



Prompting sustainability in the citrus derivatives industry: A case study

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ABSTRACT

A systemic approach was proposed to analyse a complex system such that of food value chains. Typical management methodologies were applied to a citrus derivatives industry and, based on the survey outcomes, a sustainable optimisation plan was formulated integrating the critical domains of the water-food-energy nexus. The overall process was mapped in detail. The SWOT analysis was applied to identify strengths, weaknesses, opportunities, and threats related to each step of the production chain of the citrus derived products. To prioritize its critical output factors, the Impact-Feasibility Map tool was defined. Critical issues characterised by the highest impact and easiest feasibility were the un-optimized fertilization and irrigation, non-objective human inspections, lack of production standardization and accumulation of organic waste.

Structured interviews to the company managers were conducted to identify the most relevant company's needs.

With a view on process and product sustainability, suggestions based on good manufacturing practices and on literature were scheduled within a 10-years industrial development plan accomplishing a circular economy scheme. The performed analysis is preliminary to optimisation actions in view of process sustainability that will be carried out according to the classic engineering approach. The present actual goal is to contextualize the engineering interventions in relation to the needs of the producers. Indeed, empirical contextualised research will be necessary to assess whether the sustainable actions and measures identified in this study can be validated in actual practice with conventional chemical engineering optimisation procedures.

1. Introduction

A sustainable food production chain is profitable throughout all of its stages (economic sustainability), has broad-based benefits for society (social sustainability), and has a positive or neutral impact on the natural environment (environmental sustainability) (FAO, 2014). Fragmented information are often available regarding the quantification of economic, social and environmental sustainability parameters for specific food manufacturing processes, mainly focusing on the primary production aspects or on the treatment of waste that are generated along the entire production chain.

However, rarer is finding critical analysis of food production chains in their entirety, going through each step of the production and keeping in mind the importance of single unitary operations evaluation.

The key topics for food production sustainability currently deal with: 1) lowering the use of fossil fuels in manufacturing by introducing renewable energy sources and by optimizing energy efficiency; 2) reducing freshwater consumption by suitable water management and recycling; 3) reducing waste generation by decreasing losses along the process lines and by increasing waste reuse/recycling (Beccali et al., 2010); 4) providing optimized human resources involvement. Making unit operations sustainable is necessary behind each of the above mentioned sustainability topics, but it is still undefined in most cases due to the complexity of the food production systems which prevent from the possibility to establish a univocal procedure. Ad-hoc solutions are related to the geographical location, the technology readiness levels, raw materials and products specific handling and processing requirements and, finally, the legislative framework.

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A systemic approach was, therefore, proposed to gain a complete overview of any food production chain and, most importantly, a detailed knowledge of the fundamental critical points that could imply a hazard along the entire production process. Based on the survey outcomes, it will be then possible to start drawing up an individual blueprint for sustainable development of the food value chain under study.

Following such systemic approach, this paper aims to display a 360° survey over the strengths, weaknesses, opportunities and treats of each operational step related to the case study of an Italian citrus value chain. Indeed, both the aspects related to the primary production and those related to the raw material transformation were addressed in a production analysis towards sustainability.

In Europe, Italy is the third nation, after Spain and Turkey, with the highest citrus production counting 2.8 million tons per year (Schmid, 2019). Almost half of the national fruit production is located in Sicily (ISTAT, 2019) where oranges, lemons, tangerines, clementine, and bergamots are marketed as fresh products or processed. In particular, the main products coming from the industrial processing of citrus fruits are natural or concentrated juice (35–45%w/w), essential oils (0.3–0.7%w/w) (Beccali et al., 2010), and a by-product, called ‘pastazzo’ in the common technical language (55–65%w/w), that is composed of spent peels and squeezed pulp residues (Comparetti et al., 2016).

A number of scientific publications deal with the processing of citrus fruits, that provide details on the main production techniques (Kimball, 2012) and industries development strategies (Tan et al., 2020), but few information are available addressing a thoroughgoing analysis of the value chain bottle necks and potential improvements in terms of sustainability balance. Only waste treatment has already been widely discussed in the literature by several authors (Zema et al., 2018) who evaluated a sustainable management of citrus processing waste to recover energy and/or value added products (Sharma et al., 2017).

The paper introduces a systemic approach following typical management methodologies for a detailed process operations evaluation on which basis an optimisation plan structured over 10-years was proposed. This will put the foundation to further necessary empirical researches to

assess whether the identified sustainable actions and measures can be validated in actual practice with conventional chemical engineering optimisation procedures.

2. Materials and methods

2.1. Structured analysis procedure

Main critical issues all along the citrus production and transformation chains were identified and a set of solving opportunities were evaluated for feasibility and prioritised by means of a structured strategic planning technique (Fig. 1).

2.2. Italian citrus industry case study

The citrus industry chosen as case study is located in Sicily, Italy. The citrus processing company is headquartered in San Pier Niceto, Messina, while the three citrus plantations are located in Sicily (one) and Calabria (two), covering an area of 384 and 6 ha, respectively. The total mass of processed citrus per day is, on average, 220 tons with typical yields in essential oil and juice production equal to 0.3–0.7%w/w and 30–40%w/w, respectively. Spent peels generation instead yields 52–58%w/w.

A careful, in-depth study of the citrus chain was the first step of the process analysis. This was possible through on site visits and interviews to the plantations holders and to the plant owner. Citrus agricultural and transformation steps were split in macro-areas and sub-stages. In this way, it was possible to represent in a schematic form the specific citrus industry dynamics and to identify the critical issues to be improved.

2.3. SWOT analysis

In order to design a structured strategic planning, the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis or SWOT matrix was applied to identify factors related to the production chain of the citrus derived products. This tool is usually implemented in the preliminary stages of decision-making process by business analysts or

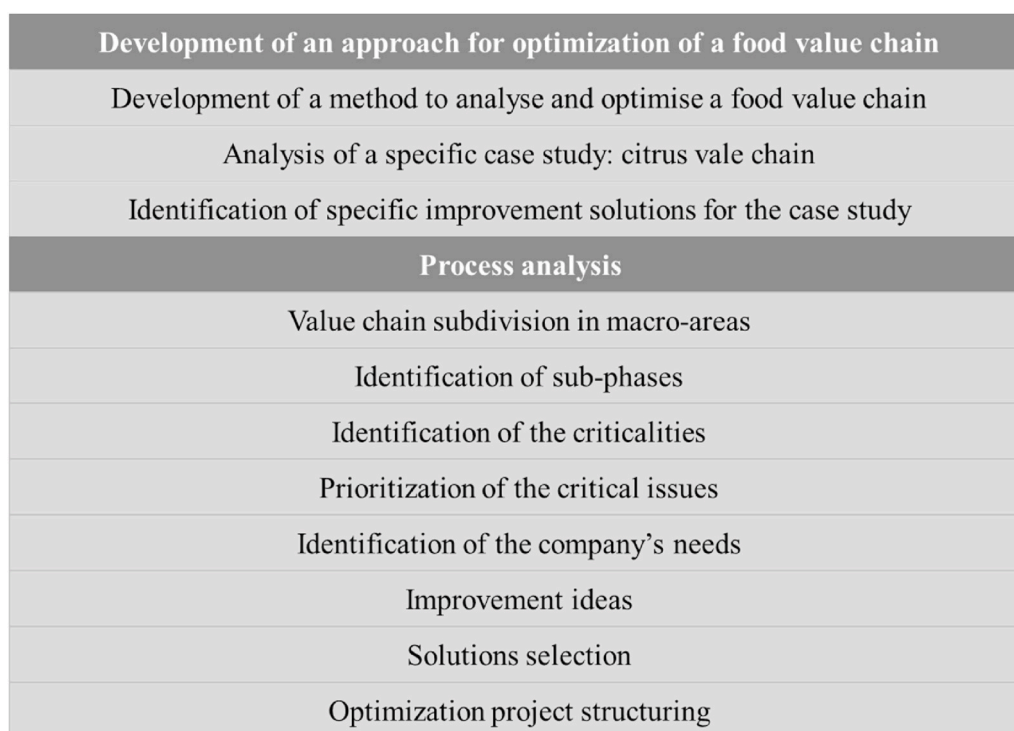


Fig. 1. Analysis and optimisation of the citrus value chain: goals and procedure.

project managers (Gürel and Tat, 2017).

SWOT allows to identify and categorize in a 2×2 matrix the internal factors (strengths and weaknesses) and the external factors (opportunities and threats) typical of the subject that is analysed (Falcone et al., 2020). The definition of the different points characterizing the matrix is the result of qualitative considerations influenced by human subjectivity (Phadermrod et al., 2019). As a consequence, this makes difficult to use the SWOT analysis as a single decision-making tool, since it lacks in objectivity. That is way it was accompanied by the Impact-Feasibility Map, as explained below.

2.4. Impact feasibility map

Being traditionally a form of brainstorming, SWOT might be criticised due to its intrinsic subjective nature strongly dependant on the views of the individuals that are asked (Phadermrod et al., 2019). Therefore, to prioritize its critical output factors, the Impact-Feasibility Map tool was applied. The tool was adapted for this specific case study from the Impact-Effort Map typically used in the service design sector (McLennan, 2019).

It consists of a quadrant model that ranks initiatives by impact and feasibility. A grid is generated, where the y-axis is the 'impact' axis (with a scale from low to high), which expresses the relevance that the proposal could have for users, while the x-axis is the 'feasibility' axis (with a scale ranging from difficult to easy to realize) related to the feasibility of realization for the designer (Johnson, 2016).

The impact categories on which the critical issues were weighted are:

- environment;
- quality and yield;
- selling price;
- production rate/speed;
- production efficiency;
- worker safety;
- automation;
- customer satisfaction.

With respect to the feasibility variable, it was instead considered the easiness/difficulty in removing each specific criticality with respect to time, cost, and resources.

2.5. Optimisation planning

To move towards the direction of process and product sustainability, a similar procedure used in the Chemical Product Design (CPD) was adapted (Gani et al., 2020). CPD is a branch of chemical engineering that deals with the development of new chemicals by acting as an interface between consumers and industry, identifying customer needs and translating them into commercial products (Moggridge and Cussler, 2000). The typical items of the CPD methodology are namely needs, ideas, selection, manufacture, and final project. A necessary adaptation to the case study of a food production chain, are presented in the paper as follows.

Structured interviews to the general manager and CEO of the company were conducted to identify the enterprise's most relevant needs. Collected answers made it clear that it was a priority to focus on the issues affecting both environment sustainability and customer satisfaction. Possible solutions for each identified criticality were suggested based on literature studies and GMPs and the selection of the solutions to be implemented was then operated on the basis of both the prioritization through the Impact-Feasibility Map and the company's need, their validity needs to be proved by mass-energy-water balances and cost and benefit analysis. In this paper, only the citrus processing plant is analysed for sustainable optimisation.

A hypothetical 10-years plan for sustainable interventions was designed with the attempt to optimize the citrus production chain

following the circular economy principles withal.

3. Discussion

3.1. Citrus production process

The citrus production process under study (Fig. 2) begins with the cultivation of lemons, oranges, tangerines, and bergamots which are then processed to recover juice and essential oils.

The production chain can be split into four macro-areas, each characterised by its own sub-phases:

- Primary production: planting, cultivation, harvesting;
- Up-stream processes: unloading, visual inspection, leaf removal, washing;
- Fractionation: primary and secondary extraction;
- Downstream processes: packaging and shipping, by-products, wastewater and solid wastes treatments.

Fruits entering the process are fractionated into intermediate products that are further processed. Essential oils and citrus juice, obtained through fractionation by extraction of the harvested citrus, are primary commercial products. As regards the "pastazzo" (spent peels), the main intermediate product, alternative final use decisions are to be taken. Currently, spent peels are stocked in silos and sent to an external company for their dewatering and residual essential oil extraction. Pastazzo could otherwise be exploited as animal feed (Ajila et al., 2012), a source of pectins (Huang et al., 2021), or even as biosorbent for the removal of textile dyes (Contreras et al., 2012). Citrus waste (residual fruits, seeds, leaves) is left sun drying and then is sold as compost.

Water from cooling, distillation, and concentration lines, having flowed only within the system pipes, is directly sent to sea after the compulsory checking of its temperature which must be below 28 °C (D. Lgs. 152/06). Wastewater, including spent citrus washing water, machinery washing water, and that coming from the fractionation lines, is conveyed to the in-situ wastewater treatment unit operating only primary and secondary treatments (the latter being based on a biological treatment mainly represented by an activated sludge oxidation tank) whose effluent is sent to the nearest water treatment plant in town. The resulting sludge is instead stabilised, dewatered and sold as fertiliser.

3.2. Critical issues from the SWOT analysis and their prioritization using the Impact-Feasibility Map

The SWOT analysis was carried out with the aim of identifying strengths, weaknesses, opportunities, and threats characterizing the macro-areas along which the citrus value chain extends. Table 1 displays the whole picture.

The SWOT analysis enabled to highlight 18 critical issues (see Table 2) which were then prioritised both in terms of consequences on the eight chosen impact categories and in terms of feasibility, based on time, cost, and resources. The impact matrix for the selected 18 process issues highlights how products' quality and yield are the core risk points and how the un-optimized fertilization and irrigation, the non-objective human inspections, the production standardization and the accumulation of organic waste prior its treatments are highly the riskiest points of the overall production process. The resulting total impact was simply calculated as the sum of the crosses in each row. The feasibility was instead classified as easy (E), medium (M), or difficult (D), to which a corresponding weight was associated, namely 5, 3, and 1, respectively. The final feasibility score was then calculated as a medium of the influences on time, cost, and resources (Dora et al., 2013).

Impact and feasibility final scores associated with each critical issue allow generating the Impact-Feasibility Map (Fig. 3) which simply enable a graphic overall picture of the analysis' outcomes. Criticalities located in the top right quadrant are those that should be primarily

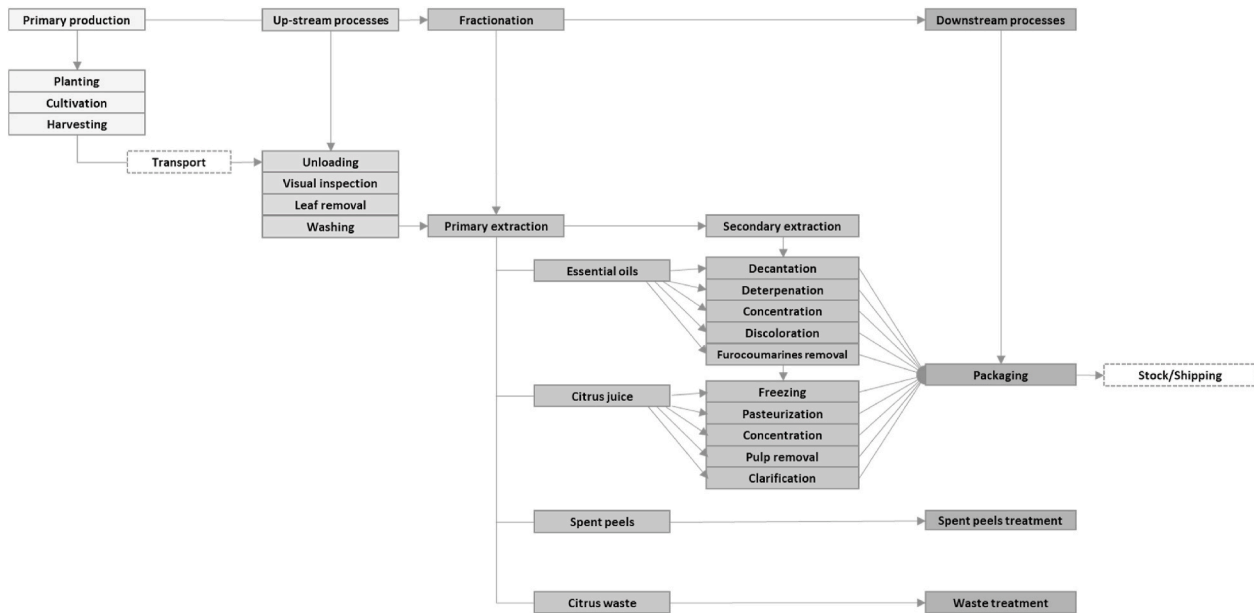


Fig. 2. Master production diagram for the citrus derivatives production.

addressed, because with the highest impact and easiest feasibility. Main highlights were that the visual inspection by a single operator is currently highly detrimental, but an efficient corrective action is feasible. Equally reasonable is an intervention on process standardization.

On the bottom left quadrant, the critical issues with the lowest impact and feasibility and therefore with an associated lowest priority to be solved, are grouped, that is: bulk transport of fruits within trucks, unquantified environmental impacts, partial recovery of cooling water.

3.3. Optimisation criteria

Once process risk points were highlighted and prioritised, possible solutions were suggested by the analysts together with the company owners in order to solve or improve each specific issue as summarized in Table 3.

Since citrus campaigns change yearly in terms of harvested product quantity and level of ripeness, process flexibility must be such that the company always manages to adapt to the quality and quantity of the incoming raw material. It is fundamental to set up product specifications in order to comply with a standardised procedure. Two types of standards exist (Raajeswari and Pragatheeswari, 2019): product standards (specifications and criteria for the characteristics of products) and process standards (criteria for the way the products are made) which can be further subdivided into performance standards (those establishing verifiable requirements on processes) and management system standards (those establishing criteria for management procedures such as documentation or monitoring procedures). Food processing standardization guarantees the same product standard over time assuring the satisfaction of the market demand and a controlled food cost while minimizing the effects of employee turnover on food quality. Defining a standardised procedure and suggesting the latest high-tech machineries for a better process automation within the citrus processing company under study is out of the scope of the paper. However, suggestions for the other most relevant criticalities are shown in details here below considering advantages and disadvantages:

- **Drip irrigation and use of slow release fertilizer hydrogels:** drip irrigation consists in allowing water to drip slowly to the roots of plants, either from above the soil surface or buried below the surface. The goal is to allocate water directly into the root zone, minimize

evaporation, and ensure the plant a quantity of water corresponding to its real needs, reducing waste of surplus water. The weak points of the solution are the difficulty in identifying any leaks in the pipes and the higher attention that must be paid by the workers during the pruning and ploughing phases.

Slow release fertilizer hydrogels (SRFH) have been developed in order to face some of the problems in agriculture, such as the high porosity of soils, high irrigation of water and low fertilizer retention. SRFH are a combination of a super absorbent hydrogel and a fertilizer with both water retention and slow release properties (Ramli, 2019). Despite the many positive effects, this technology would lead to a net increase in the final product cost and, depending on the hydrogel formulation, it could present long degradation times and release toxic residues (Mohite and Adhav, 2017).

- **Use of the WATNEEDS model** (Chiarelli et al., 2020): such model can be applied to calculate water needed for plant growth and to subdivide crop water use in 2 components of water footprint: green and blue water footprint. Green water footprint represents the water volume contributed directly by rainfall and then uptaken as soil moisture by the roots, blue water is the water volume provided by irrigation. Through the application of this spatially distributed and dynamic agro-hydrological model, it is possible to estimate the actual evapotranspiration and to calculate the crop water requirements and irrigation requirements based on soil, climate, and crop data. It could be considered both a starting point for the quantification of the environmental impact of the process under study and an important tool for the evaluation of the water footprint (i.e. Zoidou et al., 2017).
- **Bins to prevent fruit damages:** mechanical compression is the primary cause of damage to fruits when they are handled in bulk (Zacarias et al., 2020). The use of bins is one possible method to reduce damaging impacts in harvesting and postharvest handling system (when the daily processing amount is up to 200/300 tons). Bins can absorb the impact energy, enable a better sanitisation, an enhanced automation of the system while protecting the citrus. On the other hand, transport in bins is more expensive, it implies increased energy consumption due to the adaptations of the loading and unloading lines within the processing plant, and it may imply a delay in identifying unsuitable fruits on the bottom of the bins. The

Table 1

SWOT analysis outputs presented in consecutive 2 × 2 matrixes of the internal factors (strengths and weaknesses) and of the external factors (opportunities and threats) characterizing all the macro-areas of the citrus value chain.

Primary production – planting, cultivation, harvesting	
STRENGTHS Avoidance of pesticides and fungicides, Operators deep knowledge of land and plants, Manual citrus harvesting, Superior fruit quality (PGI - Protected Geographical Indication)	WEAKNESSES No surplus water recovery, Old irrigation and fertilization system, Unquantified production environmental impact
OPPORTUNITIES Specific quantification of water and nutrients needs for plants using a software, Automation of agricultural techniques, Advanced irrigation method, New types of fertilizers (e.g. hydrogels)	THREATS New legislation for environmental impact, Exhaustion of water resources, New plant diseases, Competitive costs from other companies, Further restrictions for organic farming, Restrictions for substances allowed as fertilizers
<i>Up-stream processes – unloading</i>	
STRENGTHS Local citrus (only from Sicilian and Calabrian plantations), Minimum distance truck travels in the production area, Use of 400 kg bins, High fruit storage capacity (storage silos), Partial process automation (robot and bins tippers)	WEAKNESSES Use of diesel trucks, Bulk transport, Crushing of fruits, Difficulty to send fruits to visual inspection
OPPORTUNITIES Use of large trucks (40 tons in bulk, 24 tons bins), Trucks running on greener fuels/electric trucks, Use of trains for transportation, Product traceability, Automation, Better transport logistics	THREATS Competition with fruits from non-EU countries, More competitive costs
<i>Up-stream processes – visual inspection</i>	
STRENGTHS Multiple lines in parallel, One line only dedicated to organic farming fruits, Leaves removal, Quality control through random sample check	WEAKNESSES Presence of a single operator, Not externally visible fruit damages, Human error
OPPORTUNITIES Use of electronic systems to check fruit quality, Automation of the whole process	THREATS New citrus diseases
<i>Up-stream processes – washing</i>	
STRENGTHS Effective and efficient citrus washing, One line only dedicated to organic farming fruits, Automated system	WEAKNESSES No spent washing water recovery
OPPORTUNITIES Cutting-edge spent washing water treatment, Systems for recycling spent washing water or using it for irrigation, Fruit dryers	THREATS Stricter Legislation on water consumption, Environmental impact (water is not an infinite resource)
<i>Fractionation – primary and secondary extraction</i>	
STRENGTHS Production flexibility, Cutting-edge technologies with high production yields, Final products excellence, Products protection against oxidation	WEAKNESSES Need for product standardization, No recovery of cooling and condensation water, Not optimized juice extractors, Use of energy from non-renewable resources
OPPORTUNITIES New machinery for post-extraction treatments, Alternative and sustainable sources of	THREATS High cost of new high-tech machineries

Table 1 (continued)

Primary production – planting, cultivation, harvesting	
energy, Pinch analysis (Di Pretoro and Manenti, 2020) to reduce both energy and water consumption, Spent water recovery for irrigation	
<i>Downstream processes – wastewater treatment</i>	
STRENGTHS Adequate system capacity, Activated sludge treatment system, No odour emissions	WEAKNESSES Uncovered wastewater plant, No treated water recovery systems
OPPORTUNITIES Modern membrane systems, Treated effluent reuse	THREATS Changing maximum contaminant levels in the treated water
<i>Downstream processes – by-products and solid waste management</i>	
STRENGTHS Commercialisation for the recovery of pectin and biogas	WEAKNESSES Risk of accumulation, No-independency for the disposal procedures
OPPORTUNITIES Implementation of an in-situ digester for biogas production, High market interest in by-products	THREATS Changing agreements with external companies, Market demand reduction

company could proceed with the replacement of one of the three lines served by the loading hoppers with a different line adapted for bins and identify any positive or negative response of the system (e.g. fruits accumulation, production costs).

- **Increased tutoring for employees and digital support:** planning a tutoring program can be useful to raise awareness among operators about how to increase their attention and accuracy in carrying out their tasks, in particular during the visual inspection. An external group/company can be engaged in a contractual tutoring work. The main final achievement would be the reduced human error in the detection of unsuitable fruits with a consequent increase in the quality of the final product. To boost the operators' motivation, a yearly prize for the most efficient team can be established.
- **Bio-digester and drying oven:** installing an anaerobic digester in the company can be a solution to the problem of the accumulation of solid waste residues from the citrus processing. Rather than letting citrus waste drying (step which requires a lot of space), the company can anaerobically digest it together with the sludge resulting from the wastewater treatment unit while recovering biogas as sustainable source of heat and electricity. The daily generation of citrus waste and sludge and their quality must be measured and characterised for dimensioning the most appropriate anaerobic digester on the basis of organic loading rate and complete digestion time. Then, the resulting digestate physicochemical properties (in particular the content of macro-elements and heavy metals) should be analysed to assess its safe use as a fertilizer (Koszel and Lorencowicz, 2015). The weak point of this solution would be the seasonality of the substrate to be treated, that is why co-digestion with other types of feedstock coming from the surrounding area could be considered. In any case, another feasibility study and impact-cost assessment are needed.

Other noteworthy solving opportunities, spread upon several different technological areas and requiring the application of specialized and advanced knowledge, deserve to be mentioned as follow:

- **Implementation of a spent washing water treatment and recycling system:** to reduce the huge amount of water used during the fruits washing phase, a spent water treatment unit and a following recycling system can be designed. The continuous reuse of citrus washing water can be possible if water gets filtered and demineralized by means of the reverse osmosis technique, and subsequently disinfected and made free of bacterial charges by means of Chlorine Dioxide or UV disinfection (CSTA, 2015). This innovation within the

Table 2
Impact and feasibility matrix of all the critical issues found through the SWOT analysis.

	Critical Issue	Impact								Feasibility			Scores	
		Environment	Quality and yield	Selling price	Production rate/speed	Production efficiency	Worker safety	Automation	Customer satisfaction	Time	Cost	Resources	Resulting impact	Average feasibility
1	Absence of irrigation water recovery	X							X	D	M	E	2	3
2	No efficient irrigation and fertilization	X	X		X				X	M	D	E	4	3
3	Unquantified environmental impacts	X		X					X	D	D	D	3	1
4	Fruits manual handling				X	X		X		M	D	E	3	3
5	Use of gasoline-engine trucks	X							X	D	M	E	2	3
6	Bulk transport of fruits within trucks		X					X		D	D	D	2	1
7	Crushing of fruits in silos		X							M	D	M	1	3
8	Human error in visual inspection of fruits		X	X		X		X		M	M	E	4	4
9	Visual inspection by a single operator		X	X	X	X	X			E	E	E	5	5
10	Fruits with (hidden) internal damages		X	X				X		E	D	E	3	3.5
11	No citrus washing water recovery	X		X					X	M	E	E	3	4.5
12	Production standardisation		X	X	X	X			X	D	M	M	5	2.5
13	Partial recovery of cooling water	X		X					X	D	D	M	3	1.5
14	Energy from non-renewable resources	X		X					X	M	M	M	3	3
15	Not optimized juice extractors		X	X					X	M	D	M	3	2.5
16	No recovery of treated wastewater	X		X					X	E	M	E	3	4.5
17	Uncovered wastewater plant	X					X			D	D	E	2	2.5
18	Accumulation of organic solid waste prior its management	X		X		X			X	E	D	E	4	3.5

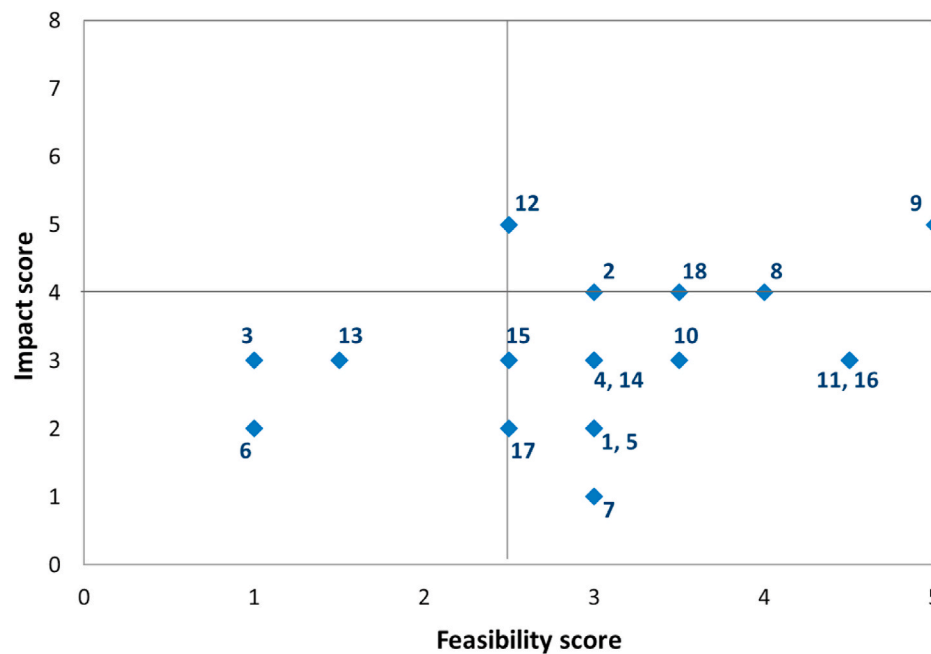


Fig. 3. Impact-Feasibility Map. The numbers within the graph are referred to the 18 critical issues mentioned in Table 2.

Table 3

Critical issues in citrus process and operative suggestions for a future improvement.

	Criticality	Ways to optimize
1	Absence of irrigation water recovery	Drip irrigation and use of slow release fertilizer hydrogels
2	No efficient irrigation and fertilization	
3	Unquantified environmental impacts	WATNEEDS software (Chiarelli et al., 2020) to define the water necessary for a correct irrigation of the plantation and the water footprint
4	Use of gasoline-engine trucks	Trucks running on greener fuels/electric trucks
5	Fruits manual handling	Bins to prevent fruit damages
6	Bulk transport of fruits within trucks	
7	Crushing of fruits in silos	Lines with storage silos replaced with lines with bins tippers only (possible only if the above idea is implemented)
8	Human error in visual inspection of fruits	Increased tutoring for employees and digital support
9	Visual inspection by a single operator	Second operator addition
10	Fruits with (hidden) internal damages	Insertion of visual control tools (e.g. AWETA Advanced Vision 3D (AWETA, 2015)) ^a
11	No citrus washing water recovery	Implementation of a spent washing water treatment and recycling system
12	Production standardisation	Greater automation and digitalisation of the supply chain. Flexibility increase
13	Partial recovery of cooling water	Coupling of multiple cooling water currents
14	Energy from non-renewable resources	Photovoltaic panels insertion
15	Not optimized juice extractors	More advanced machinery purchase ^a
16	No recovery of treated wastewater	Construction of a complete wastewater treatment plant and foresee reuse of the treated effluent
17	Uncovered wastewater plant	Modification of the in-situ wastewater treatment unit ^a
18	Accumulation of organic solid waste prior its management	Bio-digester and drying oven

^a Relying on the outputs of a feasibility study and a cost and benefit analysis.

plant, would determine a lower environmental impact in terms of freshwater use and, indirectly, a lower final product cost. However, a capital investment would be necessary for commissioning to an external engineering company the design and manufacturing of the water recycling plant and the choice should be based on a cost-benefit analysis.

- **Photovoltaic panels insertion:** Sicily is characterised by a yearly high percentage of sunny days, therefore, the choice of installing photovoltaic panels seems an optimal alternative to reduce the consumption of fossil fuels (Filippini et al., 2019). After evaluating the available spaces (i.e. offices and sheds roofs) and type of panels to be installed, the amount of energy they can guarantee should be evaluated to check the feasibility of the project. The global warming emission associated with the production, panels transport, installation, maintenance, decommissioning and dismantling is not null, but it is overall lower than that associated with the production of energy from fossil sources (Chiaromonte et al., 2019).
- **Construction of a complete wastewater treatment plant and foresee reuse of the treated effluent:** substituting the in-situ wastewater treatment unit with a complete one (up to tertiary treatments which must include filtration and disinfection), the company could use the resulting treated effluent water both for fields irrigation and for the toilets of the office buildings. A feasibility study and cost and benefit analysis should be made keeping into account the necessity to respect the Italian limits values for water reuse (20 mgBOD₅/L, 100 mgCOD/L, 15 mgTN/L that need to be periodically verified) (Kirhensteine et al., 2016) and the need for changing most of the water pipe systems.

In general terms, it can be concluded that analysis in perspective mode (system planning) that has been carried out, based on the main weaknesses that have been uncovered by farm management analysis in diagnostic mode, and the consequent restructuring weak activities or formulating new ones, allows to the construction of an input-output activities budget. However, this planning or adjustment budget does not specify what the farmer should do in terms of the technological and engineering aspects of the transformation processes, from preliminary operations on the fruit, to the extraction of essential oils and the fractionation operations for the production of juice or the enhancement of

spent peels are not considered as risk elements for the purpose of sustainable optimisation or to meet market demands for product quality.

Essential technology and engineering factors related to food quality and safety are to be considered in perspective. To implement solutions for minimization of materials, water and energy consumption and to design interventions to company's economic advantage, mass and energy and water accounting is necessary. In this paper a preliminary set of material, energy and water balances was calculated to give an idea of the company's size.

The scheme of the balances regarding general input and output data about the citrus fractionation process is given in Fig. 4.

Some observations may help in evaluating the results of the balances analyses. The energy consumption value reported on the balances scheme is a yearly medium value. The input energy (Fig. 4b) was not specified since it rises and falls according to the amount of citrus tons to be processed, depending on the citrus seasonality, with a lower peak between June and September. Input water (Fig. 4c) includes citrus washing water to wash fruits before processing them, sanitation water to wash the machinery at the end of each production cycle, process water to carry out all fractionation and post-extraction operations, cooling/condensing water used as a cooling fluid in the distillation columns and for cooling concentrates and juices, and water for steam production which is needed in concentrators, pasteurisers and distillation columns. Fig. 4c shows that the fluxes exiting the black box are conveyed to the nearest wastewater treatment plant after being pre-treated in-situ or directly sent to the sea (only cooling and condensation water).

However, only based on more detailed mass, energy and water balance evaluations and based on proper cost and benefit analysis, it will be possible to select the most environmentally and economically advantageous solutions that are worthy of implementation.

As a conclusion, a 10-years project was developed to suggest a potential way to optimize the citrus production chain. Solutions are proposed in Table 4. Goals have been set with a 2-years-step structure on the basis of the above presented management criteria.

Empirical research will be necessary to validate the feasibility of suggested solutions in actual practice with conventional chemical engineering optimisation procedures.

The full accomplishment of the above mentioned goals would lead the citrus processing to the direction of the circular economy especially when dealing with citrus washing water recycling and with the possibility to introduce an anaerobic digester unit to recover biogas and

Table 4

10-years plan for the optimisation of the citrus production chain in terms of sustainability.

Time	Goals
2 years	<ul style="list-style-type: none"> • WATNEEDS analysis for all the company's citrus suppliers • Implementation of the citrus washing water recycling system • Use of treated wastewater and water coming from cooling, distillation, and concentration lines for plantation irrigation • Employment of two workers for the visual inspection phase • Push towards citrus bins transport
4 years	<ul style="list-style-type: none"> • Collection of site-specific climatic data (forecasting for irrigation) • Modernization of the irrigation system relying on the WATNEEDS analysis results
6 years	<ul style="list-style-type: none"> • Improvement of the wastewater treatment unit • Purchase of modern agricultural machinery and sustainable use of fertilizers • Solar panels installation (renewable energy) • Pinch analysis (Foo, 2009) to ensure optimal use of water and energy in the company
8 years	<ul style="list-style-type: none"> • Design and construction of an anaerobic biodigester • Use of the resulting digestate as fertilizer • Purchase of greener trucks (running on renewable fuels or electric) • Study of the different production lines present in the company
10 years	<ul style="list-style-type: none"> • Modernization of the machinery for production lines optimisation • Automation of some processes (unloading with bins tipplers) • Introduction of a packaging system for citrus sale in the supermarket

fertilizer (in the form of digestate) from solid waste residues. Praising the development of a sustainable agriculture and the dramatic reduction of wastewater generation, the company could then claim and highlight even on its marketable products the engagement in putting in operation the best practices to reduce its environmental footprint by adopting an effective environmental management system.

4. Conclusions

A full survey over the strengths, weaknesses, opportunities and treats of each operational step related to the case study of an Italian citrus value chain was given. Starting from the raw material production operations and ending with waste and wastewater management, 18 critical issues were highlighted from the SWOT analysis and prioritised in order to draw up a blueprint for sustainable development.

Process critical points, that should be primarily addressed because with the highest impact and easiest feasibility, were: the un-optimized

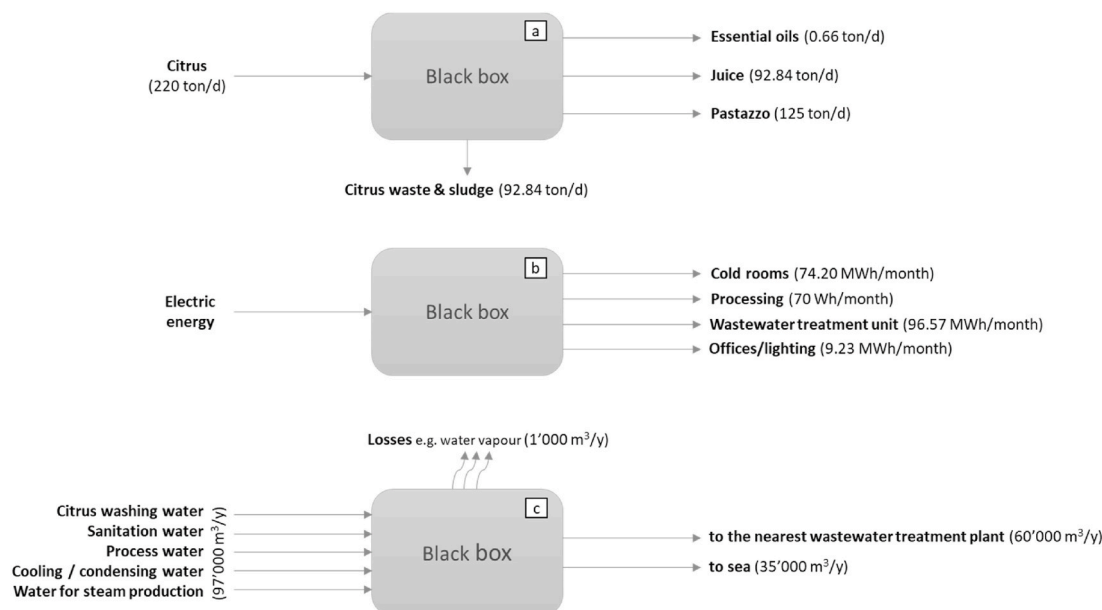


Fig. 4. Mass (a), energy (b), and water (c) balances for the citrus fractionation process. Data are referred to a medium value over the last 5 years.

fertilization and irrigation, the ineffective citrus visual inspection by single operators, the lack of production standardization and the accumulation of organic waste prior its management.

The overall outcome of the preliminary optimisation options developed in the paper led to the setup of a 10-years industrial development plan accomplishing a circular economy scheme. Optimisation suggestions were given based on good manufacturing practices and on literature. The main contribution of this paper is to show how a structured field analysis based on a systemic approach within a food industry can lay down the basis to highlight the main criticalities, resulting as an optimum starting point in the development and adoption of practices and performance management in order to mitigate the impacts generated by food production throughout the supply chain. Having the possibility to enquire to business owners and workers integrates the systemic approach resulting in a more complete and reliable final survey as the one described in the present paper.

The adopted methodology allows supporting the corporate strategy process, because currently the direction towards sustainability is declared to be an undeniable priority by the business owners. Empirical research is, however, necessary to assess whether the sustainable actions and measures identified in this study can be validated in actual practice with conventional chemical engineering optimisation procedures.

Future studies can address the following main interest points:

- the need to develop process simulators applied at least to the main citrus processing unitary operations making easier to identify the bottle necks
- use of risk engineering and management tools to innovate and optimize the citrus processes starting from the critical issues identified through the work here presented, in order to verify the efficiency of alternative and/or improvement solutions, including possible side effects in the decision.

Making decisions to optimize and innovate production processes would help stakeholders in detecting possible new improvement projects. The inclusion of relational elements characterizing the process and allowing the sustainability enhancement of the supply chain is strongly advocated.

Credit author contribution statement

Giulia Bozzano: Conceptualization, Methodology, Supervision, Writing - review & editing. Martina Raymo: Investigation, Formal analysis, Writing - review & editing. Flavio Manenti: Methodology, Validation, Writing - review & editing. Maria Cristina Rulli: Conceptualization, Methodology, Supervision, Writing - review & editing. Francesca Girotto: Formal analysis, Validation, Writing - original draft, Writing - review & editing. Laura Piazza: Conceptualization, Methodology, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clet.2021.100127>.

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