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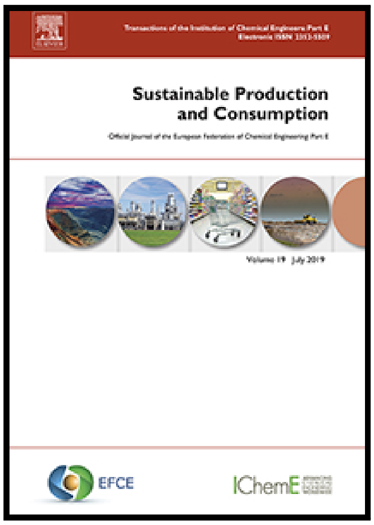

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The Monetarized Footprint Index of Paprika

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ABSTRACT

The Monetarized Footprint Index (MFI) of paprika powder grown in either Israel or India and packed in plastic jars or bags in Israel was obtained from land, water and carbon footprints under a life-cycle perspective. It was found that although the shipment distance of the paprika powder from India to Israel is relevant, a high demand for irrigation water in Israel plus the fact of the water's source from a relevant carbon footprint reverse-osmosis desalination process led to higher footprints of the Israeli products cultivated and packed there compared to India. In addition, packaging in jars required much more PET compared to bags. Thus, the growth of the pepper in India and the use of PET bags instead of jars was the best scenario, yielding MFI of 0.51 €·kg^{-1}. Moreover, considering the difference in cost-of-living and environmental performance between the two countries led to significant differences between the normalized MFI values of the Israeli and the Indian-sourced product. For example, normalizing the *MFI* based on the Gross Domestic Product per capita gives results which reveal that all the scenarios have similar scaled normalized values (167±17). In contrast, the use of Big Mac Index and Environmental Performance Index for normalization highlights the scenario of growth of the pepper in India and use of PET bags as the clear best performer.

Keywords

Monetarized Footprint Index (MFI); land footprint (LF); water footprint (WF); carbon footprint (CF); Paprika; life cycle assessment (LCA)

Indexes

i scenarios [1,2,3,4]

c countries [$Israel, India$]

f footprints [$LFurb, LFagr, WF, CF$]

j production stages [$Growth, Drying, Grinding - packing - cooling, Transportation, Packing$]

r resources [$Agricultural\ land, water, electricity, cooking\ gas, transportation, PET$]

t normalization references [$GDP, BMI, EPI, EPIS, EPISGDP$]

Variables

BMI_c Big Mac Index value for the country c

cost allocated to each footprint f in the country

$_c$ Environmental Performance Index value for the country c

equivalence factor for the resource r in the country c into the footprint

$_{cf}$ footprint f in the country c

total footprint value for the footprint

Gross Domestic Product for the country c

Monetarized Footprint Index for scenario

contribution of the country c to the

$_i$ Normalized Monetized Footprint Index based on the BMI for scenario

Normalized Monetized Footprint Index based on the EPI for scenario i

Normalized Monetized Footprint Index based on the EPI for scenario considering

$_{P,i}$ Normalized Monetized Footprint Index based on the EPI for scenario considering S_f and corrected by GDP per capita

Normalized Monetized Footprint Index based on the GDP per capita for scenario

$_{ti}$ Normalized Monetized Footprint Index for each scenario i considering the t different normalization references

$_{,ii}$ ratio of the $NMFI_{GDP,i}$ value corresponding to the scenario i and the value of the scenario ii

relative share of each footprint f within the EPI normalization procedure

$_{cji}$ amount used of the resource r in the country c for the process j in the scenario

relative share S_f

1. Introduction

The current growth of human population within the restricted land available on our planet, the continuous increase in per-capita resource use related to lifestyle changes, and the limited amount of resources afforded by nature, has led to an irreversible degradation of the environment, as seen in the accelerating threat of global warming and rates of biodiversity loss which are typical of an extinction period. These factors have driven governments, NGOs and societal movements around the world to pursue sustainable solutions for growth. Moreover, in 2015, the UN set down an international Agenda for Sustainable Development—Agenda 2030—featuring 17 Sustainable Development Goals which call for actions to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere. One of these goals, The Zero Hunger Goal, which is also connected to the other goals, envisions the search for sustainable food-supply systems (Gliessman, 2014; Berry et al., 2015).

In general, sustainable agriculture refers to food production practices that maximize desirable outcomes without over-consumption of resources and without creating negative externalities (Molina-Maturano, 2020). This means that more food will have to be produced using fewer natural resources—land, water, materials and energy—while reducing the net emissions of pollutants to the environment. Moreover, it stresses that the global food production systems should be able to support the feeding of more individuals than current systems allow. However, such systems must be updated to minimize the impact on the environment while supporting the world's biocapacity to sustain the production of food in the future (Holt-Giménez et al., 2012).

The agriculture sector places a serious burden on the environment in the process of providing humanity with food and fibers (Reisch et al., 2013; Notarnicola et al., 2017). While the need for agricultural output is constantly growing, it is simultaneously at odds with the demand to keep areas in their natural state and avoid immoral or unethical practices that harm the generations to come, who are clearly identified as subjects with rights.

The agriculture sector is the world's largest consumer of freshwater resources, accounting for about 70% of the world's total water supply (FAO, 2017). In addition, more than a quarter of the world's energy consumption is involved in the production and supply of food, and it is estimated that 25% of total global greenhouse gas emissions are directly caused by crop and animal production along with forestry (IPCC, 2014). Agricultural crops also make extensive use of open areas and have a significant impact on the environment (FAO, 2013), due to the use of fertilizers and pesticides and the production of great amount of biowastes. It is therefore necessary to identify the key elements of the balance between global demand for agricultural products and sustaining the natural services provided by the Earth for ourselves as well as future generations.

2. Literature review

A very well-established methodology to quantify the potential environmental impact of the food production supply chain on the environment is the Life Cycle Assessment (LCA), which quantifies environmental burdens through a production life cycle for any number of chosen scenarios (Roy et al., 2009; Notarnicola et al., 2017; Mehzabeen et al., 2018). LCA analyzes the environmental impacts of a product, process or service at each stage of its life cycle, from cradle to grave. It provides quantitative information on the consumption of resources for the entire life-cycle and on the emission of pollutants to the different environmental compartments caused by each process (Guinée, 2002; Finkbeiner, 2010). Indeed, LCA provides a welcome quantitative basis for analyzing the environmental dimensions of any production system.

With regard to the LCA of food systems, “from field to fork”, there are two different and usually separate assessments that can be done: one for food production systems and the other for food consumption patterns. The second assessment is obviously more difficult to follow (Özilgen, 2017). In addition, the LCA of food production systems is usually described by means of greenhouse gases emissions, i.e. its carbon footprint, and/or its water consumption rate, i.e. its water footprint (Hayashi et al., 2006; Roy et al., 2009). Other impact categories can also be assessed, such as acidification, ecotoxicity, etc., though these are often not taken into account. In addition, due to its inevitable presence, land use is often also considered in the analysis of food production systems.

Thus, in order to obtain a broader and fairer comparison between production alternatives, a combination of three well-established indicators, namely the carbon footprint (CF), the water footprint (WF) and the land footprint (LF), translated into one simple measure, can help decision-makers reach decisions regarding food production systems. Today these indicators are usually employed separately to evaluate the environmental sustainability of various processes, products and/or services.

Moreover, monetization of the environmental impacts, i.e. expressing the emissions into the environment in monetary value with the goal of an economic quantification of the environmental damage caused by a product or process, can enable integration with other economic measures and yield data that allows decisions which reflect sustainability choices. If monetary valuations of environmental impacts have the same units as those used in financial accounting (e.g. $, € and other local currencies), producers and other stakeholders will be able to easily identify sustainability hotspots in production chains and recognize the “real costs” of production. Nunes (2014), reviewed some of the available monetary valuation methods, and grouped them into three categories: (1) market demand approaches (market prices, travel cost, hedonic pricing), (2) cost approaches (replacement cost, mitigation or averting expenditure, avoided-damage cost) and (3) non-market demand approaches (contingent, valuation, choice experiment). He pointed out that these methods all suffer from deficiencies, making no single approach ideal. In addition, because of the difference in methodologies, not all monetary valuation approaches are compatible with LCA (Pizzol et al., 2015). Kerig et al. (2013) proposed a simplex algorithm, which is based on the outcomes of a LCA, and is specific for every product or service. The outcome of the analysis is a portfolio that fulfils the goal of reduced environmental impact with minimal costs. In another work, de Silva et al. (2018, 2019) developed a mixed integer linear programming model (MILP) that accounts for the economic and environmental pillars in the same objective function by monetizing environmental impacts. The goal was to maximize the difference between the expected net present value and the environmental impact while minimizing the associated risk.

Scientific support for such a selection and economic weighting of CF, WF and LF was also described in a previous research work by the authors. In that work, we conceived an environmental index, the so-called Monetized Footprint Index (MFI), which integrates an economic weighting of land, water, and carbon footprints (Herrero-Gonzalez, 2018). The production of freshwater from desalination was used as a case study, comparing different scenarios in countries with different energy mixes such as Spain and Israel. This novel index translates the land requirements, net water consumption and greenhouse gas equivalent emissions into a robust economic value that can be employed to compare different scenarios/alternatives and support decision-makers concerned with sustainability. Although it is well-known that these kinds of monetization procedures may help when there are several indicators, they also can induce methodological choices and issues that need a proper clarification prior implementation (Benetto et al., 2018). To avoid any problems, both in the original and in this paper, all details regarding issues and choices were made totally explicit.

While the core of our MFI methodology has remained intact, three advances have been added to our original paper on the development of the MFI. Where the supply chain of freshwater from desalination takes place entirely in the same country, in our original paper this feature was not considered to have a specific purpose, so costs for it were not taken into account (Herrero-Gonzalez, 2018). Consequently, the first upgrade was to make explicit the fact that the natural resources contributing to each footprint can be different depending on the location (e.g., via electricity use). Also, while agricultural land can potentially act as CO_2 sink, that potential use of this natural resource was not included in the original work. Thus the second improvement to our model was the clear distinction between urban and agricultural LF, in the latter of which carbon uptakes must be reflected.

Thirdly, we included an in-depth analysis of the effect of normalizing the MFI results which reflects the fact that different resources are consumed in different locations. In order to do so, we chose as normalization vectors the Gross Domestic Product, The Big Mac Index, the Environmental Performance Index, and combinations among them. The added value from this analysis is to balance the effects derived from using a weighting procedure to combine the land, water and carbon footprints. Consequently, the novelty of this work relies obviously not in the conception of the MFI but in the described improvements in methodology and the in-depth analysis prompted by using different normalization options. A description of the improvements in the MFI methodology and in the normalization procedure is given later in the methodology section.

Regarding applicability, LCA has been applied to many kinds of foods from food-production systems. However, we did not find any information about one very particular class of world-wide culinary product—spices—and in particular about *paprika*. Spices are ingredients that are added to food to enhance its flavor and/or color (Purseglove et al, 1981). They originate from plants, and can be derived from the fruit, seed, root, or bark of the plant. Humans began using spices already in ancient times, initially as a means of preserving food, since some spices inhibit the development of bacteria in food. However, spices have also other uses in the food market, for example in the medical field, and various spices have been scientifically demonstrated to have healing properties. Furthermore, most spices contain active organic compounds, such as antioxidants, and essential oils or aromatic compounds that give them their characteristic color, odor, and taste, which can be used in the food, pharmaceutical and cosmetic industries.

Paprika (Fig. 1a) is an orange-red powder species produced from the pepper plant fruit, *Capsicum annuum*, which is a strain of chili pepper originating in South America (Somos, 1984). Paprika can be mild, sweet, or hot, thus it can be used in food and beverage for flavoring and coloring. In addition, it contains betacarotene, which the body turns into Vitamin A, and its color is due to the presence of zeaxanthin, a carotenoid. Furthermore, paprika has excellent anti-inflammatory, anti-aging, anti-depression, and antioxidant properties, thus it is also used in the medicine industry (Anu and Peter, 2000). Moreover, the dark red color of paprika makes it excellent candidate to be used as a natural color in cosmetics.

(a) Paprika powder, to be packed, at 10% wt. moisture

(b) Paprika powder jar (100 g of paprika + 20 g of PET), corresponding to Scenarios 1 and 3

(c) Paprika powder bag (100 g of paprika + 3 g of PET), corresponding to Scenarios 2 and 4

Fig. 1. Paprika powder packed in PET jars or bags

Paprika is mainly grown and produced in Brazil, China, Peru, and India. The optimal growing conditions of the chili pepper are a temperature of 20 °C, soil with good water capacity and a pH ranging from 5.50-6.83. Lastly, the moisture content of fresh paprika is between 40% wt. and 50% wt., and in order to obtain a powdery product it is necessary to dry the plant and reduce the moisture to about 10% wt.

The paprika production process begins by planting the chili pepper seeds in a soil that suits the growing conditions. Once the pepper grows, it is harvested and transferred to a nearby paprika-producing plant. The harvested plant undergoes cleaning and separation of the pepper from the stems, followed by drying and grinding. Finally, after grinding, the paprika powder is further cleaned by sifting, and then is packed and refrigerated. Figure 1b and 1c displays the packed paprika powder in Israel marketed under the commercial brand that was used during collection of the main data for "*Spices of the Negev*".

The global paprika market has grown in recent years and is expected to grow further in the coming years due to demand for spice oils in the food industry (Zion Market Research, 2020). The global paprika market size was valued at USD 432.7 million in 2018 and is projected to expand further at a composed annualized growth rate of 5.3% over the forecast years. The rising consumer awareness of paprika's health benefits, compared to other spices, also boosts expectations of an increase in the global consumption of this spice. Moreover, the demand for specialty and natural products in cosmetics is also on the rise. However, recently, the growth of paprika in major manufacturing countries such as China and India has been replaced by cotton growth, due to cotton's higher profits; this may result in low paprika production and market shortages. As mentioned before, the major industries that use paprika are food (~50%), pharmaceuticals (~35%) and cosmetics (~15%) (Zion Market Research, 2020). The food industry has been dominating the paprika market in recent years, due to the increased use of paprika in dairy products, salt products, meat, beverages and confectionery products. Nowadays, Europe is the largest market for paprika followed by Asia-Pacific and North America, with the main exporter to European countries being India (Notarnicola et al., 2017). The key factor driving the European market is the strong demand for spice oils and food coloring.

While consumer demand is mainly driven by price and quality, the environmental aspects of the final paprika product have not been explored. To the best of our understanding, this is the first LCA study to consider paprika powder production. No other references to similar products have been identified in the literature or are available in LCA food databases. Therefore, the aim of this work is the environmental assessment of packed paprika powder using the environmental sustainability MFI. This will make it possible to analyze the potential environmental costs and benefits of Israeli-packed powdered paprika. The methodological novelty of this work consists in both the improvement in the MFI assessment and in the use of a novel set of normalization vectors for better understanding the obtained results compared to our previous work. Our model reflects the fact that this spice was cultivated in either Israel or India and was later packed in Israel using two different types of PET packaging: bags and jars. The assessment is supported by the LCA methodology using a cradle-to-gate approach, equivalent to a field-to-market supply chain. First, an assessment of the main footprints, the LF, WF and CF of each scenario, was made. Then the MFI was calculated and normalized based on different approaches. Finally, an interpretation of the data is made and recommendations are given for future work. In the present work, we follow the ISO 14040 standards (ISO 14040, 2006).

3. Methodology

3.1 Definition of Goals and Scope

The goal of this work is the environmental assessment of packed paprika powder using the environmental sustainability MFI. The reason to perform this study is to better understand the environmental consequences of the production of paprika powder and of the choice of location for the actual production, either Israel or India. Triggered by the fact that no previous work for such a food product is available, we took the opportunity to analyze the product as a case study in which the sourcing data company ("*Mimon Spices Manufacturing and Marketing*", Israel) can have a future interest. Thus, the intended use of this study is both as a reference in future studies/databases related to food systems and as an aid for the particular company, which can improve its environmental performance and potentially opt for an environmental declaration of its product.

The scope of this work covers the production of powder paprika both in Israel and India. When the powder is produced in India, it is shipped by freighter to Israel. All the final packaging is completed in Israel. Therefore, this study covers the resources and associated burdens from the field to the market (equivalent to be ready for delivery at the gate of the packaging facility). The chosen functional unit of the product system is 1 kg of paprika powder with a moisture content of 10% packed in PET jars or bags (hereafter, 1 kg of paprika powder). Different scenarios were considered, the variability consisting of the country in which the pepper plant fruit is originally grown (Israel or India), and the type of plastic packaging used (plastic jar or plastic bag). Assuming that the packaging is done exclusively in Israel, four different scenarios, marked as i, are described:

1. Scenario 1, Field-to-market production of 1 kg of paprika powder, grown in Israel, packed in Israel in a quantity of 100 g using PET jars.
2. Scenario 2, Field-to-market production of 1 kg of paprika powder, grown in Israel, packed in Israel in a quantity of 100 g using PET bags.
3. Scenario 3, Field-to-market production of 1 kg of paprika powder, grown in India, packed in Israel in a quantity of 100 g using PET jars.

4. Scenario 4, Field-to-market production of 1 kg of paprika powder, grown in India, packed in Israel in a quantity of 100 g using PET bags.

Additionally, it should be noted that we did not account for consumption, i.e., the resources involved in sales, transport from the store/distribution center to the final consumer of the paprika, or the end of life of the packaging (Gomes et al., 2019). As already mentioned, this is due to the fact that a cradle-to-gate/field-to-market approach is considered. Unless otherwise stated, all numbers refer to the year 2019. The paprika powder production process involves five key steps or processes, marked as j: 1) growth, 2) drying, 3) grinding, packing, and cooling, 4) transportation, and 5) packaging. The system's boundaries are presented in Figure 2.

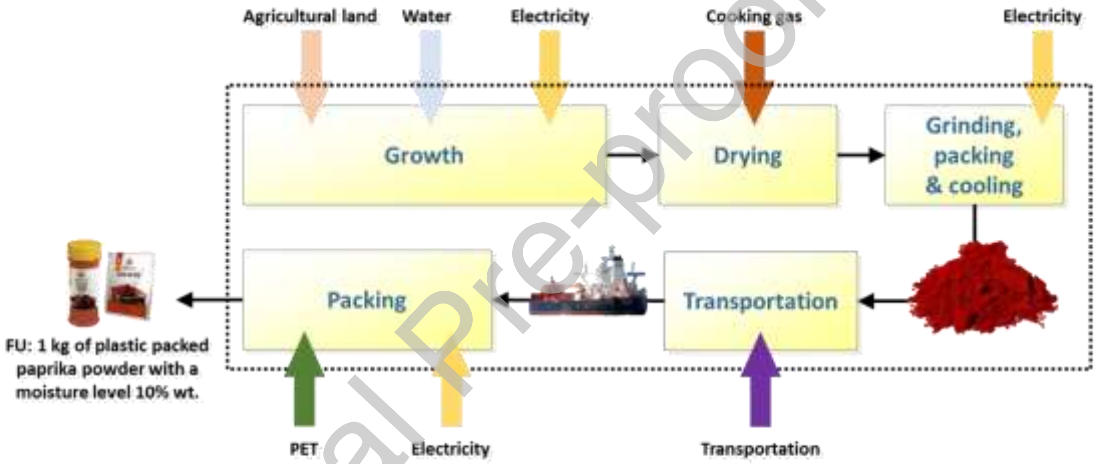

Fig. 2. System boundaries for the cradle-to-gate production of 1 kg of packed paprika powder: 1) growth, 2) drying, 3) grinding, packing, and cooling, 4) transportation, and 5) packaging

3.2 Life Cycle Inventory

After a clear declaration of the goal and scope of the study, with an explicit mention of the intended use, we reach the life-cycle inventory (LCI) stage. The LCI for the scenarios 1 and 2 are: growing, handling and packaging of the paprika in Israel; for scenarios 3 and 4 they are: growing and handling of paprika in India while shipping it to Israel and packaging it in Israel. Data were mainly based on manufacturer's details, with some additional information based on literature reviews under different assumptions to close data gaps. As a first step, the different stages of the process were defined and the different flows of mass and energy were depicted. Data was then collected and the quantities of the various materials and energy sources were calculated and converted to the aforementioned values of the footprints, marked as f: $LFurb$, $LFagr$, WF, and CF, and in the MFI_i values in a later stage. When a resource r is used, it is stated for the type of LF considered. A summary of the amount of the different involved resources U_{rcji} is provided in Table 1, where r is the index for each resource, c for each country, j for each process and i for each scenario.

3.2.1 Description of scenarios 1 and 2: growing and packaging in Israel

The growth of the paprika and the pre-packaging data are based on the Israeli manufacturer's text, "*Spices of the Negev*", and the final packaging data is based on data from the packaging company, "*Mimon Spices Manufacturing and Marketing*" (Table 1). A rigorous set of surveys in the different facilities was needed to compile a robust and coherent inventory. A detailed description of the different stages is provided next.

Growth. In Israel, planting is done in March and harvesting in September. An area of one *dunam* (1000 m^2) yields ~800 kg of raw paprika and requires ~700 m^3 water. No fertilizers were considered for the growth stage (This date was not available). As the moisture of the raw paprika is estimated as 40% wt., this leads to 1.25 (m^2·yr)·kg^{-1} of paprika (raw), i.e., $LFagr$, and 0.88 m^3·kg^{-1} of paprika (raw) or 1.88 (m^2·yr)·kg^{-1} of paprika (10% wt.) and 1.31 m^3·kg^{-1} of paprika (10% wt.). In addition, as the growth period is already after the end of the wet season, the water supply is entirely based on the drinking water network. Today in Israel, most of the drinking water network for agricultural and residential use is based on desalinated water: ~70%. (Israel EU embassy, 2020). In addition, while some Israeli farmers use reclaimed wastewater that has been purified, in the case of paprika no reclaimed water is used to prevent potential contamination. Thus, it may be assumed that the water usage is based mostly on desalination. According to the Israeli water authorities report, the energy consumption for desalinating water is ~2.5 kWh·m^{-3}, and its transportation and distribution involve an additional amount of ~1.5 kWh·m^{-3}. Thus, assuming 70%

desalination water and 30% blue water from upper and ground reservoirs, the overall energy consumption was taken as 3.25 kWh·m^{-3} (the footprint of the electricity in Israel is displayed in Table 2). In addition, this electricity production also requires land, i.e., $LFurb$. Finally, as cropland is considered as a CO_2 sink due to CO_2 adsorption during the growth period, the use of agricultural land as a resource gives -0.06 kg CO_2 eq./kg of paprika (10% wt.) which in terms of CO_2-eq. has an absorption value of 0.032 kg·m^{-2}·yr^{-1} (Poeplau and Don, 2015).

Drying. In the drying process, the moisture is reduced from 40% wt. to 3% wt. The drying process in Israel is carried out in continuous ovens, at a supply of 2 ton·h^{-1}. The ovens work with hot air at 100 °C, by using 0.8 kg of cooking gas (70% propylene and 30% isobutylene) per kg of paprika (40% wt.) or 1.2 kg of cooking gas (70% propylene and 30% isobutylene) per kg of paprika (10% wt.) until the 3% wt is reached. The air flows continuously so that it absorbs all the water. As a result, 3.04 kg of CO_2 are released per kg of cooking gas consumed.

Grinding, packing, and cooling. The grinding takes place from September to December, when the dry paprika enters the grinding machine and becomes powder. The powder is then further aerated to make sure that the product is clean; then it goes directly to the mixer where water is added to the product until it reaches 10% wt. moisture. The reason why the moisture is reduced to 3% wt. and only then increased to 10% wt. is that in order to perform the best grinding and at the fastest rate, the product must be dried to a low moisture content so that it can pass through the grinding machine without problems. Then, the moisture content of the product is increased back to 10% wt. as that is the maximum percentage for retention of the red and fresh color of paprika over time, and the minimum percentage in which bacteria growth is kept limited. After receiving a product with 10% wt. humidity, the paprika powder is packed in 25 kg paper bags and transported to refrigerated warehouses. The paprika powder is kept refrigerated until transported to the packing house, to slow down chemical and biological processes. The power consumption on pre-packing—drying, grinding, and cooling in the plant— is ~2500 kWh per day, and the packaging in big bags process consumes ~1000 kWh per day. The plant produces 800 kg·h^{-1} of paprika (10% wt.) during 24 hours for a period of two months.

Transportation. The transportation distance of the bags from the paprika production plant located at Beit Kama junction (Israel), to the packaging house that is located in Be'er Sheva (Israel), is 22 km. The carbon emissions per ton cargo per kilometer was assumed as 0.062 kg·(ton·km)$^{-1}$ of CO_2 (Guidelines for Measuring, 2011).

Final packing. In the spice factory, the paprika is packed in either plastic jars or plastic bags (Fig. 1 b and c, respectively), containing 100 gr of final product (10% wt.). For the plastic jars, the machine consumes ~25.5 kWh per day and produces jars weighing 20 gr and made from polyethylene terephthalate (PET). For the plastic bags, the machine consumes ~25.5 kWh per day and produces bags weighing 3 gr and made from PET. Yet in order to calculate the carbon emissions of the packing, besides machine electricity, the life cycle emissions from plastic jar/bag manufacturing should be also considered. A value of CO_2 emissions of 0.014 kg·g^{-1} of PET (Botto et al., 2011) is used as a reference. In addition, production of PET jars and bags also requires water. This water consumption was assumed to be 0.71 L·g^{-1} of PET (Tandon et al, 2014).

3.2.2 Description of Scenarios 3 and 4: growing in India, shipping and packaging in Israel

The growth of the paprika and the pre-packaging data are based on the manufacturer's data (Table 1), while the final packaging data is similar to scenarios 1 and 2. A detailed description of the different stages is provided next.

Growth. In India, planting is carried out in June and harvesting in December to February. An acre (4,046 m^2) of growing land typically yields ~1,600 kg of paprika, leading to 2.53 (m^2·yr)·kg^{-1} of paprika (raw) or 3.79 (m^2·yr)·kg^{-1} of paprika (raw). No fertilizers were considered for the growth stage. (This date was not available) Also, ~4 L of water is required for each m^2 of irrigated land, which results in a water consumption of 0.01 m^3·kg^{-1} of paprika (raw) or 0.015 m^3·kg^{-1} of paprika (10% wt.). The climate in India is divided into two main seasons: the wet season and the dry season. Unfortunately, no data were available for the sources of water for growing paprika in India, thus as proxy, data were taken from a study conducted in Indonesia, as both countries are in the same geographical area (Bafdal et al., 2017). According to the study, in the dry season, there is hardly any rain, and in the wet season, there are torrents of rain that sometimes destroy the agricultural soil. The alternative to solve this problem is to use rainfall during the wet season and harvest it for dry season irrigation. Rainwater harvesting is a relatively simple technological solution that does not entail high costs. Also, this technology is environmentally friendly and can be adopted by farmers in rural and urban areas. In addition, this technology can optimize the use of available rainwater and provide a self-irrigation system. This irrigation system is an automatic system of irrigation, without the use of electricity and pumps, providing the same results and effectiveness as other irrigation systems. In India, this method is also used in some locations, so we can hypothesize that the energy for irrigation is minimal and negligible. Thus, the associated greenhouse gas emissions for this stage is almost zero. Only as mentioned previously, a small absorption of CO_2 takes place; in this scenario a value of -0.12 ·kg CO_2 eq.·kg^{-1} of paprika (10% wt.) was assumed.

Drying. The drying stage in India is usually done by direct natural air drying until 10% wt. is reached. Although this process takes longer than the drying in Israel, it does not require any external energy source, and uses only natural resources. In other words, at this stage we can state that the energy consumption too, and thus the amount of greenhouse emissions, is negligible.

Grinding, packing, and cooling. Because of the lack of data regarding the energy consumption in the grinding, packing and cooling stage, and due to differences in culture and development between India and Israel, it was hypothesized that this stage in India requires, on average, half of the energy that was consumed in Israel, due to the use of non-electrical power sources. However, it is important to note that this phase is not the most critical and influential stage of paprika production life cycle assessment in India, as is later discussed. Nevertheless, the footprint of the electricity in India is displayed in Table 2.

Transportation. "*Mimon Spices Manufacturing and Marketing*", sited in Israel, receives paprika deliveries from India once a month. Shipping to Israel is done on a freighter, and it contains 4 containers of 16 tons of paprika (dried). The distance between Israel and India is estimated as 4,018 km. In order to calculate the carbon emissions of the transport stage, a CO_2 emissions factor of 0.0115 kg·(ton·km)$^{-1}$ was used (Guidelines for Measuring, 2011).

Packing. The packaging of the product in jars or bags is carried out in Israel, and therefore the calculations are the same as previously described in scenarios 1 and 2.

Table 1

Summary of the main values of the LCI in each studied scenario. The last column shows explicitly the footprint to which each resource is contributing. The unit of mass here considers a moisture content of 10% wt.

				Scenario				Footprint
		Resource	Unit	1	2	3	4	
Growth	Raw paprika yield	Agricultural land	$(m^2 \cdot yr) \cdot kg^{-1}$	1.88	1.88	3.79	3.79	LFagr, CF
	Water consumption for paprika growing	Water	$m^3 \cdot kg^{-1}$	1.31	1.31	0.015	0.015	WF
	Electricity for water consumption for paprika growing	Electricity	$kWh \cdot kg^{-1}$	4.27	4.27			LFurb, WF, CF
Drying	Cooking gas	Cooking gas	kg CO_2 eq.$\cdot kg^{-1}$	1.2	1.2			CF
Grinding, packing & cooling	Electricity for grinding, packing and cooling	Electricity	$kWh \cdot kg^{-1}$	0.18	0.18	0.09	0.09	LFurb, WF, CF
Transportation	Transport needs	Transportation	km	22	22	4018	4018	CF
Packing	Electricity for packing	Electricity	$kWh \cdot kg^{-1}$	~0	~0	~0	~0	LFurb, WF, CF
	PET demand for packing	PET	$g \cdot kg^{-1}$	200	30	200	30	WF, CF

Table 2

Values of the footprints f for the electricity from the grid mix in each country c. Contributions of the different electric power sources were sourced from IEA and transformed into the values of the footprints f as described in (Herrero-Gonzalez, 2018)

Selected footprint	Unit	Israel	India
CF	kg·kWh^{-1}	0.634	0.73
WF	m^3·kWh^{-1}	0.002	0.0049
LFurb	(m^2·yr)·kWh^{-1}	0.005	0.011

3.3 Life Cycle Impact Assessment

Once the LCI for the selected four scenarios is available, the third stage in the LCA study corresponds to the Life Cycle Impact Assessment (LCIA) stage. In this stage, instead of using the conventional ready-made metrics to quantify the burdens due to all potential environmental effects, we used the already mentioned three footprints: land footprint (LF), water footprint (WF) and carbon footprint (CF). The description of the calculation of each footprint can be found elsewhere (Herrero-Gonzalez, 2018). Its economic weighting leads to the key index proposed as reference in this work, which is the Monetized Footprint Index (MFI). The description of the MFI including the methodological novelties proposed in this work are described next. The assessment of the MFI values for the four different scenarios based on the LCI and reported in Table 1 were calculated in a Microsoft Excel spreadsheet. Other alternatives for estimating the LF and WF such as Land Use Indicator Value Calculation in Life Cycle Assessment (LANCA), and Available Water Remaining (AWARE) model were not considered in this study due to the lack of reliable input data as previously explained in section 2.2.

3.3.1 Monetarized Footprint Index (MFI)

As previously noted, we proposed a novel tool to support decision-making by translating the main footprints of environmental sustainability, LF (urban, $LFurb$, and agricultural, $LFagr$), WF and CF, into a robust monetized index, MFI, which is calculated by equation 1 and graphically summarized in Figure 3:

$$MFI_i = \sum_c \sum_f C_{cf} \left[\sum_j \sum_r \left(U_{rcji} E_{rcf} \right) \right] \qquad \textbf{Eq. 1}$$

Where the sets are: i for the scenarios $[1,2,3,4]$, c for the countries $[Israel, India]$, f for the footprints $[LFurb, LFagr, WF, CF]$, j for the production stage $[Growth, Drying, Grinding - packing - cooling, Transportation, Packing]$, and r for the resource $[Agricultural\ land, water, electricity, cooking\ gas, transportation, PET]$;

U_{rcji} represents the amount used of the resource r in the country c for the process j in the scenario i; E_{rcf} is the equivalence factor for the resource r in the country c into the footprint f; C_{cf} is the cost allocated to each footprint f in the country c. As later used,

MFI_{ic} is the contribution of the country c to the MFI_i, and FP_{cf} would be the value of the footprint f in the country c, and can be calculated as $FP_{cf} = \sum_j \sum_r (U_{rcji} E_{rcf})$, where FP_f, calculated as $FP_f = \sum_c FP_{cf}$, would be the total FP value for the footprint f. Basic details about the methodological aspects of MFI can be found elsewhere (Herrero-Gonzalez, 2018).

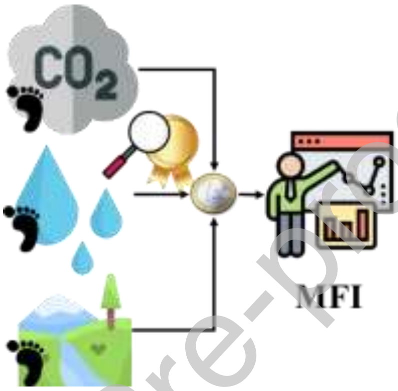

Fig. 3. Schematic description of the MFI calculation procedure

As previously mentioned in the introduction section, in this work, two methodological improvements were added, compared to our original paper on the development of the MFI (Herrero-Gonzalez, 2018): 1) resource r can have different contributions to each footprint f depending on the location, such as the chosen country c. As a result, individual resources cannot be merged or combined alongside the supply chain but can only be considered at the country level; 2) the LF was explicitly divided into two individual footprints, both the urban LF, $LFurb$, and the agricultural LF $LFagr$.

Unless otherwise stated, MFI values refer to the chosen functional unit. Table 3 displays the values of the costs of each footprint f as represented by the C_{cf} values updated from (Herrero-Gonzalez, 2018). A limitation of the present work is the fact that the $C_{India,f}$ values were assumed to be derived from adjustments to well-known values from Israel and Spain by means of the Cost of Living Index (53.77 for Spain, 81.15 for Israel and 24.58 for India) (Numbeo, 2020). As a final remark, it is important to remind to the reader that 1) the lower the MFI_i value, the better from an environmental perspective, and 2) for international applicability the index can be easily tuned just by considering the c involved countries at each j stage. As a result, any practitioner can apply the methodology to a certain product just by considering the national framework conditions.

Table 3

Summary of the costs of each footprint f as represented by the C_{cf} values. All costs are updated from (Herrero-Gonzalez, 2018)

Footprints	Units	Israel	India
LFurb	$€·(m^2·yr)^{-1}$	1.51	0.46
LFagr	$€·(m^2·yr)^{-1}$	0.3	0.091
WF	$€·m^3$	2.91	0.882
CF	$€·kg^{-1}$	0.225[a]	0.225[a]

[a] Integration in an European market is adopted from https://carbonpricingdashboard.worldbank.org/map_data

3.3.2 Normalized MFI using macroeconomic indicators such as Gross Domestic Product and Big Mac Index

Within the LCIA, it is possible to proceed to a normalization step. In this work, instead of the assessment of results of conventional impact indicator categories, we use the MFI values. As this MFI calculation is based on the exchange value, i.e., the market value of each footprint as represented by C_{cf}, it is obviously dependent on the supply and demand in each country c, and on the cost-of-living, population size, land size, etc. In addition, there is also a relevant difference in the environmental performance rates of each chosen country. In this regard, the difference between the two countries, Israel and India, can be expressed by two selected macroeconomic indicators: 1) Gross Domestic Product (GDP) per capita, i.e., the purchasing power parity value of all final goods and services produced within a country in a given year, divided by the average population for the same year; and 2) the Big Mac Index (BMI), i.e., an indicator of the purchasing power of an economy. BMI is a simple indicator of the fundamental value of currencies globally. It determines the cost of a consumer basket for each country. The corresponding equations for the normalized

MFI values $NMFI_{GDP,i}$ and $NMFI_{BMI,i}$ (equation 2 and 3, respectively) are presented next:

$$NMFI_{GDP,i} = \sum_{c} \frac{\sum_f C_{cf}\left[\sum_j \sum_r \left(U_{rcji} E_{rcf}\right)\right]}{GDP_c} \qquad \textbf{Eq. 2}$$

$$NMFI_{BMI,i} = \sum_{c} \frac{\sum_f C_{cf}\left[\sum_j \sum_r \left(U_{rcji} E_{rcf}\right)\right]}{BMI_c} \qquad \textbf{Eq. 3}$$

Where GDP_c is the GDP per capita value for the country c and BMI_c is the BMI value for the country c. The chosen values GDP_c and BMI_c are summarized in Table 4 and converted to € from the original reference. To provide a better picture, we define $R_{GDP,i,ii}$ as the ratio of the $NMFI_{GDP,i}$ value corresponding to the scenario i and the $NMFI_{GDP,ii}$ value of the scenario ii as described in equation 4:

$$R_{GDP,i,ii} = \frac{NMFI_{GDP,i}}{NMFI_{GDP,ii}} \qquad \textbf{Eq. 4}$$

3.3.3 Normalized MFI using the Environmental Performance Index

As both GDP per capita and BMI are economic measures, another way to normalize the MFI is to consider the overall environmental state and activities of each country, e.g., percentage of open land, fish stock and air pollution control. For instance, using the environmental performance index (EPI) provides a quantitative basis for comparing, analyzing, and understanding environmental performance for 180 countries, while scoring and ranking different countries based on environmental health and ecosystem vitality indicators (EPI, 2020). Produced by the Yale Center for Environmental Law & Policy, the EPI calculation is based on an assessment of the policies of 180 nations, reflecting whether they are meeting internationally established environmental targets or, in the absence of agreed targets, how they compare to one another. Hence, the EPI values can also be used to normalize the MFI values of the chosen countries according to equation 5:

$$NMFI_{EPI,i} = \sum_{c} \frac{\sum_f C_{cf}\left[\sum_j \sum_r \left(U_{rcji} E_{rcf}\right)\right]}{EPI_c} \quad \textbf{Eq. 5}$$

Where EPI_c is the EPI value for the country c. The chosen values EPI_c are also included in Table 4.

3.3.4 Normalized MFI using Environmental Performance Index weighting as reference

Another route to normalizing the MFI values is to assign a different weight to each footprint f, which reflects its relative importance in the calculation of the whole MFI, i.e., the real effect of each footprint f on the natural environment. It can be based on local or global scales. For example, how does each footprint affects the loss of biodiversity, i.e., the global extinction of species, and also the local reduction or loss of species in a certain habitat? Using such measurements will allow the allocation of the relevant share to every footprint f. Moreover, as previously mentioned, MFI assigns national exchange values to weight each footprint f, but it gives each footprint f an equivalent share, although the influence of land use on biodiversity, for instance, is not the same as the influence of carbon footprint and global warming on biodiversity. In addition, the MFI is based only on actual or direct usage of resources r, without considering the overall pool of these resources, i.e., the inventory, or the effects of the loss of these resources. As such, land use does not account for the effect of land loss on climate change, for example. Furthermore, the MFI also does not consider the effect of resource use or loss on natural environments such as the effect of the greenhouse gases emissions on human health or on marine life. Further, it does not reflect the quality of each footprint f, for example the fact that cropland has lower value to biodiversity than an open natural forest area, or even that grassland is less valuable to nature than the forest area.

Thus, another possibility for normalizing MFI values is also included here. It is based on weighting the relative importance of each footprint f, using the EPI methodology that divides the overall contribution into different indicators to which are assigned relative percentages, as illustrated in Table 5. The overall index considers two objectives: 1) environmental health, which is mainly associated with effects on human health, and is responsible to 40% of the overall index; and 2) ecosystem vitality, which considers the effect of human activity on nature, and is responsible for 60%. Each objective is expressed by several indicators, and the share of each indicator for each objective is indicated in Table 5. For instance, of the 40% of environmental health objective share, 33% is allocated to environmental risk exposure. Thus, it is possible to allocate the factors for each footprint f based on each objective based on the overall index. Table 6 summarizes the allocation of each indicator to the four footprints f that are used in this study, as well as their relative share S_f, while the share of other indicators that are relevant to all the footprints, were divided into three. The $NMFI_{EPIS,i}$ values were calculated based on equation 6:

$$NMFI_{EPIS,i} = \sum_{c}\sum_{f} S_f C_{cf}\left[\sum_{j}\sum_{r}\left(U_{rcji}E_{rcf}\right)\right] \qquad \textbf{Eq. 6}$$

where S_f is the relative share for each footprint f. The values S_f are those reported in Table 6. The same value is used for $LFurb$ and $LFagr$ thus $S_{LFurb} = S_{LFagr} = S_{LF}$. Finally, the last normalized version of the MFI, $NMFI_{EPISGDP,i}$ can be obtained after considering both the EPI methodology and the values of the GDP per capita for each country c according to equation 7:

$$NMFI_{EPISGDP,i} = \sum_{c}\frac{\sum_f S_f C_{cf}\left[\sum_j \sum_r \left(U_{rcji}E_{rcf}\right)\right]}{GDP_c} \qquad \textbf{Eq. 7}$$

Consequently, there is a total of 5 different $NMFI_{ti}$ values, where t represents the index for the t different normalization vectors. Again, it is important to bear in mind that the lower the $NMFI_{ti}$ value, the better from an environmental perspective. The normalization of the MFI values for the different indicators was also calculated in a Microsoft Excel spreadsheet.

Table 4

Summary of the selected normalization values to create the $NMFI_{ti}$ values

Normalization value	Units	Israel	India
GDP per capita	€·$(cap)^{-1}$	41559	2188
BMI	€	4.06	2.26
EPI	-	75.01	30.57

Table 5. Environmental Performance Indicators (EPI) indicators and original corresponding shares

Objective	Share (%)	Issue Category	Share (%)	Indicator	Share (%)
Environmental health	40	Health Impacts	33	Environmental Risk Exposure	100
		Air quality	33	Household Air Quality	30
				Air pollution - Average Exposure to PM2.5	30
				Air pollution - PM2.5 Exceedance	30
				Air pollution - Average Exposure to NO2	10
		Water and sanitation	33	Unsafe Sanitation	50
				Drinking Water Quality	50
Ecosystem vitality	60	Water resources	25	Wastewater treatment	100
		Agriculture	10	Nitrogen use efficiency	75
				Nitrogen balance	25
		Forests	10	Change in forest cover	100
		Fisheries	5	Fish stocks	100
		Biodiversity and habitat	25	Terrestrial Protected Areas (National Biome Weights)	20
				Terrestrial protected areas (Global Biome Weights)	20
				Marine protected areas	20
				Species protection (National)	20
				Species protection (Global)	20
		Climate and energy (25%)	25	Trend in carbon intensity	75
				Trend in CO2 emissions per kWh	25

Table 6

The relevance of each EPIs' indicator to each footprint and their relative share.

	LFP	Share %	WF	Share %	CF	Share %
	Environmental Risk Exposure	4.4[a]	Environmental Risk Exposure	4.4	Environmental Risk Exposure	4.4
	Species protection (National)	1	Species protection (National)	1	Species protection (National)	1
	Species protection	1	Species	1	Species	1

		(Global)		protection (Global)		protection (Global)	
		Change in forest cover	6	Unsafe Sanitation	6.6	Air pollution - Average Exposure to PM2.5	4
		Terrestrial Protected Areas (National Biome Wei ghts)	3	Drinking Water Quality	6.6	Air pollution - PM2.5 Exceedance	3
		Terrestrial protected areas (Global Biome Weights)	3	Wastewater treatment	15	Air pollution - Average Exposure to NO2	1.3
				Marine protected areas	3	Trend in carbon intensity	11.2 5
						Trend in CO_2 emissions per k Wh	3.75
Total value	(%)		17.4		37.6		29.7
			S_{LF} -		S_{WF} -		S_{CF} -
Share of each footpri nt	-		**0.21**		**0.44**		**0.35**

[a] For example: based on EPI, Environmental Risk Exposure is responsible for 30% of objective 1, Environmental Health, and it is equally effect the three footprints, thus the calculation is 40%*0.33/3=4.4%.

4. Results and discussion

Once the results from the LCIA are available, the final stage in the LCA study is the interpretation of those results. The results and discussion section reports the main conclusions extracted from the work and proposes recommendations for future action. This section first shows the values obtained for each footprint, then the MFI values and finally the normalized values.

4.1 Footprint results

The $LFurb$, $LFagr$, WF and CF footprints for the production of 1 kg of packed paprika powder at a moisture of 10% wt. in the four scenarios are summarized in Table 7. With regard to $LFurb$, scenarios 1 and 2 show that 100% of the value $FP_{Israel,LFurb}$ of 0.02 (m^2·yr)·kg^{-1} comes from the use of electricity for water pumping. Scenarios 3 and 4 do not have any relevant value for $FP_{c,LFurb}$. The $FP_{Israel,LFagr}$ shows a value of 1.88 (m^2·yr)·kg^{-1} in scenarios 1 and 2 derived from the agricultural land used in Israel while a value of $FP_{India,LFagr}$ of 3.79 (m^2·yr)·kg^{-1} in scenarios 3 and 4 derive from the same resource in India. This might be attributed to the high technological systems and the use of genetic engineering in agriculture in Israel, which reduces the pepper growing area and thus increases the yield per unit area, compared to the older and more traditional agricultural practice in India.

Regarding the use of water as summarized by WF, scenario 1 shows a value of $FP_{Israel,WF}$ of 1.46 $m^3 \cdot kg^{-1}$ while scenario 2 shows a value of 1.34 $m^3 \cdot kg^{-1}$. This difference comes from the different mass amounts of PET used in the two Israeli scenarios. In scenario 3, a value of FP_{WF} of 0.16 $m^3 \cdot kg^{-1}$ is obtained being $FP_{Israel,WF}$ equal to 0.14 $m^3 \cdot kg^{-1}$, derived from the use of PET. A $FP_{India,WF}$ value as small as 0.02 $m^3 \cdot kg^{-1}$ is obtained in scenario 3 due to the restricted water demand for growing the spicy fruit in India. In contrast, scenario 4 reports a value of FP_{WF} equal to 0.04 $m^3 \cdot kg^{-1}$, with $FP_{Israel,WF}$ equal to 0.02 $m^3 \cdot kg^{-1}$, derived again from the lower demand of PET (20 g per jar versus 3 g per bag) while the value of $FP_{India,WF}$ remains as small as 0.02 $m^3 \cdot kg^{-1}$ as previously mentioned. This is explained in terms of the relatively warm and dry climate in Israel compared to the conditions in the region in which the pepper is grown in India, which eventually lead to differences in irrigating.

CF is the footprint which presents contributions due to all individual resources. In scenario 1, a $FP_{Israel,CF}$ value of 9.21 kg CO_2 eq.$\cdot kg^{-1}$ was obtained. 29% of this value comes from the electricity for water consumption, 40% from drying and 30% from the PET material. The sequestration of CO_2 from the agriculturally-used land, the electricity for grinding, the internal transportation in Israel and the electricity for packing have a minor contribution to the overall value. When the amount of PET is reduced in scenario 2, electricity for water consumption jumps to 39%, drying to 53% and PET material decreases to just 6%. In scenario 3, a FP_{CF} value of 2.79 kg CO_2 eq.$\cdot kg^{-1}$ was obtained. This value is totally controlled by the contribution of the PET material used in Israel for packaging as the contribution of $FP_{India,CF}$ is not relatively small but even negative, with a value of -0.01 kg CO_2 eq.$\cdot kg^{-1}$, due to the fact that the contribution of electricity for grinding, packing and cooling in India plus the shipment to Israel (total value of 0.11 kg CO_2 eq.$\cdot kg^{-1}$) is almost balanced by the sequestration of CO_2 in the agriculturally-used land (-0.12 kg CO_2 eq.$\cdot kg^{-1}$). In scenario 4, a FP_{CF} value of 0.41 kg CO_2 eq.$\cdot kg^{-1}$ was obtained due to the lower demand in PET material compared to scenario 3.

Usually, when goods are transported a long distance, as in the case of the transportation of the paprika from India to Israel in scenarios 3 and 4, the transportation stage in the LCA tends to dominate the FP_{CF}. However, the LCA approach demonstrated that in this particular case, the transportation stage has a minor contribution. As a result, the FP_{CF} values of paprika that was grown and packed in Israel is much higher (9.21 kg CO_2 eq.·kg^{-1} and 6.83 kg CO_2 eq.·kg^{-1}) than the one grown and packed in India (2.79 kg CO_2 eq.·kg^{-1} and 0.41 kg CO_2 eq.·kg^{-1}). The contribution of the electricity for water due to the different on-field irrigation practices, the use of cooking gas for drying and the PET material are the resources that contribute most to the overall FP_{CF}. Not only does paprika in Israel require more water per unit of mass of product, but most of the water in Israel is also based on desalination, which consumes a relatively high amount of electricity. By contrast in India, as previously mentioned, the water is mainly sourced from rain harvesting, which is obviously more efficient than desalination. In addition, while drying in Israel is performed in a closed oven, using cooking gas, in India the drying process takes place mainly in the open air. Another stage in the LCA of goods that usually consumes a relatively high share of the emissions is packaging, with respect to both, production of the raw materials and machinery for packaging. Packaging in jars requires much more PET compared to bags (20 g per jar verses 3 g per bag). This helps explain the differences between scenarios 1 and 3 compared to scenarios 2 and 4. Even if the used cropland is considered as a CO_2 sink, due to CO_2 adsorption during the growth stage, the reduction in the FP_{CF} value is relatively modest.

Table 7. Summary of the footprint values FP_{cf} of the studied scenarios i.

Scenario		Footprints			
		LFurb (m^2·yr)·kg^{-1}	LFagr (m^2·yr)·kg^{-1}	WF m^3·kg^{-1}	CF kg CO_2 eq.·kg^{-1}
1	Israel	0.02	1.88	1.46	9.21
	India				
2	Israel	0.02	1.88	1.34	6.83
	India				
3	Israel	0.00	0.00	0.14	2.80
	India	0.00	3.79	0.02	-0.01
4	Israel	0.00	0.00	0.02	0.42
	India	0.00	3.79	0.02	-0.01

4.2 Monetized Footprint Index (MFI)

As previously noted, MFI was calculated according to equation 1, by multiplying each FP_{cf} value from Table 7 by its corresponding C_{cf} cost value. The aggregated MFI_{icf}, which are the MFI values for each scenario i in each country c due to the FP_{cf} and the total MFI_i for each scenario i, is reported in Table 8:

Table 8. Summary of the Monetized Footprint Index MFI_{ic}values for each country c and the MFI_i values of the studied scenarios i.

Scenario		$MFI_{ic,LFurb}$ €·kg^{-1}	$MFI_{ic,LFagr}$ €·kg^{-1}	$MFI_{ic,WF}$ €·kg^{-1}	$MFI_{ic,CF}$ €·kg^{-1}	MFI_{ic} €·kg^{-1}	MFI_i €·kg^{-1}
1	Israel	0.03	0.56	4.26	2.07	6.93	6.93
	India	0.00	0.00	0.00	0.00	0.00	
2	Israel	0.03	0.56	3.91	1.54	6.04	6.04
	India	0.00	0.00	0.00	0.00	0.00	
3	Israel	0.00	0.00	0.41	0.63	1.04	1.40
	India	0.00	0.34	0.01	0.00	0.36	
4	Israel	0.00	0.00	0.06	0.09	0.16	0.51
	India	0.00	0.34	0.01	0.00	0.36	

As can be seen from the results in Table 8 and 9, the MFI values of paprika that was fully produced in Israel, i.e., scenarios 1 and 2, are significantly higher than the values of the paprika that was grown in India and packed in Israel, i.e., scenarios 3 and 4. In particular the MFI_1value (MFI value for scenario 1) of 6.93 €·kg^{-1} is 15% higher than the MFI_2value (MFI value for scenario 2) of 6.04 €·kg^{-1}. This difference is mainly due to the additional amount of PET material needed in scenario 1 compared to scenario 2. The MFI_3value (MFI value for scenario 3) of 1.40 €·kg^{-1} is roughly a fifth of the MFI_1value. This highlights the influence of moving the j stages, of growth, drying and grinding, packing & cooling, to India instead of having these be done in Israel, due to the fact that the share of the transportation stage is relatively meaningless, showing $MFI_{3,transportation}$ a value of 0.01 €·kg^{-1}. In addition, the reduction in the MFI_4value (0.51 €·kg^{-1} of paprika) compared to the MFI_3value highlights the benefits of using a lighter package based on a lower amount of PET material.

Table 9 shows the contribution of each stage j to the total MFI_i value. In this regard, it is worth mentioning that the total MFI_i values reported in Table 9 must be equal to the total values that were reported in Table 8, as they are simply grouped by a different criterion. As presented in Scenario 1 and scenario 2, the growth stage has the highest contribution to the MFI values, ~73% for scenario 1 and ~83% for scenario 2. In scenarios 1 and 2, the MFI_{WF} value represents ~76% of the $MFI_{1,growth}$ and $MFI_{2,growth}$ values. Therefore, MFI_{WF} has the higher contribution to the total MFI values in scenarios 1 and 2 due to the growth stage. In scenario 3, the growth stage represents ~24% of the MFI_3 value, being the packaging stage with a ~75% share. However, in scenario 4, due to the change in the amount of PET material needed, the growth stage represents ~64% of the MFI_4 value, while packaging is ~31%. Therefore, according to the results presented in Table 9, the use of the MFI supports scenario 4 as being the one with the lowest monetarized environmental burden, due to 1) the use of rain-water for growing pepper in India instead of desalinated water in Israel, 2) the natural drying done in India instead of using cooking gas in Israel, 3) the use of a packaging option with a low amount of PET material (20 gr vs 3 gr). Furthermore, the transportation burdens from India seem to be negligible, thus they do not dwarf the other stages.

Table 9. Summary of the Monetized Footprint Index MFI_{ij}values for each process j and the studied scenarios i.

		Scenario			
		1	2	3	4
Growth	€·kg^{-1}	5.04	5.04	0.33	0.33
Drying	€·kg^{-1}	0.82	0.82	0.00	0.00
Grinding, packing & cooling	€·kg^{-1}	0.03	0.03	0.02	0.02
Transportation	€·kg^{-1}	0.00	0.00	0.01	0.01
Packing	€·kg^{-1}	1.04	0.16	1.04	0.16
MFI_i	€·kg^{-1}	6.93	6.04	1.40	0.51

4.3 Normalized Monetized Footprint Index (NMFI)

Though the MFI values clearly reflect the higher consumption of water and energy in the Israeli product (scenarios 1 and 2), it also reflects the high cost of living in Israel compared to India. Hence, though the MFI values allow integrating various measures to one comparative number, by definition, it may not take into account potential local and global effects as well as the similarities and the differences between two chosen countries or regions. In addition, the MFI value, which was calculated based on national prices weights for each footprint f, does not reflect the local or temporal relevance of each footprint f unless the national process can reflect that very variation. Thus, in order to yield a more accurate and reliable perspective of the MFI values for each scenario i, $NMFI$ values should be calculated as described in the next section.

As previously stated, the $NMFI_{ti}$ values can be calculated based on different perspectives, using exchange-values or use-values, on local or global level, and by correcting the whole MFI values as one (per country c) or each footprint alone (per footprint f). The different equations that were used for the normalization of the MFI_i values were explained in the methodology section, and Table 10 summarizes the scaled $NMFI_{ti}$ values.

Table 10. Summary of the Normalized Monetized Footprint Index $NMFI_{ti}$values for the studied scenarios i. ($NMFI_{GDP,i}$ was scaled by 10^6; $NMFI_{BMI,i}$ by 10^2; $NMFI_{EPI,i}$ by 10^3; and $NMFI_{EPISGDP,i}$ by 10^2 in order to display proper reporting values.)

	$NMFI_{GDP,i}$	$NMFI_{BMI,i}$	$NMFI_{EPI,i}$	$NMFI_{EPIS,i}$	$NMFI_{EPISGDP,i}$
Scenario					
1	167	171	92	273	66
2	145	149	81	238	57
3	188	42	26	48	45
4	167	20	14	14	37

At a first glance, the use of $NMFI_{ti}$ values appears to be helpful for a better discussion and interpretation of the MFI_i values. As previously mentioned in the MFI values section, scenario 4 was chosen as the best performer because it reported the lowest value (0.51 €·kg^{-1} of paprika). However, the use of $NMFI_{GDP,i}$ shows that $NMFI_{GDP,2}$ offers the lowest value (145). The reason for this swap between scenario 2 and scenario 4 as the best performer is due to the normalization process. In Israel the GDP per capita value is around 19 times the value in India. As a result, the MFI_{ic} values can vary drastically so the contribution of India to scenarios 3 and 4 becomes relevant.

$R_{GDP,1,3}$ has a value of 0.89, which is almost equal to $R_{GDP,2,4}$, which has a value of 0.87. This highlights that moving the production to India, once the normalization by

GDP per capita is carried out, is maybe not such an interesting option. However, if instead of GDP per capita, we use the BMI for normalization, then the $NMFI_{BMI,i}$ values suggests that once again scenario 4 is the best performer (20). The reason for that is the similarity in the value for the BMI values between the two countries (it is just 1.8 times instead of the 19 times as in the case of the GDP per capita). In addition, the normalization based on the EPI supports similar conclusions to BMI as the ratio between the two countries is 2.5, which is similar to the ratio for BMI (1.8). Once the normalization takes into account the S_f values, scenario 4 is distinctively shown to be the best performer (14), which means that scenario 1 is 20 times worse than scenario 4. The correction of the normalization by EPI and GDP per capita as $NMFI_{EPISGDP,i}$ values equally presents scenario 4 as the most favorable (37), but in this case the average distance to other scenarios is not so marked. Consequently, the normalization procedures based on the GDP per capita values, due to the differences on the values for India and Israel (a ratio of 19), may lead to conclusions in which the 4 scenarios perform almost similarly, 167±17 for $NMFI_{GDP,i}$ and 51±13 for $NMFI_{EPIGDP,i}$. In contrast, the use of BMI and EPI for normalization (not including GDP per capita) highlights scenario 4 as the clear best performer.

Finally, it can be seen that the normalization procedure may play a major role in selecting the best scenario. Thus, the following insights should be considered. Firstly, the index for decision making is the MFI. This means that the normalization procedure is developed to add insights and not to distort the recommendation provided by the original MFI. Secondly, we provided a set of values for normalization but they are evidently subjective, and other normalization procedures might be used. Lastly, we explored GDP per capita, BMI and EPI and their combinations to consolidate our initial guess: choosing different normalization vectors can lead to different conclusions. The added-value provided to decision-makers is to offer them a choice among alternatives based on their experience and professional judgement.

The scientific relevance of this work stems from the fact that the distance of shipment by freighter of the paprika powder from India to Israel environmentally compensates for the high demand for irrigation water in Israel and its supply by an RO desalination process, which ultimately leads to higher footprints of the products entirely cultivated and packed in Israel. Moreover, the difference in economic and environmental performance between both countries, leads to significant differences between the normalized MFI values for the selected product. This work highlights that the differences in the country-based footprint of the used resources must be considered, thus transport burdens (freighters) can compensate for more geographically-suited agricultural production practices (low water footprint). This was objectively and quantitatively demonstrated by applying the proposed normalization procedure on top of the MFI values used. What emerges is that considering the difference in the cost-of-life as depicted by GDP per capita or BMI, and considering environmental performance by using EPI values, might provide a much more accurate picture. Accordingly, decision-makers can tailor their capacity for selecting alternatives via an upgraded portfolio of economic and environmental normalizations.

Future work will aim at a more precise normalization of each footprint, while taking into account further characteristics of each country such as the density of settled land and the different uses of the land, e.g., shares of built-up and agriculture/cropland, as well as freshwater resources and greenhouse gases emission per capita. In future work there is a need to investigate the influence of further metrics such as LANCA and AWARE for LF and WF, to collect more reliable on-site data as well as to perform a Monte Carlo uncertainty study considering the most influential parameters.

4.4 Sensitivity analysis

In order to check the effect of several parameters on the MFI value, a sensitivity analysis was performed (Table 11). The sensitivity analysis considered the following assumptions and findings: 1) In the methodology section, it was hypothesized that in India all the water was harvested from rain, thus no energy was required; 2) Because of the lack of data regarding the energy consumption in the grinding, packing and cooling stage, and due to differences in culture and development between India and Israel, it was hypothesized that this stage in India requires, on average, half of the final energy that was consumed in Israel, due to the use of non-electrical power sources; and 3) The relevant contribution of *WF* as one of the main contributors to the total value of MFI. Therefore, the main parameters that were considered in the sensitivity analysis of the MFI_i were: 1) The energy for water production in India was updated to 50% of the value for Israel, which leads to 2.13 kWh·kg^{-1}; 2) The energy for grinding, packing and cooling stage was updated to 100% of the value for Israel, thus assuming similar machinery; and 3) The value of WF was set on 50% more than in all countries and 50% less than in all countries.

As can be seen from the results in Table 11, the greatest difference compared to the original values shown in Table 8 is displayed in the case of scenario 4, after updating the energy requested for water harvesting (~73%). In addition, the variation of WF is more pronounced in scenarios 1 and 2, in which variations around 31% were observed. These highlights the fact that the prices of the f footprints must be carefully managed and made transparent to the decision-maker at all times.

Table 11. Summary of the Monetized Footprint Index MFI_i values for the sensitivity analysis

Scenario	Updated energy for harvesting water in India	Updated energy grinding, packing and cooling in India	50% increase in the WF value	50% decrease in the WF value	MFI_i €·kg^{-1}
1	6.93	6.93	9.06	4.80	6.93
2	6.04	6.04	8.00	4.09	6.04
3	1.77	1.42	1.61	1.19	1.40
4	0.88	0.53	0.55	0.48	0.51

5. Conclusions

The environmental sustainability index that we have called the Monetized Footprint Index, MFI , which combines assessments of land, water, and carbon footprints, is a tool for the economic weighing of environmental burdens. As such, it can be used to select the most environmentally sustainable alternative among proposed scenarios and is geared toward easing decision-making processes. This MFI was used to compare four different scenarios of packed paprika powder, which was grown either in Israel or in India and packed in Israel in either bags or PET jars. According to the MFI values, the growth of the pepper in India and the use of PET bags instead of jars (scenario 4) is assessed to be the best scenario (0.51 €·kg^{-1}). The transportation of the dried product by freighter from India for packing in Israel has a minor footprint contribution, and is environmentally compensated for by the high-water demand of RO desalinated water for irrigation in Israel. The normalization procedure described here, based on different macroeconomic indicators such as the national Gross Domestic Product or the Big Mac Index and environmental values such as the Environmental Performance Index, can yield additional insights. Using economic or environmental performance measures for the normalization can alter the discussion about which is the best performer, compared to direct use of the MFI as a guiding index. For example, using the GDP per capita as a normalization vector gives results which reveal that all the scenarios have similar scaled normalized values (167±17). This can be explained by the difference in the national environmental MFI contributions, which are modified by differences in the GDP per capita values of both countries. However, using the EPI for normalization provides similar insights to those of a straightforward application of the MFI. Thus, from the case study of packed paprika, we argue here that the MFI can be very useful for an objective, fast, simple and reliable environmental assessment, offering decision-makers a single index that covers key environmental issues. A subsequent normalization process can provide additional insights, geared always to the decision-makers' chief economic or environmental concerns.

Conflict of Interest Statement

We declare here that we have no conflict of interest. LCA has been applied to assess the footprints of paprika, while using the MFI and normalized MFI to select between different scenarios. As such, the new manuscript includes date about land use, water use and greenhouse gas emission, as well as economic output, as part of the scope of the journal.

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