

# A Progressive Approach Towards a More Sustainable Food Industry

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In this work, the main direct environmental impacts of the food industry, as well as greenhouse gas (GHG) emissions for the agro-food system in industrialized countries, were pointed out. A simple and stepwise approach, based on the mere assessment of the product Carbon Footprint (CF), was used to improve the sustainability of small- and medium-sized food and drink enterprises before analyzing the impact of other impact categories than climate change. By applying previously developed LCA models, the cradle-to-grave carbon footprint of dry pasta and malt beer was estimated and practically halved by resorting to a series of mitigation options. A cost/benefit analysis is required to assess the feasibility of each selected option.

## 1. Introduction

The current food system was regarded as ecologically unsustainable (Church, 2005). Fossil fuels are essential to afford crop production, animal husbandry, and food production and distribution, as well as to construct and maintain machinery and processing equipment, transportation vehicles, and infrastructures.

Although from the millenary climate observations the warming since the middle of the 20<sup>th</sup> century might be primarily attributed to natural causes, such as solar activity and random variations (de Larminat, 2016), the human contribution cannot be retained as negligible (IPCC, 2013). The human population has grown from about 3.03 to 7.67 billion people since 1960 (Anon, n.d.), and in all probability has exerted a primary impact on the environment. It is, indeed, responsible for the huge release of the so-called greenhouse gases (GHG), namely CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, hydrochlorofluorocarbons (HFCs), perfluorinated chemicals (PFCs) and SF<sub>6</sub>, in the atmosphere. Since 1980 the volumetric concentrations of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in the atmosphere over marine surface sites have definitely increased from about 380 to 405 ppm (NOAA, n.d.), 1566 to 1835 ppb and 301 to 328 ppb (EEA, 2017), respectively. In the great majority of studies, the climate change and several other impact categories (Table 1) have been used to assess the environmental performance of the food supply chain. The food, drink, tobacco and narcotics area of consumption in the EU-25 accounted for 22-31% for climate change and 20-30% for most of the other impact categories, with the exception of 59% for eutrophication (Tukker et al., 2006).

The food and beverage industry is thus seeking to improve its environmental performance by identifying which actions are really suitable for a more sustainable production (Moresi, 2014). Life cycle assessment (LCA), as standardized by ISO (2006), provided a way to categorize the environmental impacts of each phase of the food supply chain (Minkov et al., 2016), and is the basic procedure for several international standard methods (Table 2). Except the Environmental Product Declaration<sup>®</sup> and Product Environmental Footprint (PEF) methods, the great majority of the international standards account for the single impact category of climate change. Since the PEF method requires the estimation of as many as 14 impact categories, it was severely criticized by numerous stakeholders for being uselessly complex and very expensive, especially for the 99% EU food and drink enterprises (Cimini and Moresi, 2018a).

The aims of this work were to point out the main direct environmental impacts of the food industry and GHG emissions for the agro-food system in industrialized countries, and outline a stepwise approach directed to reduce the product Carbon Footprint (CF) of food and drink products before analyzing the effect of other impact categories than climate change.

Table 1: Main impact categories used in several LCA standard methods, as extracted from Cimini and Moresi (2018a): impact category (IC) definition, and indicator unit (ICIU).

Impact category	Category definition	ICIU
Climate Change (CC)	It represents the potential change on the Earth climate as due to human activity and GHG release.	kg CO <sub>2e</sub>
Ozone Depletion (OD)	It measures the industrial gas concentrations accelerating O <sub>3</sub> decomposition in the Earth's stratosphere, this affecting living organisms.	kg CFC-11 <sub>e</sub>
Acidification (A)	It measures the release of NO <sub>x</sub> and SO <sub>2</sub> which combine with water in the atmosphere forming HNO <sub>3</sub> and H <sub>2</sub> SO <sub>3</sub> .	mol H <sup>+</sup> <sub>e</sub>
Eutrophication- aquatic (NPA)	It measures the release of N- and P-rich nutrients in surface waters resulting in excessive plant growth.	Fresh water: kg P <sub>e</sub> ; Marine water: kg N <sub>e</sub>
Eutrophication- terrestrial (NPT)	The deposition of N from the emissions released by N-rich nutrients affects terrestrial ecosystems too.	mol N <sub>e</sub>
Photochemical Ozone Creation (POC)	It measures the formation of ground-level O <sub>3</sub> as due to the reaction of NO <sub>x</sub> and volatile organic compounds that causes irritation for humans and damage for plants.	kg NMVOC <sub>e</sub>
Ecotoxicity-aquatic, freshwater (ET)	It measures how chemical compounds interact with organisms in the environment.	CTU <sub>e</sub>
Human Toxicity- cancer effects (HTC)	It measures how chemical compounds may cause a variety of types of cancer in humans or chronic	CTU <sub>h</sub>
Human Toxicity- non-cancer effects (HTNC)	non-cancer effects including mutagenicity, toxicity, etc.	CTU <sub>h</sub>
Particulate Matter (PM)	It measures how particulate matter may cause respiratory problems.	kg PM <sub>2.5e</sub>
Ionizing Radiation- human health effects (IR)	It measures how ionizing radiation affects the risk for human cancer incidence and mortality increase.	kg U <sub>235e</sub>
Resource Depletion- water (RDW)	It measures the use and depletion of fresh water, minerals and fossil resources, this impacting ecosystems and the survival of many species.	m <sup>3</sup> of water related to local water scarcity
Resource Depletion- mineral/fossil (RDMF)		kg Sb <sub>e</sub>
Land Transformation (LT)	It considers the extent of changes in land properties & the area affected.	kg Soil Organic Matter

Table 2: Brief description of some international standard methods for product and service environmental assessment together with their mid-point impact categories (IC) accounted for (same labels as in Table 1), as extracted from Cimini and Moresi (2018a).

Standard method	Description	Mid-point ICs
Life Cycle Assessment (LCA)	It specifies requirements and provides guidelines for LCA studies.	CC; OD; A; NP; POC; RD; LU.
Carbon Footprint of Product (CF)	It allows the calculation of CF, based on LCA specified in ISO (2006).	CC; LUC.
PAS 2050	It provides a standardized guidance for calculating the CF of goods & services.	CC; LUC.
Bilan Carbone®	It is a GHG emissions assessment tool developed by ADEME (2007).	CC; LUC.
Environmental Product Declaration (EPD®)	It was supported by the Swedish government.	CC; OD; A; NP; POC; RD; LU.
GHG Protocol	This standard defines how measuring, & reporting GHG emissions in the USA.	CC
Product Environmental Footprint (PEF)	It is a novel European Community methodology under development.	CC; OD; A; NPA; NPT; POC; ET; HTC; HTNC; PM; IR; RDW; RDMF; LT.

## 2. The environmental impact of food processing

The complete supply chain of the food industry from the production of raw materials via food processing to the consumption and disposal by the consumer is quite complex, as schematically sketched in Fig. 1.

The main direct impacts of food processing derive from waste generation, water use, and energy use (Dieu, 2009). Food waste is intense in the farm due to spoilage (~21% of supply), but limited to ~7 % throughout food processing. Food solid waste may be inedible materials or rejected products from sorting, grading, peeling, trimming, and squeezing. It may amount to the 50-70% of fresh citrus fruits or crab and shrimp processed (Dieu, 2009). Packaging materials (i.e., paper- and card-board, plastics, glass, metals, and wood) are largely used to protect processed foods not only from deterioration and/or contamination (primary packaging), but also from mechanical damage through the distribution and retailing operations (secondary and tertiary packaging).

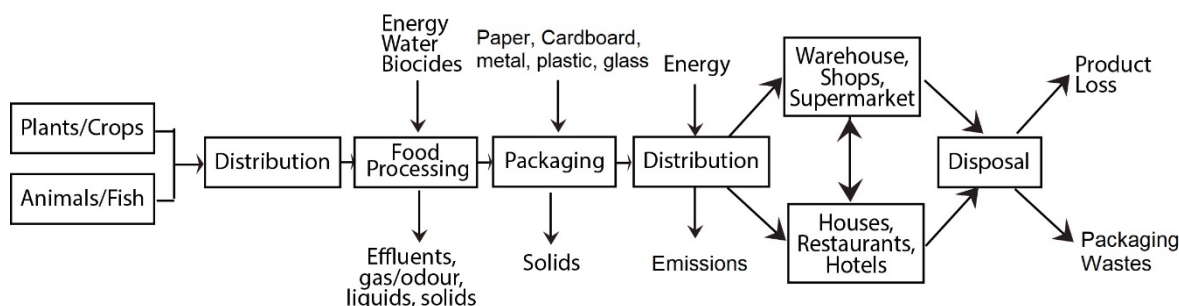


Figure 1: Simplified flow sheet of the supply chain of the food industry, as adapted from Moresi (2014).

In food processing large volumes of water are used as the main ingredient in drink formulation, initial and intermediate cleaning source, transportation conveyor of raw materials, and principal agent used in sanitizing plant areas and machinery (Dieu, 2009). The water consumption in fruit and vegetable processing ranges from 4 to 32 m<sup>3</sup> per Mg of product treated, the 50% of which being approximately used just for washing and rinsing. The water used to make beer or milk products may vary from 9 to 18 m<sup>3</sup> Mg<sup>-1</sup>. The resulting wastewaters are generally rich in organic matter, sometimes being contaminated with pesticide residues from raw material treatments. Up to 50-60 % of their amount might be reclaimed and reused after screening, filtering or dilution with fresh water. Air emissions during food processing may contain fine particles, combustion products (CO, CO<sub>2</sub>, NO<sub>x</sub>), volatile organic compounds, and in the case of fish by-products unpleasant odorous contaminants, such as H<sub>2</sub>S, and (CH<sub>3</sub>)<sub>3</sub>N (Dieu, 2009). The energy needs of food industry are of low or medium intensity. Some sectors (e.g., wet corn milling, beet sugar, soybean oil mills, malt beverages, meat packaging, canned and frozen fruits and vegetables, bread, and baked products) are however high-energy users (Dieu, 2009). The 38% of all the energy consumed by the Italian agro-food industry is of the electric type, while the remainder of the thermal one (MISE, n.d.). The total impact of energy use might be lessened by minimizing the energy needs, producing energy from waste, and using renewable energy sources.

### 3. GHG emissions for the agro-food system in industrialized countries

The GHG emission space per capita and year should be limited to 2400 kg of CO<sub>2</sub>, 59 kg of CH<sub>4</sub>, and 0.67 kg of N<sub>2</sub>O (Carlsson-Kanyama, 1998; IPCC, 1996) to allow any person now living on the Earth and those expected to live until 2100 to exert the same rights to emit GHGs, if the atmospheric concentration of CO<sub>2</sub> be less than 450 ppm with CH<sub>4</sub> and N<sub>2</sub>O emissions kept at the same levels measured in 1995. The permitted GHG emissions per capita and year within a 20-yr time perspective were estimated by summing the mass of each GHG times its corresponding global warming potential as (1x2400+72x59+289x0.67=) 6842 kg CO<sub>2e</sub>. To assess whether such GHG emissions were congruent with the current ones, one has to refer to the national inventory reports (NIR) published by UNCC (2018). The direct per capita emissions in the year 2007 ranged from as high as 24.0 Mg CO<sub>2e</sub> for the USA to as low as 1.6 Mg CO<sub>2e</sub> for India (Berners-Lee, 2010). The current Italian GHG emissions (including those adsorbed by land use, land use change and forestry, LULUCF) amount to circa 398 Tg CO<sub>2e</sub> (ISPRA, 2018), this resulting in an Italian per capita CF of about 6.7 Mg CO<sub>2e</sub> yr<sup>-1</sup>. Altogether, these emissions were mainly composed of CO<sub>2</sub>, followed by CH<sub>4</sub> and N<sub>2</sub>O, while the contribution of HFCs, PFCs and SF<sub>6</sub> was of minor importance. The main GHG source was the energy sector (347.1 Tg CO<sub>2e</sub>), followed by the industry (32.1 Tg CO<sub>2e</sub>), agriculture (30.4 Tg CO<sub>2e</sub>), and waste (18.3 Tg CO<sub>2e</sub>) sectors, while the category LULUCF was the main GHG sink (-29.9 Tg CO<sub>2e</sub>). More specifically, the agriculture sector mainly emitted CH<sub>4</sub> from animal husbandry [i.e., enteric fermentation (14.0 Tg CO<sub>2e</sub>) and manure management (3.1 Tg CO<sub>2e</sub>) and rice cultivation (1.7 Tg CO<sub>2e</sub>], and N<sub>2</sub>O from agricultural soils (8.9 Tg CO<sub>2e</sub>) and manure management (2.1 Tg CO<sub>2e</sub>). The industrial processing ones were mainly due to the iron and steel industry, followed by the chemical, and pulp, paper and print ones. The food processing, beverages and tobacco sector emitted ~3.7 Tg CO<sub>2e</sub> (ISPRA (2018).

The contribution of the agro-food sector to the overall direct GHG emissions cannot be directly extracted from any NIR, since most of its subsectors (namely, agro-food product transportation; production and transportation of packaging materials; food transport from retailer to consumer's house; electric energy consumed to preserve foods in the home freezer, fridge, etc.; gas and/or electric energy consumed to cook foods; disposal of food losses or wastes) are aggregated in other sectors. The Italian contribution was found to be about the 19% of the overall GHG emissions (Moresi, 2014), this falling within the range estimated by Tukker et al. (2006).

#### 4. Key elements for sustainable food processing

No food processing is nowadays 100% sustainable owing to the lack of energy, ingredients and packaging materials derived from renewable resources; excessive water use; the CH<sub>4</sub> and N<sub>2</sub>O emissions associated with crop production and animal husbandry; and lack of biodegradable packaging materials (Morawicki, 2012). Nevertheless, to relieve its environmental impact a food company might resort to a simple and progressive approach to sustainability. Firstly, food processing plant efficiencies for energy, water, and raw and packaging material consumption should be improved and fossil energy usage replaced with renewable one by purchase or self-generation. Then, the GHG emissions associated with the transportation of raw materials and final products, field phase, and post-consumer disposal of packaging materials and food loss should be reduced. Despite firm-oriented, such an approach might result in mitigation actions exerting a minimum reduction in the product carbon footprint. Thus, the mitigation opportunities should be prioritized starting from the life cycle stages with the highest contribution to the product CF, as previously assessed (Cimini and Moresi, 2018b).

#### 5. Case studies: Lager beer and dry pasta production

The cradle-to-grave CF of a malt lager beer (Cimini and Moresi, 2016, 2018c), or an organic durum wheat semolina pasta (Cibelli et al., 2017) was previously estimated by applying the PAS 2050 standard method (BSI, 2008). All the LCA canonical stages (i.e., goal and scope definition, inventory analysis, impact assessment, and interpretation of results) were referred to a functional unit consisting of 1 hL of beer or 1 kg of dry pasta, as packed in 66-cL glass bottles or 0.5-kg polypropylene (PP) bags, respectively. The system boundaries for these case studies are shown in Fig. 2. According to PAS 2050 (Section 7.2), the geographic and time scopes of this LCA study were referred to Western Europe and to the years 2006-2016. Finally, process data were of the primary type (Cibelli et al., 2017; Cimini and Moresi, 2018c).

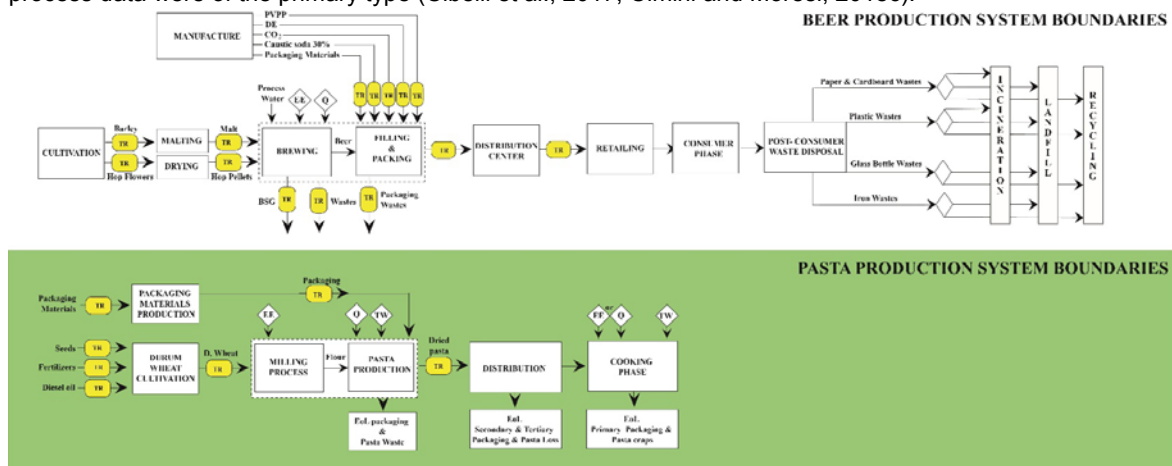


Figure 2: Beer and dry pasta system boundaries, as adapted from Cimini and Moresi (2018c) and Cibelli et al. (2017). Main identification items: EE, electric energy; EoL, end of life; Q, thermal energy; TR, transport; TW, process water.

In this work, to explain better the mitigation strategy extracted from LCA using the single impact category of climate change, a large-sized brewery with an annual beer capacity of  $3 \times 10^6$  hL was assumed as reference case (RC). The essential data used to run the LCA model were given previously (Cimini and Moresi, 2018b). The beer CF value was of about  $127 \text{ kg CO}_{2e} \text{ hL}^{-1}$ . The life cycle phases most contributing to CF were, in descending order, associated with packaging material manufacture ( $\sim 56 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ), transportation ( $\sim 29 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ), production of malted barley and processing aids ( $\sim 23 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ), consumer use ( $\sim 19 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ), beer production and packaging ( $\sim 12 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ), and waste disposal ( $1.2 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ). CO<sub>2e</sub> credits derived from the use of spent grains and surplus yeast as animal feed ( $2.1 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ) and from recycling of glass bottles, paper and cardboard wastes ( $11 \text{ kg CO}_{2e} \text{ hL}^{-1}$ ) (Cimini and Moresi, 2018b). Instead of adopting the aforementioned Morawicki's approach to sustainability, a series of sequential improvement opportunities was scheduled to relieve the GHG emissions associated with the hotspot life cycle stages. Firstly, the replacement of 10% recycled glass bottles with 100% recycled ones reduced CF by about 21% with respect to the reference case. By shifting the transportation mode from 100% of road freight to 100% of rail freight to manage logistics flows, an additional 10% decrease in CF was achieved. The use of organic instead of conventional barley grown locally had the effect of decreasing CF by another 9%. A quasi zero-carbon alternative for electricity generation is solar-photovoltaic electricity. Such a shift further lessened CF by 13%.

As shown in Table 3, the above sequential series of mitigation options allowed the beer carbon footprint to be practically halved from about 127 to 60 kg CO<sub>2e</sub> hL<sup>-1</sup>.

*Table 3: Effect of the sequential mitigation strategies used to minimize the cradle-to-grave beer and dry pasta carbon footprint (CF) and its cumulative percentage variation with respect to that pertaining to the reference case ( $\Delta CF/CF_{RC}$ ). The sequential step-wise procedure started from the most impacting life cycle phase as resulting from the single-issue LCA procedure used.*

Mitigation strategy	Parameter varied	Unit	CF	$\Delta CF/CF_{RC}$ [%]
<b>Beer reference case (RC)</b>				
100% recycled glass bottles	EF <sub>RB</sub> 1.08 → 0.48	kg CO <sub>2e</sub> kg <sup>-1</sup>	127.2*	0
Malt & beer rail transport	EF <sub>RT</sub> 0.168 → 0.039	kg CO <sub>2e</sub> (Mg km) <sup>-1</sup>	100.3*	-21
Organic malt	EF <sub>OM</sub> 1.143 → 0.546	kg CO <sub>2e</sub> kg <sup>-1</sup>	88.2*	-31
Local malt	d <sub>LM</sub> 500 → 250	km	76.6*	-40
Photovoltaic electric energy	EF <sub>PEE</sub> 0.324 → 0.055	kg CO <sub>2e</sub> kWh <sup>-1</sup>	76.5*	-40
<b>Dry pasta reference case (RC)</b>				
Eco-sustainable cooking	P <sub>C</sub> 2.3 → 0.4	kWh kg <sup>-1</sup>	60.2*	-53
Organic rotation cropping	EF <sub>ORC</sub> 0.534 → 0.36	kg CO <sub>2e</sub> kg <sup>-1</sup>	1.807 <sup>#</sup>	0
Thermal energy from biogas	EF <sub>BG</sub> 0.231 → 0.029	kg CO <sub>2e</sub> kWh <sup>-1</sup>	1.283 <sup>#</sup>	-29
Photovoltaic electric energy	EF <sub>PEE</sub> 0.513 → 0.055	kg CO <sub>2e</sub> kWh <sup>-1</sup>	1.056 <sup>#</sup>	-42
Pasta rail transport	EF <sub>RT</sub> 0.168 → 0.047	kg CO <sub>2e</sub> (Mg km) <sup>-1</sup>	0.923 <sup>#</sup>	-49
Pasta regional distribution	d <sub>P</sub> 900 → 250	km	0.767 <sup>#</sup>	-58
Durum wheat local supply	d <sub>LDW</sub> 150 → 50	km	0.720 <sup>#</sup>	-60
			0.695 <sup>#</sup>	-62
			0.675 <sup>#</sup>	-63

\* [kg CO<sub>2e</sub> hL<sup>-1</sup>]; # [kg CO<sub>2e</sub> kg<sup>-1</sup>]

In the case of organic dry pasta, all primary data were collected from a medium-sized pasta factory with a capacity of ~125 Gg yr<sup>-1</sup>. All process data were reported by Cibelli et al. (2017). The dry pasta CF was of about 1.8 kg CO<sub>2e</sub> kg<sup>-1</sup>. The life cycle phases were ranked as follows: field phase (~0.67 kg CO<sub>2e</sub> kg<sup>-1</sup>), home pasta cooking (0.65 kg CO<sub>2e</sub> kg<sup>-1</sup>), pasta production and packaging (~0.20 kg CO<sub>2e</sub> kg<sup>-1</sup>), transportation (~0.15 kg CO<sub>2e</sub> kg<sup>-1</sup>), packaging material manufacture (~0.11 kg CO<sub>2e</sub> kg<sup>-1</sup>), durum wheat milling (~0.05 kg CO<sub>2e</sub> kg<sup>-1</sup>), end of life of packaging materials (~0.03 kg CO<sub>2e</sub> kg<sup>-1</sup>) and pasta losses (~0.02 kg CO<sub>2e</sub> kg<sup>-1</sup>). CO<sub>2e</sub> credits resulted from the use of wheat milling by-products, and pasta making and packaging wastes as animal feed (~0.07 kg CO<sub>2e</sub> kg<sup>-1</sup>) in alternative to soybean meal fodder (Cibelli et al., 2017). Use of the eco-sustainable pasta cooking procedure with a cooking water-to-dry pasta ratio of 2 L kg<sup>-1</sup> (Cimini et al., 2019) would cut CF by 29% with respect to the reference case (RC). Use of organic crop rotation enabled CF to be decreased by another 13 %. By replacing the methane needed for the steam generating boilers with biogas, CF reduced by 7% further. Use of solar-photovoltaic electricity lessened CF by an extra 9 %. By shifting from road to rail freight transport, a supplementary 2 % reduction in CF was obtained. Finally, as the final product or grain delivery distance was as low as 250 or 50 km, respectively, CF still reduced by 2 or 1%. In total, such a sequential series of mitigation options allowed the dry pasta CF footprint to be reduced from 1.81 to 0.68 kg CO<sub>2e</sub> kg<sup>-1</sup> (Table 3). In both cases, a cost/benefit analysis is finally required to relate the increase in the overall processing costs to the reduction in the product environmental load resulting from any option.

## 6. Conclusions

A simple and stepwise approach, based on the PAS 2050 standard, allowed the reduction of the CF of 1 hL of beer packed in 66-cL glass bottles from about 127 to 60 kg CO<sub>2e</sub> hL<sup>-1</sup>, and that of 1 kg of dry organic pasta packed in 0.5-kg PP bags from 1.81 to 0.68 kg CO<sub>2e</sub> kg<sup>-1</sup>, respectively. The former was mainly due to the use of 100%-recycled glass bottles, while the latter firstly derived by a more environmentally sustainable pasta cooking practice. Since the only assessment of GHG emissions might result in burden shifting, a further step should investigate other environmental impacts and processing costs.

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