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Energy and economic balance of a production line of cold pasteurized fruit juices using high hydrostatic pressure. Company analytical survey on a medium-sized production plant

by

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Energy and economic balance of a production line of cold pasteurized fruit juices using high hydrostatic pressure.
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Abstract. Today, the economic policies related to the green economy are of great relevance: most countries on the planet have set out to encourage all those social choices that take into consideration the protection of the environment. Only a decade ago talking about environmental policies was a privilege of a few intellectuals, now it turns out to be a sensitive issue and on everyone's lips, even more so after the arrival of the dreaded COVID-19 coronavirus that it imposed on humanity a change in the way of life favoring the application of policies on social distancing for the human being and favoring alternative working methods such as smart working. The relationship between man and the environment is fundamental for the survival of the human race: to have a lower impact on the planet it is important to have production processes that allow savings in terms of emissions. In order to have a lower impact on the planet, a corporate social responsibility is essential that pushes companies towards more eco-compatible and less polluting technologies.

Keywords: techno-economic assessment; corporate social responsibility; product carbon footprint; food technology; sustainability.

1.Introduction

This paper will examine the control tools of corporate social responsibility capable of defining which product has an environmental impact higher and, if the company deems it appropriate for economic and / or ecological reasons, make changes to make production more efficient and with fewer emissions. The case study that will be proposed is that relating to the production line of orange fruit juices of a company from Emilia Romagna. In the last decade the company has started producing high pressure cold stabilized juices and smoothies with HPP technology. Within this company, energy data relating to the production line of high pressure juices, in particular orange juices, were collected. The results obtained were then compared with other data collected in the literature, in particular with Cacace et al. (2020). Thanks to this comparison it will be possible to understand which process is characterized by lower emissions and, consequently, which one best responds to an ecological vision of corporate social responsibility.

1.1 Corporate Social Responsibility

Following the recent climatic changes that occur day after day such as: melting of perennial ice sheets, rising sea levels, ever more frequent tides, anomalous heat / cold waves, alarming pollution levels, etc., many companies have begun to take seriously the environmental problem. The theme of corporate social responsibility (CSR) fits into this perspective, an innovative and important concept that represents a new challenge for companies and sees them as protagonists of a much more complex environment than before. With CSR we mean that the company is no longer just an exclusively economic entity, whose sole purpose is to generate profit for the shareholders, but also an entity with responsibilities that go beyond simple economic performance and simple profitability; adopting a vision that also includes external stakeholders, it is possible to observe how the company is immersed in a much more complex social context with interactions with various environments such as: social, environmental, political, etc. and, consequently, with much more responsibility than a company with only profit-oriented goals. Being "good", understood as being attentive to social and environmental issues, is no longer just a whim / fashion prerogative of small unconventional companies but, in recent years, also thanks to the increase in information and news, a good reputation can make consumers tend to buy products from one company rather than another.

An approach that frames the company in a broader context is the three bottom line (TBL). The term was coined in 1994 by the English sociologist and economist John Elkington as his way of measuring performance in American companies; the basic idea was that a company can be managed in a way that not only generates profit, but also improves people's lives and the planet welfare.

According to TBL theory, companies should work simultaneously on these three bottom lines:

- Profit: This is the traditional measure of corporate profit and loss (P&L) account.

- People: measures how well an organization has been socially engaged throughout her life

- Planet: This measures how environmentally responsible a firm is.

The primary objective of the entrepreneur, therefore, will unquestionably remain the achievement of the maximum economic result, but the prudent entrepreneur - consistently with the "triple bottom line" approach - will have to choose to pursue this goal respecting and valuing society and environment. Voluntarily adopting responsible behavior will make it possible to respond to an ever growing need to see the company as an element immersed in a wider environment, in line with corporate social responsibility. Often the company is seen as subject to written laws imposed only from the outside, today, however, in order to face the increasingly frequent climate change, companies are required to impose themselves on the rules to follow; only in this way will it be possible to begin to have a "business ethics" rooted in common thinking that is current with today's problems and issues.

1.2. Carbon footprint

A company to keep its performances under control from a CSR perspective can make use of different tools such as Life Cycle Assessment (LCA), an analytical and systematic methodology that evaluates the environmental footprint of a product or service along its entire life cycle, or Water footprint, an indicator of consumption that includes both the direct and indirect use of water used to produce goods and services; in particular, in this paper the concept of carbon footprint will be examined: the carbon footprint represents the quantity of greenhouse gas (GHG) emissions generated in the entire life cycle of a product or service, the reduction of GHG emissions leads to an improvement in energy efficiency and resources, therefore also an economic saving. Carbon footprint is generally expressed in tons of CO2 equivalent (CO2 eq.) or CO2 equivalent for each kilo of product (CO2 eq. / kg) but the greenhouse gases to be included in the calculation of the carbon footprint, following the guidelines of the Kyoto Protocol, in addition to carbon dioxide itself (CO2) are:

methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF6) and perfluorocarbons (PFCs). These greenhouse gases do not all have the same effect and therefore will have to be related to CO2: for example, methane has a greenhouse potential 25 times higher than CO2. The carbon footprint is an excellent tool for monitoring the actual sustainability of products or services offered on the market as it is able to define the contribution to the greenhouse effect through the value of a single indicator. Through the communication and promotion of this index, the consumer is able to choose to have a lower impact on the environment by purchasing products / services with a low carbon footprint. To calculate the Product Carbon Footprint it is necessary to identify and quantify the emissions deriving from all the phases through which a given product passes, starting from the extraction and passing through the transformation of raw materials and through the phases of production, distribution and use up to disposal of the product itself, obviously taking into account the emissions in all these phases. Carbon footprint can be calculated not only as a whole but also in part, for example a gate-to-gate carbon footprint relating only to the production process.

The analysis of the carbon footprint not only brings environmental benefits but also the company benefits from it, as listed below:

- identify the life cycle phases of the product / service that have the greatest impact on the environment through greenhouse gas emissions in order to plan carbon reduction and lower carbon footprints;
- improve management and corporate communication in order to improve efficiency (more efficiency translates into less waste and less emissions);
- expand the business: the market increasingly demands and rewards products and services with a reduced environmental footprint that care about people's health by trying to have as few emissions as possible;
- bring consumers closer: in particular those who are increasingly attentive to green issues, respect for the environment and the protection of the planet, issues that have lately been having increasing importance;
- demonstrate the commitment to reduce greenhouse gas emissions in daily activities, respecting the development standard ISO 14067:2018 - "Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification" and highlight the commitment in Corporate Social Responsibility, that is the set of burdens which the company takes on in assuming responsible behavior towards the environment and society.

To reduce their carbon footprint and thus contribute to the mitigation of the global climate, companies can adopt a series of measures and behaviors to reduce emissions: some examples of behaviors that can reduce the carbon footprint are the installation of energy efficient lighting, the purchase of machinery that requires less electricity and consequently less emissions, an improvement of corporate communication that allows to avoid or reduce waste, or the implementation of internal policies aimed at reducing the consumption of electricity, gas or products with high CO2 emissions.

Having a low carbon footprint, in the face of an increasingly growing environmentalist sentiment in recent years, suggests that it is perceived by consumers as an index of quality and sustainability of companies. Implementing a plan to reduce the carbon footprint is therefore not limited only to the identification and implementation of interventions to reduce emissions, but also the possibility of intercepting an ever-increasing share of the market made up of those who have the moral value of safeguarding the planet; allowing the company to stand out from the competition, showing existing and potential customers proof of commitment and interest in safeguarding the environment. Pursuing a social responsibility policy means adopting strategic and operational behavior capable of responding to economic, environmental and social expectations in order to obtain an economy with a low environmental impact.

2. Production process of fruit juices

To deepen the concept of CSR, this paper will deal with the CO2 equivalent (CO2 eq.) emissions that orange fruit juice production introduces on the environment; the reason for this choice is soon explained: as it will be possible to see in this paper, there are different ways to transport, produce and store a fruit juice; in particular the high pressure processing (HPP) method, discovered at the end of the nineteenth century, has acquired more and more importance especially thanks to the fact which allows to maintain many of the nutritional values of the fresh squeezed fruit compared to traditional methods based on heat pasteurization. The methodology difference in the production of juice creates important differences, not only in terms of quality, but also in terms of economics and carbon footprint: the different methodologies taken into consideration are explained below.

First the fruit as soon as it arrives at the designated plant is inspected to verify fruit quality for pressing (as rotten, overriped fruit and foreign objects are not allowed to enter the fruit process). Fruit raw material then goes to the brushing washing machine. The oranges are cleaned by rotating brushes and rinsed with water sprays, then they are brought to the extraction platform. The fruit is on line checked again to eliminate what has escaped the first inspection or to find the one that has possibly been damaged during the washing operation; after this operation the fruit is taken to the extractor. With reference to the extractor: "the principle is the instantaneous separation of those constituent elements which, if left in contact even for a very short time, would negatively affect the quality of the final product"[1]; the operation is as follows: the citrus is mechanically placed between two cups, one upper and one lower with the task of supporting the outside of the fruit to prevent it from splitting. At this point, a lower knife cuts a disc of peel at the base of the citrus fruit and, thanks to the upper cup that begins to exert pressure, the fruit is squeezed. At the end of this process, the citrus juice is in the pre-finisher. Through a hopper, the juice reaches the juice refiner; refiners are "machines capable of separating liquids from solids via an auger and a perforated cylindrical wall. Liquids and a controlled portion of the solids are forced through the holes as the solids are pushed to a drain"[2], this allows for better quality juice. At the end of this process, the juice flows by gravity into a tank placed under the refiner. It is important to remember that peel, fibrous body and other by-products obtained from the extractor can be used for the production of livestock feed or for the production of biogas.

At this point, three different scenarios open up:

1. The first is the most common, the TP-indirect starting from the concentrate (TP-conc); "in most cases the fruit destined for juice is already processed directly in the country of origin after harvesting"[3]. After the juice has been extracted and refined in the country of origin, to facilitate its transport, it is concentrated, furthermore the citrus juice can undergo a degradation of quality at room temperature due to its enzymatic activities, therefore an evaporator is used. The evaporator is a machine with multiple effects: "the product enters and is pumped through a series of preheaters where it increases in temperature thanks to the heat of the steam […]."[4] The preheater is designed to deactivate some juice enzymes. At this point the juice subsequently passes through several stages, "at each stage the juice undergoes a flash through a distribution cone and evaporates into the next tube bundle."[5]

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[1] Diemmi (2000).

[2] Idem.

[3] https://www.pfanner.com/it/focus-sulla-frutta/come-viene-prodotto-il-succo-di-frutta/.

[4] Diemmi (2000).

[5] Idem.

At the end of this process the juice is reduced to about one sixth. The concentrate is then stored and shipped to the designated country where the juice is reconstructed by adding water and possibly sugar or flavorings. Once reconstructed it is possible to pass to the pasteurization: the term pasteurization comes from the french biologist Louis Pasteur. In 1860 he discovered that by heating the wine and bringing it for a few minutes to 60°C, it was possible to block the fermentation processes. Thanks to the high temperature, the juice is pasteurized; the goal with this treatment is to prevent the juice from generating pathogens at least until the expiry date of the product. Finally it is bottled, labeled and transported to the point of sale.

2. The second case examined is TP-indirect (TP-ind), where the fresh fruit arrives directly at the factory where, immediately after being washed, squeezed and refined (as described at the beginning of the same paragraph), it is pasteurized at high temperatures in fact “the indirect thermal treatment of the product needs a hygienic filling phase, which can be obtained by keeping the product at high (≈80 °C) temperature or ensuring aseptic conditions”[6], and then bottled, labeled and transported to the point of sale.
3. The third case (HPP-fresh) is that in which the fruit arrives, as in the previous point, fresh directly to the factory, but after squeezing, instead of being pasteurized, it is treated using the HPP process (whose mhetodology and benefits will be explained below) bottled and lastly labeled. The HPP storage method eliminates bacteria and viruses that are harmful to human health, but does not inhibit the enzymatic function of the juice, so it must be kept in a refrigerated environment in order to avoid browning; consequently, transport and display in the store must also take place at a refrigerated temperature.

2.1. High Pressure Processing

This type of treatment has numerous benefits and being a mild preservation method it is both able to inactivate potentially present pathogens such as Listeria and Salmonella, and to extend the shelf life with the same commodity quality of the products, thus reducing food waste and at the same time allowing the achievement of more distant markets with greater corporate profits. Thanks to the data collected both at the company and through the data available in the literature, it will be possible to evaluate if actually “compared to thermal pasteurization by autoclave of a fish and vegetable ready-to-eat meal with 60-day shelf life, in a comparative limited life cycle assessment, HPP had a global warming potential more than 20% lower, even when HPP processing included a pre-cooking cycle. Continuing advances in HPP equipment cycle time and productivity are further reducing energy requirements.”[7] A production process capable of reducing waste and having a lower impact on the environment is perfectly in line with the concept of corporate social responsibility expressed in the first chapter. Another positive aspect of the HPP process comes from the fact that “the continual development of food preservation methods is driven by the reluctance of consumers to the presence of extrinsic chemicals and the concerns related to the use of broadly defined biotechnology”[8], about this “HPP allows food processors to reduce or eliminate ingredients added solely for preservative effects, including chemicals that inhibit bacterial growth. Reduced ingredient usage means eliminating the environmental impacts associated with sourcing those ingredients. A simpler ingredient list also help food processors achieve "clean label," which appeals to an increasing segment of the population

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[6] Cacace et al. (2020).

[7] https://www.jbtc.com/-/media/files/foodtech/innovation/white-papers/avure/jbt-avure-hpp-sustainability-whitepaper.ashx?la=en&hash=D20D31632537F3F650B174CF887A861087C9F22D#:~:text=HPP%20allows%20food%20processors%20to,associated%20with%20sourcing%20those%20ingredients

[8] Janowicz et al (2018).

that seeks healthy, natural choices in convenient foods and beverages."[9] Always taking fruit juices as an example, those heat treated are generally subject to more steps than an HPP juice, in fact often the juice is concentrated up to 7 times and then sent to the final plant which reconstitutes it starting from the concentrate and heat-treat to preserve it; through the HPP process the juice, once squeezed, is directly preserved while maintaining its original flavor and properties. It is important to specify that even the juice recomposed starting from the concentrate could be treated by HPP, but in this way the purpose of the high pressure method would be invalidated, preserving the products without compromising their qualities, as the process of concentrating the extract in itself it is enough to significantly reduce the benefits deriving from the future intake of a reconstructed juice. Last, but not least, the positive aspect of the HPP treatment is, as anticipated several times, linked to its aspect of maintaining almost completely unaltered (in some cases even improving) the qualities and properties of the product, with particular attention to fruit and vegetables, this makes them excellent for a healthy diet.

3. Methodology and data analysis

In this section is described methodology and data analysis used to collect and analyze CO2 eq. data for different orange juice processes already discussed above, TP with concentrate (TP-conc), TP indirect with fresh oranges (TP-ind), HPP with fresh oranges (HPP). This will allow to define the energy critical points which are leading to the highest CO2 eq. output, highly influencing corporate social responsibility outcomes.

3.1. Equivalent CO2 of Orange cultivation

The first step to calculate the CO2 eq. of orange juice is to consider what is the CO2 eq. for the cultivation of oranges due to the amount of fertilizer, diesel, electricity and water, etc. used for the cultivation of oranges; in this regard, a Doublet et al. (2013) will be taken into account. Data are about a Spanish producer and were provided by Zuvamesa, a NFC (Not From Concentrate, that's mean that Juice NFC is obtained directly from squeezing fresh fruit in the process) orange juice producer in the region of Valencia. The data of the study refer to the integrated production of oranges of the "Navel Lane Late" variety. it is important to keep in mind that soil and environmental diversity are essential components: for example, a more "poor" or "richer" soil in nutrients could lead to different results. The total cultivated area is 14.42 ha with 400 plants per hectare and the total annual production is 695 tons of oranges. Consequently, the annual yield is 48,200 kg / ha. The amount of fertilizer, diesel, electricity and water used for the cultivation of oranges are shown in the *Table 1*. *Table 2* shows the names of the applied pesticides with the respective content of active ingredients, the latter being supplied by the farm in question. The biological control of parasites, as well as through the use of pesticides, is also achieved through the use of special insects; however, due to the lack of data it was not possible to calculate their impact, therefore they are not included in the table.

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[9] https://www.jbtc.com/-/media/files/foodtech/innovation/white-papers/avure/jbt-avure-hpp-sustainability-whitepaper.ashx?la=en&hash=D20D31632537F3F650B174CF887A861087C9F22D#:~:text=HPP%20allows%20food%20processors%20to,associated%20with%20sourcing%20those%20ingredients

Input	Unit	Amount per ha
Yield	kg/ha	48200
Land use	ha	1
K_2O Fertilizer	**kg-K_2O/ha**	**69**
Potassium nitrate	kg-K_2O/ha	69
N Fertilizer	**kg-N/ha**	**56**
Ammonium nitrate	kg-N/ha	30
Potassium nitrate	kg-N/ha	26
P_2O_5 Fertilizer	**kg-P_2O_5/ha**	**40**
Phosphoric acid	kg-P_2O_5/ha	40
Diesel	kg/ha	66
Electricity for irrigation pumps	kWh/ha	3498
Water (groundwater)	m^3/ha	4390

Table 1: amount of fertilizer, diesel, electricity and water used for the cultivation of oranges; source Doublet et al. (2013)

Insecticide	Amount kg/ha	Active ingredient	Content	Amount of active ingredient kg/ha
Dursban	2.5	Chlorpyrifos	75% weight/weight	1.880
Borneo	0.3	Etoxazole	11% weight/weight	0.033
Citrolina	20	Paraffin oil	98% weight/weight	4.000
Fungicide	**Amount kg/ha**	**Active ingredient**	**Content**	**Amount of active ingredient kg/ha**
Aliette	5	Fosetyl-aluminium	80% weight/weight	0.300
Herbicide	**Amount kg/ha**	**Active ingredient**	**Content**	**Amount of active ingredient kg/ha**
Iron chelate	30	FeEDTA	13% Fe 87% EDTA	3.9 26.1

Table 2: applied pesticides with the respective content of active ingredients; source Doublet et al. (2013)

“The Global Warming Potential (GWP) of 1 kg oranges at the orange grove is 0.07 kg CO2-eq. The electricity use for irrigation is the main contributor (50 %) due to the CO2 and N2O emissions resulting from the combustion of coal and natural gas. The N2O emissions resulting from the N-fertilizer application and the CO2 emissions from the production of nitric acid used for the production of the fertilizer cause 25 % of the climate change impacts. The energy use and the chemicals used in the production of pesticides generate 10 % of the GWP.”[10]

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[10] Doublet et al. (2013).

Other relevant factors are that the impacts in human toxicity cancer effects are mainly due by the P2O5-fertilizer (70%) due to the emissions of chromium, zinc and copper after application on the field, which depend on their content in the fertilizer; while, as regards the impact to human toxicity non-cancer effects the share of the P2O5-fertilizer is reduced to 56%. The main difference between cancer and non-cancer effects is the chromium, which has cancer effects. “The N-fertilizer use is the main contributor to the acidification, terrestrial and marine eutrophication impact categories, with 50 %, 70 % and 85 % respectively. The main reason is the emissions into air of NOx and NH3 due to the use on fields. The NOx, NH3 and SO2 emissions due to the electricity production are also important in these three impact categories.”[11] Regarding pesticides, the impact on fresh water cannot be neglected, which increases its toxicity particularly due to the emissions of Chlorpyrifos due to the use of the insecticide Dursban.

3.2. Equivalent CO2 of transport

To get a more complete picture it is important to analyze the impact of transport on the production of orange juice, in particular two types of transport will be taken into consideration: that by ship (container ship) and that by land (truck): the container ship taken as an example has a load capacity of 8000teu (1teu is 21600kg of goods), travels at a speed of 37km / h and consumes 150ton of diesel per day; the truck, on the other hand, was estimated to be capable of transporting 21600kg of goods with a diesel consumption of 35 liters per 100km; in the two following tables (*Table 3* and *Table 4*) various sections have been hypothesized (approximating the distance) to observe the amount of CO2 eq due to the transport of oranges, or concentrate. The quantity of CO2 eq. was calculated by multiplying the kg of diesel per kg of goods by the corresponding CO2 eq. produced, that is 3.14 g CO2 eq. for each g of diesel

Transport by ship							
Case N°	**Route**	**km**	**days**	**kg diesel per day**	**kg transported**	**kg diesel / kg transported during the route**	**g CO2 eq. / kg product**
1	Brasil - Genova	17750	20	150.000	172.800.000	0,01736	54,51
2	Egypt - Ravenna	2000	2,25	150.000	172.800.000	0,00195	6,13
3	Catania - Ravenna	1300	1,463	150.000	172.800.000	0,00127	3,99

Table 3: g CO2 eq. / kg due to the transport by ship

Transport by truck

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[11] Idem.

Case N°	Route	Km	liters / km	kg transported	kg diesel /kg product	g CO2 eq. / kg product
4	Genova - Bologna	300	35	21600	0,00486	15,26
5	Ravenna - Bologna	100	35	21600	0,00162	5,08
6	Catania - Bologna	1150	35	21600	0,01863	58,51

Table 4: g CO2 eq. / kg due to the transport by truck

Other factors that influence the quantity of CO2 eq. produced are the transported product and its relative packaging: as regards the transported product is possible to choose whether to transport an orange extract concentrate, which will be the fundamental element to reconstitute the juice, or fresh oranges, to be squeezed directly at the company of destination; in the event that it is decided to opt for the concentrate, the quantity of CO2 eq. should be divided by 5,5 as from each liter of concentrate about 5.5 liters of juice are obtained, in case instead it is decided to opt for fresh oranges the quantity of CO2 eq. should be divided by the yield of the squeezer, which in this case was estimated at 0.45 (squeezing waste could be used to produce methane and therefore have a saving in terms of CO2 eq.); the choice between concentrate and fresh fruit determines the yield factor (*Table 6*). In this case study the concentrate was estimated to come from Brazil, while the fresh oranges from southern Italy or Egypt. As regards the packaging the transport of fresh oranges or concentrates requires two different types of packaging: fresh oranges are transported in wooden bins (2.39 kg CO2 eq per bin[12]), the concentrate is transported in a 500 g plastic bag (3 g CO2 eq. per g of plastic) inserted into a steel drums weighing 25 kg (3.14 g CO2 eq. per g of steel[13]). *Table 5* shows the carbonprint effect of packing material used during transportation per kilo of product transported.

Packaging impact			
	packaging material	**kg transported for each packaging**	**g CO2 eq / kg transported**
Concentrate	plastic bag + steel drum	200	420
Fresh oranges	wooden bin	400	5,79

Table 5: g CO2 eq. / kg due to the packing

At this point it is possible to estimate the total impact of transport on the production of orange juice:

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[12] Calculated from https://www.kraftpal.com/media/uploads/2020/08/06/kraftpal-lca-corrugated-vs-wooden-pallet.pdf

[13] Calculated from https://www.reterurale.it/flex/cm/pages/ServeAttachment.php/L/IT/D/a%252F6%252Fc%252FD.14309679eec74b3148fb/P/BLOB%3AID%3D7184/E/pdf

Total transport impact						
Type of product transported	**Route**	**Cases N°**	**kg CO2 eq. / kg of product (transport)**	**kg CO2 eq. / kg of product (packaging)**	**yield factor**	**Total g CO2 eq. / kg of product**
Transport of concentrate	Brasil - Bologna	1+4	0,06977	0,42	5,5	89,05
Transport of fresh oranges	Egypt - Bologna	2+5	0,01122	0,00597	0,45	38,21
Transport of fresh oranges	Catania - Bologna	6	0,05851	0,00597	0,45	143,30
Transport of fresh oranges	Catania - Bologna	4+5	0,00907	0,00597	0,45	33,45

Table 6: CO2 eq. / kg due to the transport and packaging

According to these data, the type of transport is responsible for a huge impact on CO2 eq. production. As an example, the same Catania - Bologna route made by ship plus truck allows a saving of around 100 g CO2 eq. per kilo of product instead of only by truck. Furthermore, the packaging also has a significant impact: in the Brasil - Bologna section it represents more than 80% of the emissions of all the CO2 eq. produced in a journey of over 17000 kilometers

3.3. CO2 eq. from process

According to the data collected at the Emilia Romagna company and thanks to the data collected from the literature, with particular attention to Cacace et al. (2020), it will be possible to better analyze the differences in the CO2 eq. produced during the production process.

3.3.1. Company data analysis, 1000 ml and 250 ml

In order to obtain more consistent data, energy measurements were carried out directly on the production line of the company trough electrical, time and weight parameters measurements. By measuring data such as power, operating time, number of cycles per hour, etc., the quantity of energy produced for each machinery was precisely calculated. Based on the energy measurements taken on the various production lines, we were able to evaluate the energy required to produce 1 kg of product (Wh / kg) expressed in kWh. These kWh data multiplied by 0,4 (Italian energy mix data) yield the equivalent g CO2 produced per l kg of product. In particular, in this paragraph the differences in terms of g CO2 eq will be analyzed. between 1 liter and 250 ml formats (data shown in *Table 7* and *Table 8*).

1 liter		
Production lines	**Wh / kg**	**g CO2 eq. / kg**

Squeezing	14,813	5,925
Bottling	3,401	1,360
Pascalizer	49,166	19,666
Packaging	6,278	2,511
Total process	73,658	29,463

Table 7: g CO2 eq. / kg for liter format

250 ml		
Production lines	**Wh / kg**	**g CO2 eq. / kg**
Squeezing	14,828	5,931
Bottling	6,801	2,720
Pascalizer	54,629	21,851
Packaging	12,506	5,002
Total process	88,765	35,505

Table 8: g CO2 eq. / kg for 250ml format

With the exception of the squeezing line where per kilo of product there is a production of 5.931 grams of CO2 equivalent, between 1L and 250ml bottle there are some differences: as far as the bottling line is concerned, the production of g CO2 eq. per kilo in the 250 ml bottles is double compared to the 1 liter bottles, respectively 2,720 g CO2 eq. per kilo against

1,360 g CO2 eq. per kilo, this is due to the fact that the machines with the 1 liter bottles, which contain more juice, are able to process double the product in the same time compared to the 250 ml bottles. Another difference in the pascalizer where the 250 ml bottles require energy for 54.629 Wh / Kg, this quantity drops to 49.166 Wh / Kg in 1 liter bottles. This difference is quickly explained: the 1 liter bottles are more efficiently filling the vessel of the high pressure machinery (pascalizer), leaving less space between the bottles, than that left by the 250 ml ones and, consequently, leading to a saving both energy and g CO2 eq. produced. Consequently, the equivalent in g of CO2 per kg in the 250 ml bottles is 21.851, while in the 1liter ones it is 19.666 g CO2 eq per kilo. The same concept of the squeezing line can be applied to the packaging line, with the exception of the bins reverser of the packaging line whose consumption is the same. The quantity of g of CO2 per kilo of product will therefore be equal to 12.506 for 250 ml bottles and 6.278 for 1 liter bottles.

Another difference, in this case much more substantial, between 1 liter and 250 ml bottles is the packaging. Data were also collected on the quantity of plastic and cardboard used in the packaging of 1 liter bottles and in 250 ml bottles; emissions were calculated knowing that from 1 g of PET are generated 3 g of CO2 eq. and that 1 g carton generates 0.326 g CO2 eq. The results of these calculations have been reported in *Table 9*. For each 250 ml is needed a bottle of 24 g of PET, while for the 1 liter ones is needed 40 g of PET, more than what is needed for the 250 ml bottles but they contain more juice, the same goes for the carton, a carton for 8 bottles of 250 ml weighs 80g, while the carton for 6 bottles of 1 liter weighs just over double, 175g; an impact for PET of 288 g CO2 eq. / kg and for carton of 13.04 g CO2 eq. / kg was calculated for 250 ml bottles, while for 1 liter bottles the impact of packaging is 120 g CO2 eq. / kg deriving from PET and 9.508 g CO2 eq. / kg deriving from carton. Adding the results of the packaging to those of the process it is possible to observe that for the 250ml bottles there is a production of 336,546 g CO2 eq. per kilo of product while for the 1 liter bottles there is a production of 159,971 g CO2 eq. for kilo of product. A first reflection, in the light of these data, is that in terms of CO2 emissions per kilo of product it is convenient to consume larger formats than smaller formats, as the emissions for four 250 ml bottles are more than double of a 1 liter bottle.

Total process + packaging			
Packaging	**Weight g**	**CO2 eq. / kg juice**	**Total process + packaging g CO2 eq. / kg**
Bottle 250 ml	24	288	336,546
Carton for 8 bottles of 250 ml	80	13,04	
Bottle 1 l	40	120	159,971
Carton for 6 bottles of 1 liter	175	9,508	

Table 9: Total process + packaging g CO2 eq. / kg of 1 liter bottles and 250 ml bottles

Going into details it immediately catches the eye how significant the impact in the packaging is, in the 1 liter bottles (*Table 10*) the sum of the squeezing, bottling, pascalization and packaging lines is equal to 19% of the total g CO2 eq. / kg produced, less than a fifth of the total, packaging is responsible for 81% of the g CO2 eq. / kg produced, 75% only for

PET. This value becomes even more alarming in the 250 ml bottles where the incidence of PET and cardboard is even greater, 90% of the total g CO2 eq. / kg produced, the process has an incidence of only 10%. In the graphs below it is possible to see the percentage incidence of the g CO2 eq per kilo of product in the two bottle formats, in particular: in blue the percentage of the squeezing line, in orange the percentage of the bottling line, in gray the percentage of the pasteurizing line, in yellow the percentage of the packaging line, in cyan the percentage of PET and in green the percentage of carton.

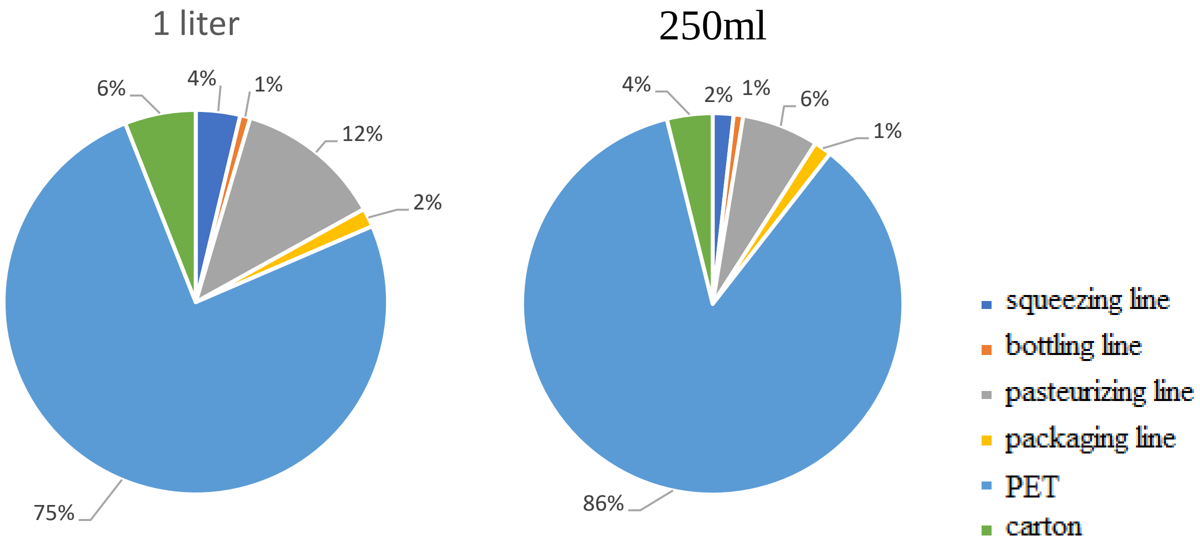

Table 10: percentage distribution of g CO2 eq. / kg of 1 liter bottles and 250 ml bottles

3.3.2. Comparison between HPP-fresh, TP-ind and TP-conc

The three tables below represent the emissions due to all the process, expressed in g CO2 eq per kilo of product (1 liter bottles), *Table 11* represents the emissions per kilo deriving from HPP with fresh fruit, *Table 12* represents the emissions per kilo of TP-indirect with fresh fruit and *Table 13* represents the emissions per kilo deriving from TP-indirect starting from the concentrate.

HPP-fresh data from company and from Cacace et al. (2020); data expressed in g CO2 eq. / kg of orange juice

Transport: Catania - Bologna (ship + truck)	Manufacturing stage	Preservation treatment	Primary packaging	Secondary and tertiary packaging	Cold room	Total
33,45	4,23[14]	29,463	120	9,51	30,1[15]	226,75

Table 11: g CO2 eq. / kg from HPP-fresh

<table>
<tr><th colspan="7">TP-ind data from Cacace et al. (2020);
data expressed in g CO2 eq. / kg of orange juice</th></tr>
<tr><th>Transport: Catania - Bologna (ship + truck)</th><th>Manufacturing stage</th><th>Preservation treatment</th><th>Primary packaging</th><th>Secondary and tertiary packaging</th><th>Cold room</th><th>Total</th></tr>
<tr><td>33,45</td><td>0,0998</td><td>160</td><td>119</td><td>24,3</td><td>0[16]</td><td>336,85</td></tr>
</table>

Table 12: g CO2 eq. / kg from TP-ind

<table>
<tr><th colspan="7">TP-conc: TP-ind data from Cacace et al. (2020) + concentrator data from Diemmi (2000);
data expressed in g CO2 eq. / kg of orange juice</th></tr>
<tr><th>Transport: Brasil - Bologna (ship + truck)</th><th>Manufacturing stage</th><th>Preservation treatment</th><th>Primary packaging</th><th>Secondary and tertiary packaging</th><th>Cold room</th><th>Total</th></tr>
<tr><td>89,05</td><td>1,538[17]</td><td>201,65[18]</td><td>119</td><td>24,3</td><td>0</td><td>435,54</td></tr>
</table>

Table 13: g CO2 eq. / kg from TP-conc

Numerous differences can be noted between the three methodologies analyzed: the first difference is in transport where the hypothesis with higher emissions per kilo of product is TP-conc; the transport and packaging necessary for the concentrate ensure that this method of transport is the one with the highest emissions; it is important to specify that emissions would change considerably if only the truck were used to transport fresh fruit from Catania to Bologna, in this case this would be the most polluting transport. The second difference can be observed for the manufacturing stage where, compared to the other two methods, HPP-fresh has higher emissions: 4,23 g CO2 eq per kg of product; with the same quantity of product in the life of the machinery, a pascalizer has a greater weight (about 50 tons) than a concentrator (about 17 tons) and than a thermo pasteurizer (about 300 kg); this involves more materials, more processes, etc. and

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[14] Calculated from Cacace et al. (2020).

[15] Idem.

[16] In case of high quality TP-ind fruit juices, the consumption of g CO2 eq. is equal to 30,1, as for HPP-fresh.

[17] 0,0998 Cacace et al. (2020) + 1,4382 Diemmi (2000).

[18] 160 Cacace et al. (2020) + 41,65 Diemmi (2000).

consequently there will be more CO2 eq. emissions per kilo. The third difference concerns the CO2 produced during the preservation treatment: in HPP-fresh it is equivalent to 29,463 g CO2 eq. / kg, in the TP-ind it is equivalent to 160 g CO2 eq. / kg; this difference is due to the fact that high temperatures are required during the hot pasteurization process (TP-ind) and this leads to higher emissions than a cold pasteurization (HPP-fresh). Regarding the TP-conc in addition to 160 g CO2 eq. / kg there are another 41,65 g CO2 eq. / kg to be added due to the concentrator. In primary packaging there are no differences, all three processes are around 120 g CO2 eq. per kilo. In secondary and tertiary packaging it can be observed that HPP-fresh has fewer emissions per kilo than the other two processes examined. The last difference is related to the cold room, as mentioned several times, cold pasteurization (HPP-fresh) does not inhibit the enzymatic function, therefore it requires refrigeration which, on the contrary, is not necessary in the hot pasteurization process (TP-ind and TP-conc), this leads to emissions of 30,1 g CO2 eq. / kg per kilo only for HPP-fresh. The total emissions (with the exception of the orange production which is equal to 70g CO2 eq. per kilo for all three methods analyzed) is therefore equal to 226,75 for HPP-fresh, 336,85 for TP-ind and 435,54 for TP-conc.

The percentage incidence on CO2 eq. emissions per kilo is analyzed below (the production of oranges was not taken into consideration in this analysis): as regards the HPP-fresh process (*Table 14*), manufacturing stage accounts for 2% (blue), transport for 15% (orange), preservation treatment for 14% (gray), primary packaging for 52% (yellow), secondary and tertiary packaging for 4% (cyan) and cold room for 13% (green).

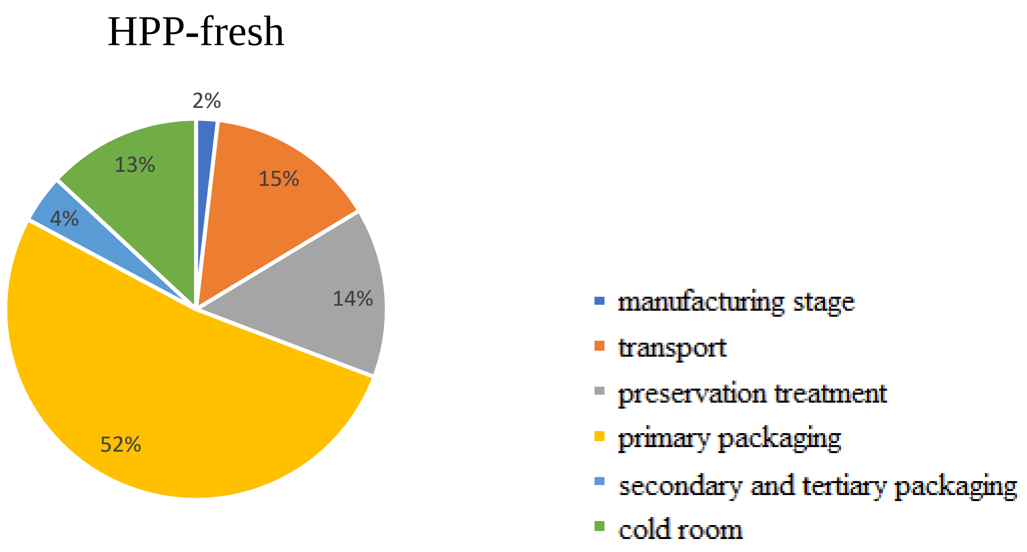

Table 14: percentage distribution of g CO2 eq. / kg of HPP-fresh

As regards the TP-ind process (*Table 15*), manufacturing stage accounts for practically 0%, transport for 10% (orange), preservation treatment for 47% (gray), primary packaging for 35% (yellow), secondary and tertiary packaging for 7% (cyan) and for 0%.

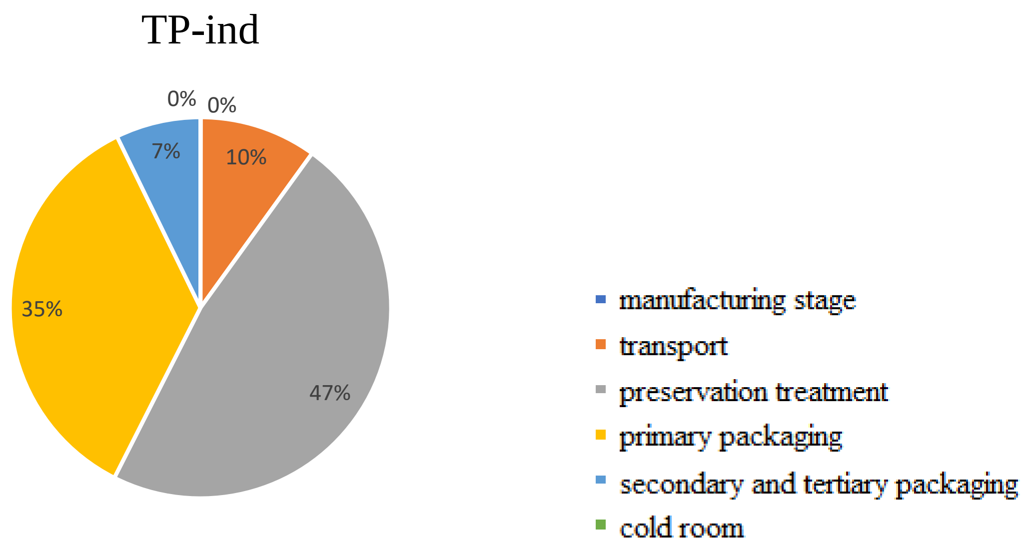

Table 15: percentage distribution of g CO2 eq. / kg of HPP-fresh of TP-ind

As regards the TP-conc process (*Table 16*) with concentrate, also in this case manufacturing stage accounts for practically 0%, transport for 21% (orange), preservation treatment for 46% (gray), primary packaging for 27% (yellow), secondary and tertiary packaging for 6% (cyan) and, obviously, cold room for 0%.

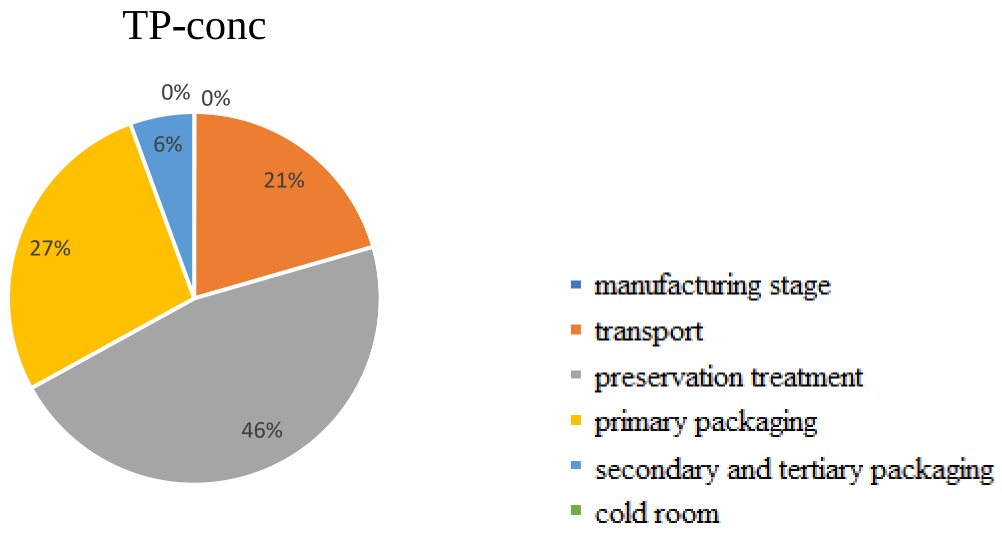

Table 16: percentage distribution of g CO2 eq. / kg of HPP-fresh of TP-conc

At this point it is possible to deduce some crucial aspects that emerge from this analysis. The choice of transport is of fundamental importance: taking as an example the HPP-fresh process (226.75 g CO2 eq. / kg) and assuming the Catania - Bologna transport only with the truck, a quantity of emissions equal to 336.6 g CO2 eq. per kilo would be obtained, practically equal to the TP-ind process (336.85 g CO2 eq. / kg), this would dissipate all the emissions savings due to preservation treatment. In both TP processes (TP-ind and TP-conc), the largest share is due to the preservation treatment, demonstrating how much this method is polluting; as regards the TP-conc process, the preservation treatment alone (201,65 g CO2 eq. / kg) impacts almost as much as the entire HPP-fresh process (226,75 g CO2 eq. / kg), unfortunately for the environment and human health, TP-conc is currently the most common and most used process. By establishing a carbon tax it would be possible to incentivize juice producers to invest in less polluting production methods which, as mentioned above, also constitute an added value for the health of the consumer. In all the processes examined, packaging is responsible for a large share of emissions: technological advancement, recycling and the use of increasingly less polluting materials is essential to reduce the impact on the environment. In conclusion, considering the process and comparing it in terms of emissions with the 70 g of CO2 eq. per kg related to the production of oranges, it can be noted that: 1 liter of HPP-fresh process juice is equivalent to about 3 kg of oranges (226,75: 70), 1 liter of TP-ind process juice is equivalent to about 5 kg of oranges (336,85 / 70) and 1 liter of TP-conc process juice is equivalent to about 6 kg of oranges (435,54 / 70). It is deduced how important it is to educate the population to the intelligent consumption of products with a lower impact on the planet, and to choose products that respect and preserve the nutritional components that the earth makes available to us.

Conclusions

As can be seen from the results of this research, it emerges that the amount of CO2 eq. per kilo emitted to produce orange juices using the high pressure process (HPP-fresh) it is lower than a hot pasteurization process (TP-ind and TP-conc); the process is not the only factor influencing this result, transport and packaging, for example, are responsible for a substantial share of CO2 eq emissions. per kilo of product. Furthermore, juices produced using HPP undoubtedly have better qualities that improve the consumer's diet and allow him to assume more vitamins than a TP juice. HPP in the perspective of corporate social responsibility, will bring benefits both to the consumer and to the environment. To accelerate a green transition to less polluting production methods, a tax on CO2 eq. emissions could be introduced to push companies towards more sustainable and environmentally friendly production lines; as reported by Richard S.J. Tol "the current price of CO2 emission permits in the European Trading Scheme is $79/tC. A carbon tax in the range of $50-$100 per metric tonne of carbon would mean that new electricity generation capacity would be carbon-free, be it wind or solar power or coal with carbon capture and storage."[19] With regard to these amounts it is important to specify that "some people use carbon rather than carbon dioxide as a metric. The fraction of carbon in carbon dioxide is the ratio of their weights. The atomic weight of carbon is 12 atomic mass units, while the weight of carbon dioxide is 44, because it includes two oxygen atoms that each weigh 16. So, to switch from one to the other, use the formula: One ton of carbon equals 44/12 = 11/3 = 3.67 tons of carbon dioxide. Thus 11 tons of carbon dioxide equals 3 tons of carbon, and a price of $30 per ton of carbon dioxide equals a price of $110 per ton of carbon."[20] This leads to the new carbon tax hypothesized by Richard S.J. Tol in a range between $ 14 to $ 28 per tonne of CO2. The price assumed for this tax can obviously vary depending on the goal that is wanted to be acheived and on the time that is wanted to use to obtain it; if the tax on emissions were higher it would mean that the CBA would be even more rewarding towards HPP-fresh, which would pay much less taxes than TP-fresh and TP-conc.

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[19] Tol R. S. J., *The Social Cost of Carbon, Annual Review of Resource Economics*, 2011.

[20] https://archive.thinkprogress.org/the-biggest-source-of-mistakes-c-vs-co2-c0b077313b/

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