products are consumed by humans and animals, and that the raw materials are grown through agricultural practices and land use. But while many supply chains for different products may be studied and improved, in order to use eco-labelling strategies, food products have restrictions. Depending on the region or country, these restrictions focus on different aspects of the product/production life cycle of food products. In a globalized economy many food products are globally sourced and processed. This is due to many reasons, one key issue is the environmental conditions that allow for the efficient production of some food products. Favourable climates for some cultures are limited to specific regions of the globe. This in turn makes the agrofood supply chain one that is globally distributed, where many steps for getting food from orchard to plate are not only related to agriculture but also to processing, manufacturing and transportation.

Environmental impact of agrofood production is thus not limited to the initial stage of production, where organic labelling applies a market pressure for improvement, but also extends to stages farther downstream. Green supply chain management paradigm provides a framework to study the full life cycle of product or service and integrates operational, economic and environmental indicators, with the aim at improving overall performance. In particular, Green Supply Chain Network Design is a process which facilitates strategic decision making on issues related to the location, installation, and allocation of resources and production capacity, through the scope of GSCM paradigm (Eskandarpour et al., 2015). Through this scope, measuring CO₂ emissions for instance along key stages in the life cycle of a product can be captured and integrated into a decision framework. This allows the decision makers (e.g. managers and executives) to improve performance and allows for the use of eco-labelling strategies targeting demanding consumers. It allows the marketing departments to take advantage of new consumer awareness (e.g. consumers having a good idea of what “CO₂ emissions/unit of product” means) in order to differentiate and add value in a commodity driven market.

This paper presents the development and deployment of a GSCND strategy that targets economic and environmental objectives through a Multiobjective Optimization formulation and solved through the use of Genetic Algorithms. The approach is applied to an orange juice supply chain case study. The finding of the study shows that Organic labelling can be complemented with Carbon labelling in order to improve key emissions hotspots outside of the scope of Organic labelling. The results of the optimized results of the supply chain network are compared with those of some reference values taken from LCA studies on conventional and organic orange juice supply chains.

2. Background

Eco-labels are defined by the International Organization for Standardization (ISO) as: “... a voluntary method of environmental performance certification and labelling that is practiced around the world. An “ecolabel” is a label which identifies overall, proven environmental preference of a product or service within a specific product/service category”. The goal of Eco-labelling is to promote

sustainability managed production and consumption, categorized in three types: A) Type I – a voluntary, multiple-criteria based, third party program that awards a license that authorizes the use of environmental labels on products indicating overall environmental preference of a product within a particular product category based on life cycle considerations. B) Type II – informative environmental self-declaration claims. C) Type III - voluntary program that provide quantified environmental data of a product, under pre-set categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party.

The scope of the case study (that is presented further down) is geographically defined by the regions that make up the SC, mainly the raw materials sourcing region (i.e. Mexico and Brazil in Latin America) and consuming regions (i.e. France and Germany in the European Union). As eco-labelling is intended to inform the consumer - the marketed region is the determinant in what labelling policies apply. In the case study these fall within the European Union (EU) policy structure.

In the EU there is a distinction between Eco-labels and Organic labels. The EU Eco-label scheme was launched in 1992 to promote the production and consumption of products that have a reduced environmental impact in comparison to existing products on the market. Through these labels transparency, reliability and scientific credibility is guaranteed to the customer without the need of any technical understanding to interpret the label. This allows the consumer to make environmentally friendly choices when purchasing products, and by this, promoting the product providers to adhere to this standard to maintain competitive stands. While Eco-labels (under the EU definition) can be applied to different product groups (e.g. cosmetics, hygiene, cleaning, clothing, paints, electronics equipment, building materials, household appliances, etc.), they do not apply to food and feed products. According to the EU Eco-label website referencing a report commissioned by the EU (Oakdene Hollins Research and Consulting, 2011) on the feasibility of developing Eco-label for food and feed products with very interesting and important conclusions.

“... the Commission is not intending to develop Ecolabel criteria for food and feed products at this time. The Commission could, however, revisit this question at some point in the future considering the possible role of the EU Ecolabel within the framework of the development of any wider EU food strategy, in particular in light of developments in methodologies, and other tools, for measuring the environmental impact (including by, for example, environmental footprinting) of products.”

Two main points are to be noted from this statement. First and foremost is that food products are outside of the scope of Eco-labels in the EU under their definition. The second is that, this could change, and there is a suggestion of taking (organizational) *environmental footprinting* (OEF) as a candidate strategy.

In (Pelletier et al., 2013), some OEFs are compared in terms of four criteria that define the European Commission Organization Environmental Footprinting (EC OEF) scheme. These are: (1) multi-criteria, (2) life cycle-based approach that considers all organizational and related activities across the supply chain, (3) provides for reproducibility and comparability over flexibility, and (4) ensures physically realistic modelling. According to (Pelletier et al., 2013) only Global Resource Initiative (GRI) takes a broad scope of environmental impact, and states that all other methods refer to single impact categories while the EC OEF proposes a multiple criteria approach.

This paper assumes the possibility of the inclusion of Food category within the EU Eco-label scheme. To illustrate the

incorporation of the multiple criteria approach proposed in EC OEF the case study is presented with to product streams *Organic* and *Carbon footprint minimized* orange juice. In addition, we adhere to the current trend to use single impact categories (i.e. GWP), as the environmental *footprinting* category within the context of the EU Commission prospective on eco-labelling and the GSCM paradigm.

2.1. Organic production

Indeed, environmental labelling does exist in the EU for food products under the category of *Organic* or *Biological* product labelling (EC-European Commission et al., 2007). The EU Organic Certification label scheme has the aim at improving environmental impact of production and consumption of agricultural products. According to "EC Council regulation No 834/2007 on organic production and labelling of organic products and repealing Regulation 'EEC' No 2002/91" states that "Organic production is an overall system of farm management and food production that combines best environmental practice, ...and a production method in line with the preference of certain consumers for products produced using natural substances and processes."(EC Council regulation No 834/2007-Art. 1). And goes on to define Organic Production as "... the use of the production method compliant with the rules established in this Regulation, at all stages of production, preparation and distribution.....and including its storage, processing, transport, sale or supply to the final consumer, and where relevant labelling, advertising, import, export and subcontracting activities" (EC Council regulation No 834/2007-Art.2).

EC Council No 834/2007 regulation continues to add specification applied to processing of Organic Food stating "... the production of processed organic food shall be based on ... organic agricultural ingredients... the restriction of the use of food additives, of non-organic ingredients... the exclusion of substances and processing methods that might be misleading regarding the true nature of the product... the processing of food with care..."(EC Council regulation No 834/2007-Art.6).

Following the principals and norms presented before, this study assumes all necessary requirements to access Organic certification are achieved in *Organic* product flow in the simulated case study. Herein the term Eco-label relates to the achievement and use of the Organic certification label that uses the logos illustrated for Germany and France in Fig. 1.

2.2. GSCND

Supply Chains are viewed as networks of elements that involve suppliers, manufacturers, distributors among other stakeholders and reflect materials, information and economic flows. They are physically constructed of natural resource extraction facilities, processing facilities, manufacturing plants, trucks, sea vessels, warehouses, etc...that are located in different locations around the world. Supply Chain Network Design (SCND) involves a decision and model framework that searches "through one or a variety of metrics, for the "best" configuration and operation of all of these (SC network) elements." (García and You, 2015).

Some of the most important challenges that SCND holds reflect the issues that complex real systems face including for example decisions at multiple scales, multiple levels, multiple periods, multiple objectives and undoubtedly multiple stakeholders.

SCND consists in formulating the SC network as nodes and arcs that connect, featured in layers for each echelon that construct the SC of interest. In each layer, different alternatives are presented that can represent differences in modes of transport, technologies used, geographical locations of sites, among many other choices, while the arcs may represent attributes and criteria of interest such as

distances, costs, time periods, etc. The process of optimizing the SCND is to find the best configuration of the network, this is to say, the best route of arcs and nodes that fulfil the single or multiple objectives that are of interest to the decision maker.

3. Problem definition

The research question is formulated in terms of the case study:

1. Is *Organic* certification a sufficient driver to minimize the environmental footprint of agrofood taking into account the full life cycle i.e. from raw material to delivery of end product to market?
2. Developing an optimal design approach for an orange juice supply chain network in order to minimize CO₂ emission at all the stages of the supply chain, with two product streams, one for organic and one for conventional - can overall performance be equal of better than that of a SC that only targets the Organic label objectives?

In order to answer these questions a mathematical model reflecting a globally distributed orange juice supply chain is formulated with the following variables to determine the following items:

- Design of production and transformation systems
 - Agro practice selection
 - Technology/equipment selection
- Composition Production « Mix »:
 - Organic vs. conventional
 - From concentrate or not?
- Location and allocation:
 - Where to install the transformation units?
 - In which region/country?
- Supplying:
 - Number of suppliers (contract farming policy)?
 - Which supplier to select?
- Sales price policy
 - Price fixing
 - Premium or not?

Historical and published data are used to define operational, economic and environmental parameters and variables. The model is designed and solved as a multi-objective optimization problem in order to find trade-off solutions from antagonistic objectives (Miranda-Ackerman et al., 2014). The two main objectives targeted are Net Present Value (NPV), reflecting the preferences and objectives of the company, and Global Warming Potential (GWP in kg CO₂-eq emissions), reflecting the preferences of society and the environment. The model is solved through a Genetic Algorithm approach in order to obtain the best compromise solutions. Different scenarios and configurations are optimized and analysed in order to highlight the performance of the supply chain in terms of the criteria being studied in relation to the research questions. The results are compared in terms of CO₂-eq emission to those of



Fig. 1. Organic certification eco-label for EU countries Germany and France (source: www.oekolandbau.de/bio-siegel/ and www.agancebio.org).

the current scientific literature.

4. Case study

Before going further presenting the different optimization schemes, let us define the key elements of the case study. It illustrates a globally distributed orange juice supply chain as represented in Fig. 2.

The Focal Company that manages this chain needs to select a project to increase capacity. In the SCM paradigm as in the GrSCM, a central or focal company (FC) as proposed in (Seuring and Muller, 2008) is characterised by being the designer or owner of the product or service offered, governing the supply chain, and having contact with all SC stakeholders including the customers. The FC can also sometimes be the processing or manufacturing company, as in the case study.

The FC is considered to be the *integrator firm* within the context of contract farming as described by (Rehber, 2000), under a Management and Income Guaranteeing contract (Richard and Kohls, 1998), also known as Production management contract (PMC) (Minot, 1986).

The potential market demand is assumed to be known. The main assumptions are the following ones:

1. Two potential raw material supplying regions are considered, i.e., Mexico and Brazil, to meet raw material requirements.
2. Only one region has to be selected, from which a set of suppliers are contracted in order to satisfy the capacity level as required by the demand and the quality of oranges.
3. The oranges will be processed at a plant located near the supplier. A selection of technologies and capacities has to be carried out to best satisfy market needs.
4. The final products are of four types, combining the label attribute (*organic* labelled, and conventionally labelled) and the processing attribute (from concentrate and not from concentrate).
5. The market target is composed of ten principal cities in two countries (France and Germany).
6. A set of 6 potential sites to locate a bottling/distribution site for each country is considered.

The decisions under the scope of the modelling and optimization framework can be synthesized in the following:

Supplier: Raw material selection, supplier region selection, supplier selection, agro practice selection, land surface to be contracted (agricultural production capacity).

Transformation: Selection of bacteriological stabilization technology (i.e; pasteurization equivalent, such as Pulse Electric Field or High hydrostatic pressure processing), Concentration technology selection (e.g. evaporators, freeze concentration, reverse osmosis).

Packaging/bottling: Bottling plant location, bottling technology selection (e.g. glass bottles, carton, PET containers).

Market: Demand coverage (i.e. market to be covered by planned production capacity), product mix (i.e. quantity of each type of product based on organic or conventional raw materials use, and if concentration or not from concentrate juice is bottled).

The parameter values used for this case study, which can be found in (Miranda-Ackerman, 2015), are taken from relevant literature and adapted to this example.

5. Methods and tools

The solution approach, is based on the coupling of Multi-objective Genetic Algorithms (Dietz et al., 2006; Gomez et al., 2010) and Multiple Criteria Decision Making (MCDM) (Ho et al., 2010) to model the complex supply chain system based on

interconnected networks from suppliers to consumers (see Fig. 3). The solution strategy is flexible enough to allow the modeller to evaluate different strategies based on the specification of the food system under consideration.

The choice of an evolutionary algorithm (EA) as a multi-objective optimization procedure is mainly influenced by the following items that make them preferable over classical optimization strategies: a) considerations for convexity, concavity, and/or continuity of functions are not necessary in EAs; b) their potential of finding multiple Pareto-optimal solutions in a single simulation run; c) Nonlinear constraints and criteria can be tackled by such algorithms; d) they are known to be efficient to tackle combinatorial problems. In the supply chain design problem encountered in this work, integer variables are considered representing the decisional choices relative to the existence or absence of a node in the network as well as the operational variables of the supply chain.

The use of NSGA-II as the stochastic search algorithm is thus justified. Table 1 summarizes the values used for the parameters required by the algorithm. They are fixed based on both empirical trial-and-error experience and on the sensitivity analysis that is not detailed here (Dietz et al., 2006). In this study a set of scenarios are described in detail and analysed in order to evaluate different modelling strategies, because of this different parameters are used when using the GA. A higher number of individuals in the population associated with a higher number of generations used for scenario 1 compared to that used for scenarios 2–6 (i.e. a double value) helps to overcome the difficulties encountered in stochastic search methods involving equality constraints. It must be highlighted that a relatively high value for mutation rate (i.e. 0.5) was adopted which can be considered inconsistent compared to what occurs in natural evolution. This phenomenon was already observed in mixed integer problems similar to the pure integer problem treated in this work (Dietz et al., 2006; Gomez et al., 2010).

The results are presented in terms of the Pareto front solutions produced by the GA.

At the final step of the strategy, a Multiple Criteria Decision Making (MCDM) provides a way to find a solution in the diversity of the solution space represented by the Pareto front. It allows the decision maker to rank solutions with the flexibility to reflect different values and preferences among the best solutions that were identified by the optimization procedure. In this work, the M-TOPSIS (Modified Technique for Order of Preference by Similarity to Ideal Solution) method proposed by (Ren et al., 2010) is used. It has a set of weight parameters that can be used to assign importance to each criterion. Unless explicitly mentioned, the same weight is allocated to each criterion. It must be yet highlighted that different values can also be used reflecting the preference of a stakeholder in real world decision-making environment. All the optimization strategies that are proposed are carried out following the Life Cycle Optimization process following the guidelines proposed in (Yue et al., 2014) and in (Ouattara et al., 2012).

5.1. Optimization model

The generalized form of the multiobjective optimization model is used to describe each instance of the different scenarios that are studied. It is formulated to capture the interrelation between the decisions variables, the model variables and the parameters that describe that system as a set of restrictions and their influence on the objective functions results, as follows:

$$\min [f_1(x,y), f_2(x,y), \dots, f_n(x,y)]; \text{ s.t. } g(x,y) \leq 0; h(x,y) = 0; x \in Z^n, y \in \{0,1\} \quad (1)$$

This formulation involves a set of objective functions (f) from 1

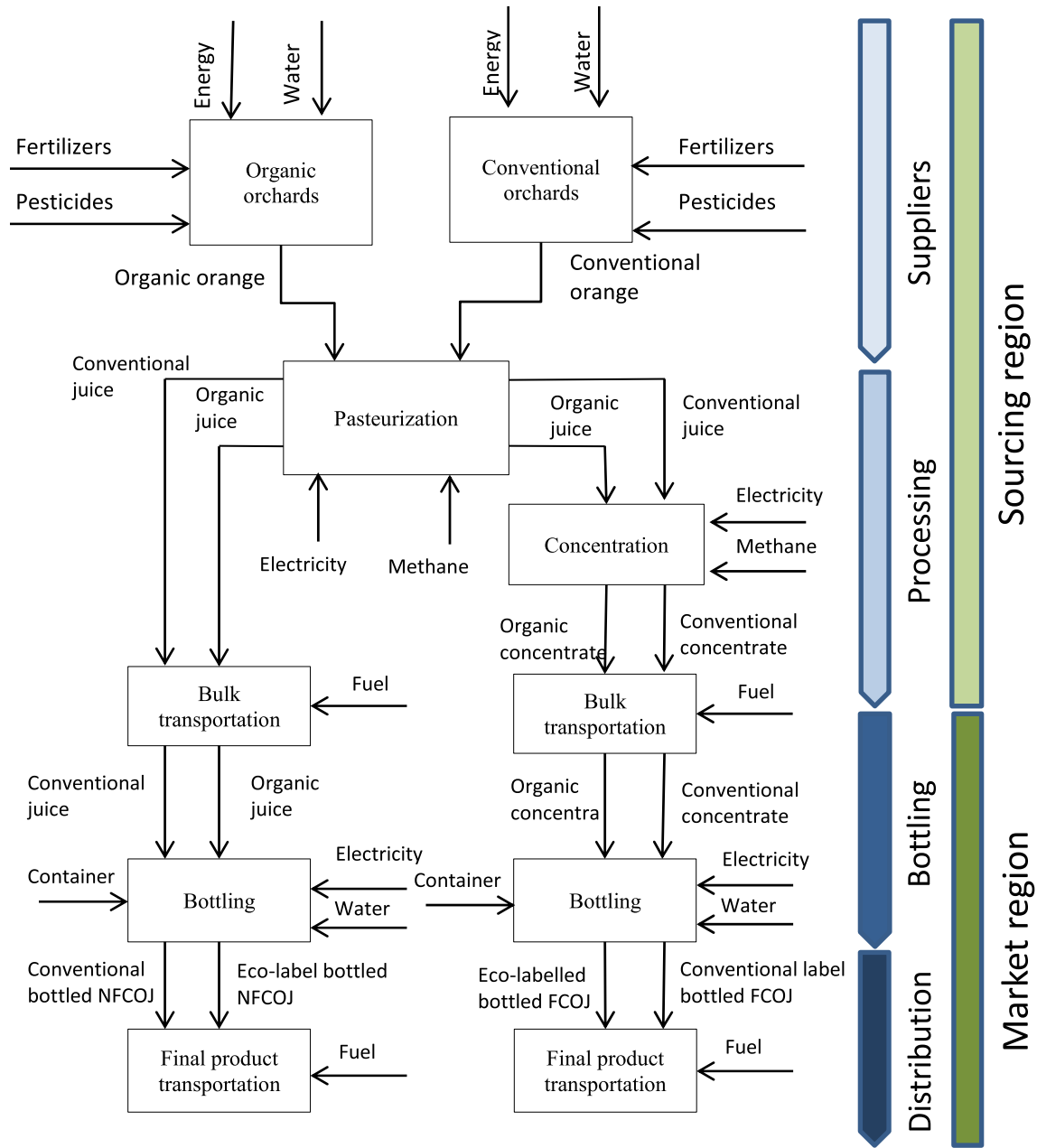


Fig. 2. Materials and resource flowchart for the case study.

to n to minimize, subject to a set of inequality constraints (g), a set of equality constraints (h), and the variables are defined as (x) for integer and (y) for binary variables.

This general multiobjective optimization model is used to formulate each scenario developed in Section 6. Each Scenario is composed of the same basic elements that are described in the following section that form the different components of the general model. For each Scenario, a mathematical model is formulated with a brief description and summary of results in section 6.1 (more detail can be found in (Miranda-Ackerman, 2015)).

5.2. Case study model

The model provides a means to represent the behaviour of the food supply chain. The mathematical formulation of the supply chain model takes into account materials flows and demand

satisfaction. The modelling strategy is used as a generalized model for each scenario instance. It is conceptually constructed in three sets of constraints that are described in what follows.

5.2.1. Mass balance and demand constraints

Materials flow throughout the network of suppliers, production plants and markets are reflected in a subset of constraints so that production capacities at each level in the supply chain can meet market demand requirements. The amount of raw materials from the Supplier Echelon interfaces as the input for the Processing Echelon, this last itself interfacing with the Market Echelon. The quantity of final product is restricted to be equal or higher than the targeted demand quantity.

5.2.2. Operational and economic functions

Using variable values on materials quantities and requirements

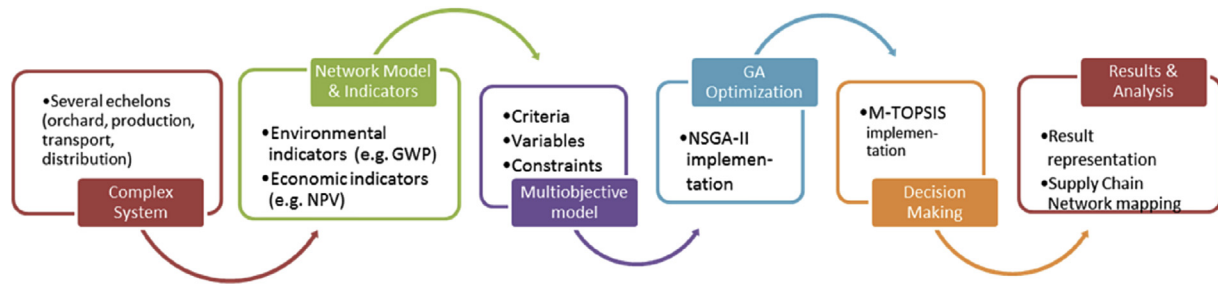


Fig. 3. MOO and MCDM workflow diagram.

Table 1
Parameter set for Multi-objective GA.

	Scenario 1	Scenario 2-6
Population size	200	400
Number of generations	400	800
Cross-over rate	0.9	0.9
Mutation rate	0.5	0.5

along with parameters related to costs at different stages in the supply chain model, a subset of operational and economic functions are constructed. The goal is to reflect the relationship between operational capacities, economic costs and market demand drivers. These integrate into the economic objective function of the multi-objective optimization model.

In this subset of functions, a key component is the Bottling Echelon that interfaces with market demand, with a range of markets that can be satisfied with different types of products based on processing attributes (i.e. from concentrate orange juice vs Non from concentrate orange juice) and by raw materials attribute (i.e. organic oranges vs conventional oranges as raw materials). Each type of product has a different price based on those attributes, and influences the results obtained both in terms of the objectives and the decision variables results.

5.2.3. Environmental impact functions

The same basic modelling structure is used for the definition of the environmental impact functions as of that of operational and economic functions, reflecting the environmental impact in global warming potential as expressed in $\text{kgCO}_2\text{eq/kg}$ based on the parameters and decision variable values.

This part of the model feeds directly into the environmental impact objective function, and captures the effects of making difference design choices related to location, allocation of resources, technologies being used, and market demands that are targeted, among many other choices reflected by the model (for example, choosing different types of equipment with different energy inputs (e.g. gas, electricity), selecting the country or region for the installation of processing or bottling plants with some countries producing electricity from less pollutant sources of energy than others).

5.2.4. Transportation functions

The transportation activities involved through the supply chain have an economic and environmental cost. The four intermediate product types, i.e., pasteurized single strength (NFCJ) organic and conventional orange juice, and concentrated multiple strength (FCOJ) organic and conventional orange juice differ from their production cost, related to their operations but share the same transportation cost in terms of kilogram.kilometer (kg.km) per mode of transport. These intermediate products are transported in bulk by different modes and route; for our case study, transport is

limited to sea freight transport from raw materials production region to consumer regions. Within each market region, a set of markets (10 in the case study) made up of the most populated cities. Economic costs are reflected in the different quantities sold and different regions chosen given the quantities and distances (i.e. $\$/\text{kg.km}$). In a similar way, environmental impact of each transport trajectory measured in $\text{kg of CO}_2 \text{ eq/kg.km}$ reflects the effect of choosing one supply chain configuration over another among other decisions that affect performance and the factors related to transportation.

Through these functions, the effects of choices related to location and allocation of resources and production targets, that in turn define the environmental and economic costs of transport, are reflected onto both economic and environmental objective functions.

5.2.5. Objective functions

In order to evaluate the performance of the supply chain network, different criteria are developed. Initially one needs to empirically or through an "objectives and preferences study" choose a set of criteria of interest, which reflect the economic and environmental performance of the SC. The model considers four possible objectives: NPV, GWP, average VUC and I.

5.2.6. Net present value (NPV) and investment (I)

One of the most widely used Key Performance Indicators (KPI) is the net present value (NPV) of a project. The advantage of this indicator is that it looks at the long-term plan taking into consideration the effect of time. Additionally, it considers the operational and the fixed capital cost within a single framework in contrast to single facets of a project such as Sales Revenue, Project Cost, among others performance indicators. Investment is reflected by the equipment cost via Lang factor (f_L) for the type of production system.

In order to calculate the NPV and Investment output, several variables need to be defined and/or calculated such as: sales revenue, sales price (SP), variable unit cost, sales margin, etc. that are reflected by the constraints and functions that conform the model.

5.2.7. Global warming potential (GWP)

Concurrently the environmental impact measurements are also determined for each optimization instance. GWP is used and defined as the sum of the environmental impact output per unit given the type of product and market to which it is transported to (i.e. each of the 20 market destinations demanding the 4 types of products, 80 unique Unit Environmental Impact) cover each product demand.

5.2.8. Average Variable Unit Cost (AVUC)

AVUC is defined by the sum of the product of each variable unit cost times the quantity that is produced (total planned production) for each type of product given its label (i.e. organic or conventional),

fabrication steps (i.e. extraction, concentration, bottling) and the marketed production output planned for all products to all markets gives the average variable cost.

6. Scenario analysis

The approach that was developed to model the Agrofood Supply Chain (SC), takes into account the different perspectives and preferences of the principal stakeholders, mainly suppliers, focal company, customers and natural environment. This approach to supply chain does not consider a chain of businesses with one-to-one, business-to-business relationships, but a network of multiple businesses and relationships. The Green Supply Chain Network Design (GrSCND) approach allows the modeller to use different techniques to formulate, experiment, evaluate and analyse the types of problems that are related to the supply chain issue. Different optimization strategies, based on the supply chain design model, were applied following different scenarios that reflect the specific targets of the interconnected stakeholders. For this purpose, three main optimization strategies are proposed:

- (1) Sequential Optimization Scheme, involving a two-stage optimization process first reflecting customer aims for cheaper and more environmentally friendly product, and then followed by company's aims related to profitability and environmental performance using the breakeven point deduced from the first step.
- (2) Concurrent Optimization Scheme, based on an integrated optimization where the objectives of the main stakeholder are simultaneously optimized, in order to find SC networks that produce environmentally friendly and profitable products.
- (3) Differentiated-Product Optimization Scheme encompassing an integrated optimization approach that similarly considers not only the main stakeholders' objectives, but also the added value of *organic* eco-labels and the sales price of the final products.

Each optimization scheme was evaluated evaluating different configurations of the model: objectives and restrictions. The set of scenarios evaluated is presented in Table 2 in Supplementary Material.

6.1. Scenario results

The generalized model adaptation to each Scenario and the corresponding characteristics and results summary are presented in Supplementary Material in Table 2. The results are aggregated in a single graph in order to provide a clearer picture through comparison. This way the advantages and disadvantages of each strategy can be better highlighted (See Fig. 4). The M-TOPSIS solution for each scenario is considered in Fig. 4 where the values for the main objective functions, mainly NPV, GWP, AVUC and Investment are indicated. The left Y axis is used to measure the NPV (blue bar), GWP (red bar) and Investment (purple line with crosses); the right Y axis is used to measure the average AVUC (green line with triangles). Looking only at the NPV bars, Sc8 is the best performing. The worst performing scenario in terms of NPV is Sc5. Looking only at GWP, Sc7 is the best performing, while Sc6 is the poorest. In terms of AVUC Sc3 followed closely by Sc4 is the best performing, while Sc7 is the worst. The main idea to take away from these observations is that the results are mixed and a clear trade-off solution is not evident. The most promising solution strategy is Sc3 that provides a compromise between all three criteria while finding the best AVUC values overall. A second important observation that

can be made is that, even though the scenarios are performed under different conditions, there is a clear relation between the Investment cost and the Variable Unit Cost. Scenarios 2, 3 and 4 perform better in relation to AVUC, but have higher Investment costs; and the contrary is true for scenarios 5, 6, 7 and 8. These last four clearly have much higher AVUC costs.

In the current literature, the most common approach to multi-objective GSCND is to only consider NPV and GWP as the objective functions. We will follow this approach in order to illustrate the main finding and emphasis on the goal of the study.

Focusing more attention on the environmental issue, Fig. 5 presents the environmental impact measuring GWP in kg CO₂ equivalent emissions per litre of juice (y-axis) - assigned by product type and market region (x-axis). Eight reference values taken from related literature on life cycle assessment of orange juice production are also shown.

Many observations and conclusions can be drawn by comparing the different values and behaviour obtained from the scenarios given the modelling and optimization approach proposed against those provided by the literature (Beccali et al., 2009; Doublet et al., 2013; Dwivedi et al., 2012; Jungbluth et al., 2013; Knudsen et al., 2011; Landquist et al., 2013). Firstly, comparing the NFC with FC for both Organic and Conventional products one sees that GWP can be higher for NFC than FC. This can be counterintuitive given that less processing is made to NFC orange juice; this behaviour is explained through the efficiency lost due to transportation and "last mile" refrigeration (i.e. bottling plant to market) for NFC orange juice; it is also partially explained by the smaller quantity produced given less agrochemicals producing an average environmental impact at the farming system that is not much different for conventional vs organic farming (Meier et al., 2015). This phenomenon can be clearly seen for most scenarios for the France market, as well as, in general for the reference values.

Secondly, in Fig. 5 Ref. 6 point value proposed by (Knudsen et al., 2011) exhibits the lowest GWP value since it does not take into account the bottling's impact. Most other reference values are within 0.6–1 kgCO₂ eq/L slightly higher than that obtained in the case study. The GWP levels obtained with the modelling and optimization approach are explained by two main factors. The first is that the SC is optimized while the reference values are based on case studies focused on measuring the SC and not on improvement of its performance. Secondly, it must be yet emphasized that the modelling approach does not entail a full LCA for each SC network evaluated. It only takes into account the effects of using agrochemicals, energy and water throughout the production and transportation processes, and thus the environmental impact is lower than that if a detailed LCA is performed. One main observation is that all product types, no matter the label or processing used on average fall beneath most reference values. In the case of German region it is clear that scenarios 7 and 8, because they use the price premium for *organic* eco-labelled products, have better performing SC network systems in terms of GWP. On average, Sc7 and Sc8 find a trade-off between regions, this is to say, while it is the best performing in the German market region it is a poor performer in the France market region; but for both regions these scenarios insure that GWP performance is as good or better than the reference values excluding Ref. 6 that, as noted before, does not consider the bottling process. By developing the model to this level of detail and proposing the Differentiated-Product Optimization Scheme, globally environmentally efficient SC networks can be found.

Lastly, comparing the difference between organic and conventionally labelled products, there is not much difference between scenarios within each region. This is contrary to popular belief that *organic* product globally outperform conventionally labelled products. If one were to take suppliers echelon in isolation

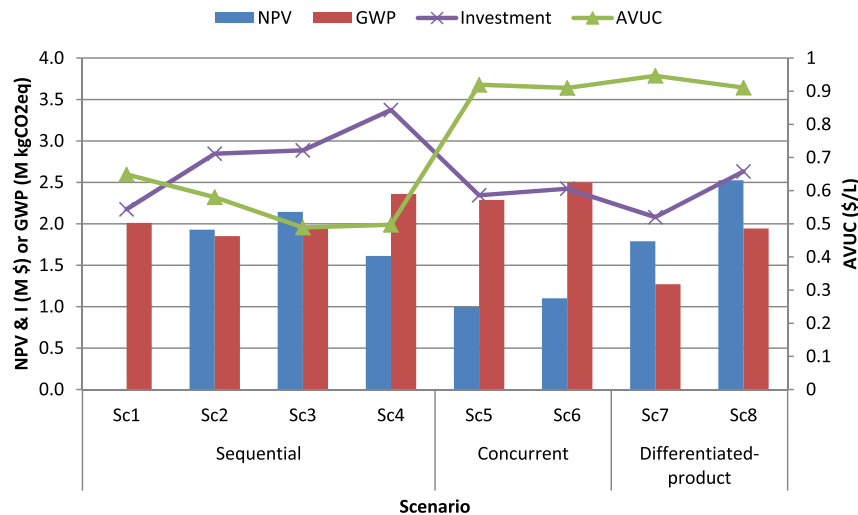


Fig. 4. Results for the main criteria per scenario.

environmental performance may be improved by using less agrochemicals, but in terms of the global supply chain strategy that is proposed, the agro practice used during raw materials production (i.e. oranges) is less important than that of the other stages (e.g. processing, transportation, bottling, etc.). This can be observed through references 7 and 8 that follow the opposite pattern, this is to say, *organic* product is outperformed by conventionally labelled product. To further illustrate this phenomenon let us compare the LCA results presented in (Doublet et al., 2013) shown in the Supplementary Material in Fig. 6 with an example taken from Sc3 M-TOPSIS best compromise solution for product (of all four types) destined for Market 1 in Germany shown in the Supplementary Material in Fig. 7.

In the Supplementary Material Fig. 6 provides a detailed allocation of the sources of GWP emissions throughout the product life cycle proposed by (Doublet et al. 2013). In addition to the classification provided by the author a set of reference clustering through brackets are proposed in order to make a comparison with the results presented in Fig. 7. While the reference LCA does provide more detail by dealing GWP in terms of more sub process, there is little emphasis on the transportation stages during the products life cycle. The example taken from Sc3 one sees that the steps are more aggregated but emphasis is given to the SC echelons and their interfaces. Nonetheless similar distribution of the sources of GWP in the different stages is appreciated. And more importantly, and looking back to the point previously developed in relation to the effect *organic* production has over GWP outcome, one sees that for both LCAs the main source is the bottling process while orange raw material production is far behind.

Furthermore one can appreciate the importance of the transportation stages for the Sc3 example as being the second most important source of GWP emissions. This is in contrast to the results presented in the reference example that indeed uses a more optimistic approach of modelling transportation. This leads us to conclude that while most literature in relation to environmental impact focus on measuring and in evaluating different technique, a more holistic approach provides better insight and a way to take advantage of the scope provided by framing the problem as one of green supply chain network design. This in term highlighted the need to consider carbon emissions minimized processes and products, and the potential that carbon footprinting and respective ecolabelling could have in order to improve agrofood supply chain beyond the farming stage.

7. Discussion

During each stage of this research work different questions arose that fell near the edge of the scope of the work but could not be covered. These questions and observations remain outstanding and could motivate future research.

Water impact modelling: it must be highlighted on the one hand that water consumption was included within the modelling scope for both the Green Supplier Selection Problem and the Green Supply Chain Design problem; on the other hand, eutrophication and acidification of water were included as environmental impact criteria in the Green Supplier Selection problem formulation. Yet, these water centric environmental impact criteria were not included in the Green Supply Chain Design problem formulation. Furthermore, other important issues, like irrigation systems, were included in a very limited way within the scope of the case study. This is not a problem for seasonal agro food products and agricultural systems that depend on the natural rain fall. But for other food products that are heavily depend on irrigation systems this issue could require additional attention.

Furthermore, the case study limited the scope of the processing step, excluding the initial washing stages of production that are pervasive for most fresh fruit and fruit-derived food products. In some cases, this can be considered negligible or inexistent, but there are cases where water consumption is very important. Related to this point, another issue is that given that many food production unit operations are in batch form, cleaning of silos, containers, hoppers, feeders, etc. may also require important quantities of **water and cleaning products as well as chemicals**, that consume water and may pollute water runoff. These could also be further detailed in future work depending on the focus and product being studied.

Land use: one very important issue that was considered in the model through the measurement of yields is the **land use**. While it was considered directly in the model formulation, its environmental impact was not quantified nor was included as an explicit optimization objective. Land use and yield are a very important issue given that food security and demographic growth have justified until now the rampant change of land use. Deforestation and erosion of many natural landscapes that should be protected must be also considered. A focus on the value obtained by limiting the changes in use of land could be an important branch of research within the Green Supply Chain domain.

GWP per unit comparison

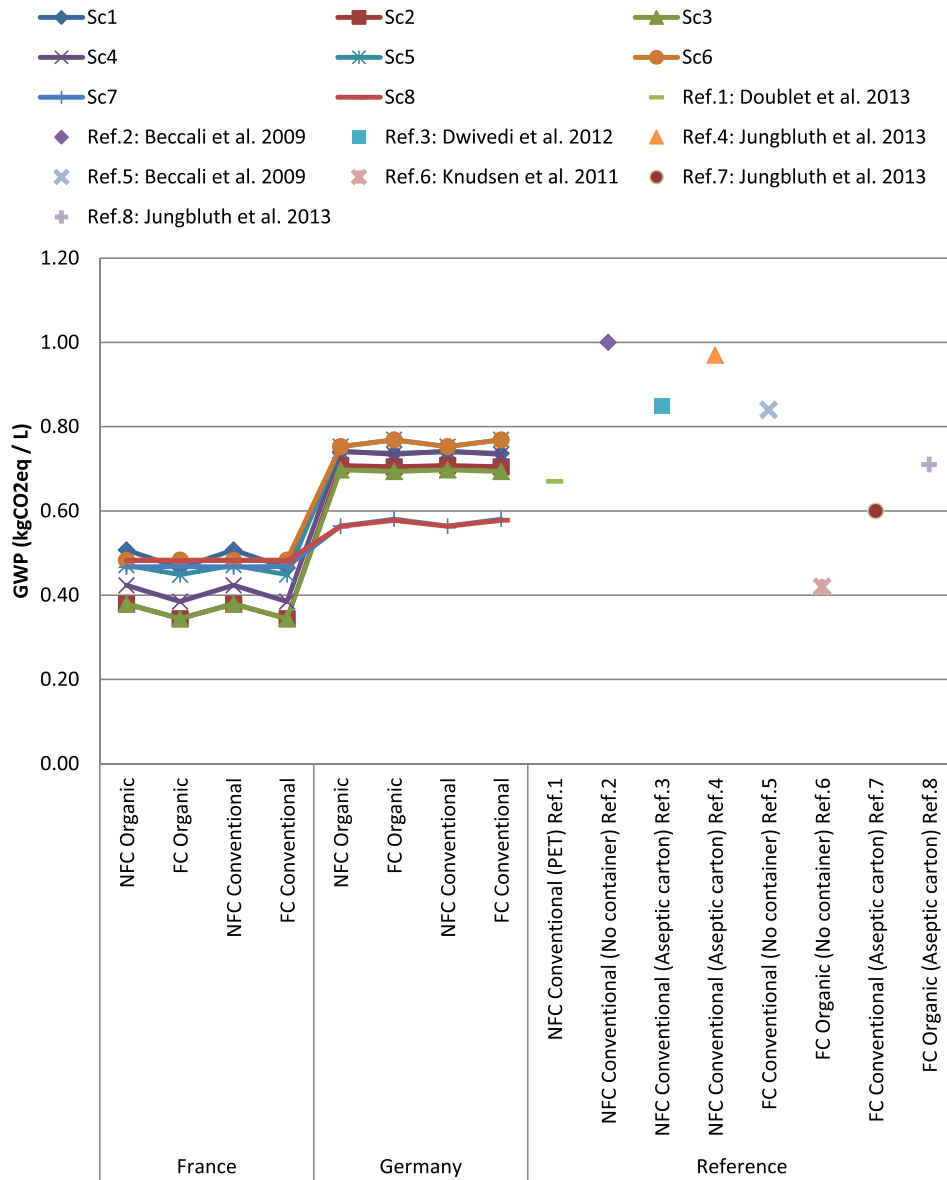


Fig. 5. GWP per unit summary divided by country and product type with reference values (Doublet et al., 2013).

Waste is another issue that fell outside of the scope of this work but is highly related to the objective being considered. **Waste** byproducts are produced in different stages in the product lifecycle. In the first stage a sorting operation is usually necessary for food products, where some residues or non-conforming products are discarded. These waste materials can be treated as solid waste (to be discarded) or could be used by other entities as a raw material. In the developed case study, the potential to consider the biomass from the extraction and concentration processes as a byproduct for the production of animal feed (Lanuzza et al., 2014) or more recently biogas (Wikandari et al., 2015) constitute a potential pathway of improvement for supply chain modelling and for product valorization. This type of reuse of waste materials has been treated in literature in different ways, some of the most popular ones are Industrial Ecology and the **Closed-Loop Supply Chain Logistics**. These approaches could be explored as potential additions or extensions of the method here proposed.

The consideration of the packaging materials at the end of life stage could be also taken into account in more detail considering **Reverse Logistics**. It relates to the recovery of materials that can be treated and reused or repurposed. In the case of the food beverage industry bottles are used that can be recovered. Each country has its own policies in place to sort and recover valuable materials and innovative solutions to recycle and recover unavoidable waste are receiving a lot of attention: for instance, in the case of Germany for example, plastic and glass bottles are **recycled** by incentivizing the consumer to sort and bring back the material to places of purchase by paying for the recovery service. Reverse logistics is not new but had been left aside for many years due to the efficiencies gained at producing very cheap packaging materials. It has yet started to become more important given the renewed awareness of the potential of limiting externalities of food consumption related to packaging. This could be considered in future work where trajectory vectors could be added to the network model to accommodate

for reverse logistics. This could be very interesting given that the finding of this work and other research papers show that one of the main contributors to the environmental impact of non-alcoholic beverages like orange juice comes from the bottle.

Additionally the scope of the work was limited to Greening the supply chain by using the Life Cycle Assessment method in order to measure and improve the environmental performance of the supply chain. Recent works have extended it to include the social aspect through the so-called Social Life Cycle Assessment (SLCA). In this approach, the aspect related to labor, social benefit, job creation, community development among other things is also measured and targeted for improvement. In this work, the social element was limited to the collaboration and contract schemes through Partnership for Sustainability. This could be extended in order to evaluate the social benefits of decentralizing suppliers, process plants, de-mechanizing processes in order to produce more jobs for instance in addition to the new social measurements that little by little are starting to be included within this new SLCA paradigm.

From a methodological point of view, some important perspectives could be incorporated into future research. The inclusion of **uncertainty** into the model framework could be important to overcome many of the random events and fluctuations inherent in agro food supply chains related to the volatility of the weather, global markets, consumer behaviour among many other uncertainties. Preliminary research on this topic has been started (Fernandez Lambert et al., 2015, 2014). But it would be interesting to incorporate uncertainty measurements and variability within the framework presented in this work. Connected to this issue is also the possibility of the inclusion of a **dynamical systems** approach where changes that occur in time could be integrated into the framework such as the yield per tree based on the age of the trees, soil erosion, soil nutrient replenishment, and other time dependent phenomena that could provide better descriptions of the system in order to make better decisions.

In summary, the contributions from this research have paved the way to extend the base model and methodology for greening the agro food supply chain and improving the integration of tools to overcome the technical challenges of developing future sustainable production systems.

8. Conclusion

Three optimization schemes to the green supply chain network problem were presented. Each has different advantages and weaknesses. First, *Sequential Optimization Scheme*, a base optimization scenario is carried out to obtain the best solution from the customers' perspective. This base scenario is then used to set the Sales Price for each product based on the type (e.g. organic, conventional, FC or NFC) and market that it will be sold and distributed to in subsequent scenarios (i.e. scenarios 2, 3 & 4). By fixing the Sales Price - the scheme proposes solutions that are evaluated during the GA optimization process that are competitive in terms of GWP and AVUC (and thus price). In the subsequent scenarios, different objective functions are used to model the focal company prerogative to be profitable. Using Key Performance Indicators such as NPV, investment cost and Variable Unit Cost, the optimization process is driven to search for solutions that minimize the investment, operations and transport cost incurred by the focal company during the production and distribution process. By evaluating different objective functions in each scenario, the Pareto front solutions can be iteratively improved in relative terms, providing the best set of alternatives to the decision maker.

In the *Concurrent Optimization Scheme*, different criteria were evaluated simultaneously. The fixed pricing strategy used in the *Sequential Optimization Scheme* was changed to a variable pricing

strategy. In this scenario, a 25% price margin cost is added to the Variable Unit Cost of the product to fix the Sales Price (SP). Because no threshold was established for the SP - different solution alternatives were found. Unexpectedly but justifiably the solutions were dominated by those found in the Sequential Optimization Scheme for the reasons presented in the result section.

Lastly, a *Differentiated-Product Optimization* strategy was evaluated. This approach takes into account the premium price that a customer is willing to pay for higher quality *organic* eco-labelled food products. This is particularly sound because the differentiation helps counteract part of the additional cost that may be incurred when producing products under an environmentally conscious SC network design. The optimization search process explores solution spaces that would not otherwise be considered. This approach takes into account the preferences of the consumer by attaching a variable Sales Price based on the Average Variable Unit Cost that is minimized. It also takes the focal company objective into consideration through the NPV criteria, while being environmentally conscious through the GWP minimization objective function.

The main finding from this part of the research lies in three main points. First, the method proves to be not only feasible but efficient at modelling and finding optimal trade-off solutions that would otherwise be impossible to find. Secondly, the different objective functions and pricing strategies that are proposed and studied, provide insight on the importance of choosing the best approach to agro food supply chain problems. Indeed, the main contribution was corroborating that, while organic certification of products in order to add value through eco-labels at the same time as improving environmental performance is useful, the use of more general eco-labelling that reflects the full supply chain could be more suitable and effective. In particular, the case study showed in the final results that the main contributors to one of the main pollution indicators, mainly Global Warming Potential, come from other stages in the supply chain, e.g. transportation and bottling. By focusing on the agricultural stages of the supply chain, important attention that should be directed at these operations is misrepresented in the current *organic* eco-labelling policy.

The contribution of this work lies in proposing an integrated and holistic approach to greening the agrofood cluster supply chain network design process. Through the case study we provided an illustrative example of its potential use. Furthermore this example allowed us to find insight into the specific case of the orange juice supply chain. The results show that each step in the supply chain holds opportunities to improve environmental performance equal or greater than that of only looking at the agriculture stage of the food supply chain. Because of this, the application and adaptation of this approach to other food products may provide a better design and improvement method for supply chain practitioners. Finally, a wider more inclusive scheme, such as the one proposed in this work can be adopted in mainstream industry and consumers in order to promote better and more effective production systems and greener consumption.

Acknowledgment

Funding: The authors would like to thank the Mexican science council (CONACYT, Mexico) and ministry of education (SEP, Mexico) for their financial support.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jenvman.2017.05.027>.

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