Life Cycle Assessment of Waste Prevention in the Delivery of Pasta, Breakfast Cereals, and Rice

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ABSTRACT

Waste prevention is the top priority of the European waste management strategy. In fact, as indicated in the latest Waste Framework Directive, the best option to deal with waste is not to generate it at all. In this framework, the distribution of loose dry food products through self-dispensing systems (so-called "loose distribution") is being considered worldwide as a practice to reduce the generation of packaging waste. This life cycle assessment (LCA) evaluates the environmental convenience of the loose distribution of dry pasta, breakfast cereals, and rice, in comparison with the traditional method of distribution. For each product, several baseline scenarios based on single-use packaging were compared with different waste prevention scenarios in which the product is distributed loose. The comparison addressed waste generation, 13 impact categories on the environment and human health, and the Cumulative Energy Demand (CED) indicator. The results are significantly different for the 3 products. The loose distribution of pasta allows a 50% waste reduction and a decrease in the potential impacts only when compared with single-use cartonboard boxes. Conversely, when the comparison is made with single-use polypropylene bags, the loose distribution can even cause an increase in waste generation (up to 15%) and in the potential life cycle impacts. For breakfast cereals, the loose distribution allows a significant reduction in both the amount of waste (up to 84%) and the potential impacts, compared to the sale of traditional single-use bag-in-box packages. Finally, the loose distribution of rice permits a reduction in both waste generation (up to 86%) and most of the potential impacts. In particular, the impact reduction is higher when the reference single-use packaging that is replaced includes a cartonboard box. *Integr Environ Assess Manag* 2016;12:445–458.

Keywords: Waste prevention, Life cycle assessment, Loose products, Food distribution

INTRODUCTION

The European Waste Framework Directive 2008/98/EC (EU 2008) sets waste prevention at the top level of its waste management hierarchy. Preventing waste means reducing the amount and hazardous content of waste, along with reducing its impacts on the environment and human health (EU 2008, article 3). In accordance with the Directive, Italy has recently adopted a national waste prevention program (Ministero dell'Ambiente e della Tutela del Territorio del Mare 2013). This document sets specific waste reduction targets for the year 2020 and identifies waste prevention measures for specific categories of waste. Among the measures targeting packaging waste, the distribution of loose dry food products (generally referred to as "loose distribution") is included. According to this practice, consumers withdraw the desired amount of food products directly from gravity bin dispensers available at retail stores, by means of lightweight disposable bags. Because the risk of overpurchasing is reduced, this practice is sometimes also perceived as a measure to prevent food waste at the domestic level. However, the focus here is only on packaging waste prevention, while the food waste issue is excluded.

The present study compares the loose distribution of dry pasta, breakfast cereals, and rice with the traditional method of distribution. These products are selected because of their high consumption rate in Italy, compared to other foods that can also be distributed as loose. The actual effectiveness of this waste prevention measure in reducing the environmental and human health impacts was evaluated by a life cycle assessment (LCA) study. In fact, the reduction in waste generation alone may not allow for a reduction of the potential environmental impacts.

Other packaging waste prevention measures concerning drinking water consumption and the distribution of liquid detergents were recently evaluated with a similar approach (Nessi et al. 2012, 2014). In Nessi et al. (2012), the substitution of single-use plastic bottles by refillable bottles

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or by the consumption of public network water was analyzed. Nessi et al. (2014) examined the distribution of loose liquid detergents through self-dispensing systems instead of through single-use plastic containers. Both studies demonstrated that the ultimate environmental convenience of a prevention activity can depend on different variables. These variables frequently depict the way the activity is actually implemented by citizens and other involved actors such as institutions and retailers. Examples of such variables are the frequency with which the container used to withdraw tap water is washed in the dishwasher, the distance travelled by car to reach public fountains, the volume of water withdrawn at the fountains, and the number of uses of refillable detergent containers.

Another recent study on the environmental impacts of waste prevention activities is reported in Cleary (2013), who investigated different packaging alternatives to conventional single-use glass bottles for wine and spirits distribution to the citizens of Toronto, Canada. In this case, the assessment was carried out both at the level of the single packages and at the municipal scale, considering the actual consumption of the different types and sizes of packages in Toronto.

MATERIALS AND METHODS

The aim of the present study was to evaluate the effectiveness of the loose distribution of pasta, breakfast cereals, and rice in reducing environmental impacts, compared to the traditional distribution method based on single-use packages. Therefore, baseline scenarios, in which traditional single-use packages are used, were compared to waste prevention scenarios in which the product is distributed loose by means of gravity bin dispensers. In the *Analyzed scenarios* section, the considered scenarios are described in detail. In the *System description* section, a brief description of the 2 alternative distribution systems is provided. In the *Scope definition* section, the functional unit, the system boundary, the time and geographical scope, the impact categories, the characterization method, and the software used in this study are indicated. Finally, in the *Modeling of scenarios* section, a description of the modeling of processes included in the system boundary is provided.

Analyzed scenarios

Dry pasta. For the distribution of pasta with single-use packages, 6 baseline scenarios were considered, based on the most common types of packaging used in the Italian market (Table 1). They differ in the material and in the size of the primary packaging.

Three waste prevention scenarios, based on the loose distribution model, were considered: 1-kg bag, 3-kg bag, and 5-kg bag (Table 1). The first 2 scenarios were defined with reference to the experiences of loose distribution currently implemented by 2 Italian supermarket chains. The 5-kg bag scenario is a hypothetically improved scenario, based on a bigger primary packaging used to fill dispensers. This scenario was chosen for the present study with the aim of reducing impacts. In each waste prevention scenario, the purchase of both 500 g and 1 kg of pasta were considered separately. These amounts coincide with the sizes of the single-use primary packages used in the baseline scenarios.

Breakfast cereals. In the Italian market, cereals are usually sold in "bag-in-box" packages, that is, single-use packages made of a high-density polyethylene (HDPE) bag placed inside a cartonboard box. The most common sizes are 300, 375, and 500 g. The largest size available (960 g) was also considered in this study. These 4 baseline scenarios were analyzed (Table 2).

For the loose distribution, a waste prevention scenario (10-kg sack), defined with reference to the experience of loose distribution implemented by an Italian supermarket chain, was

Table 1. Baseline and waste prevention scenarios analyzed in this study for the distribution of pasta

Scenario		Primary packaging[a]	Size of the primary packaging	Transport packaging	Bag for purchase of loose product	Amount of pasta withdrawn from dispensers
Baseline	500-g pillow bag	PP pillow bag	500 g	Corrugated cardboard box	—	—
	1-kg pillow bag		1 kg		—	—
	500-g dsb bag	PP dsb bag	500 g	Wooden pallet	—	—
	1-kg dsb bag		1 kg		—	—
	500-g box	Cartonboard box	500 g	LLDPE stretch film	—	—
	1-kg box		1 kg		—	—
Prevention	1-kg bag	PP pillow bag	1 kg	Corrugated cardboard box	LDPE bag	500 g
						1 kg
	3-kg bag	PP pillow bag	3 kg	Wooden pallet	Cellulose bag	500 g
						1 kg
	5-kg bag	LDPE pillow bag	5 kg	LLDPE stretch film	LDPE bag	500 g
						1 kg

dsb = double square bottom; LDPE = low-density polyethylene; LLDPE = linear low-density polyethylene; PP = polypropylene.
[a]In the waste prevention scenarios, the primary packaging is used for filling dispensers at the points of sale.

Table 2. Baseline and waste prevention scenarios analyzed in this study for the distribution of breakfast cereals

Scenario		Primary packaging	Size of primary packaging	Transport packaging	Bag for purchase of loose product	Amount of cereals withdrawn from dispensers
	300-g bag-in-box		300 g	Corrugated cardboard box	—	—
Baseline	375-g bag-in-box	HDPE bag placed inside a cartonboard box	375 g	Wooden pallet	—	—
	500-g bag-in-box		500 g		—	—
	960-g bag-in-box		960 g	LLDPE stretch film	—	—
Prevention	10-kg sack	Paper sack	10 kg	Wooden pallet LLDPE stretch film	LDPE bag	300 g 375 g 500 g 960 g

HDPE = high-density polyethylene; LDPE = low-density polyethylene; LLDPE = linear low-density polyethylene

considered (Table 2). In this scenario, where a 10-kg sack is used to fill dispensers, the purchase of 300, 375, 500, and 960 g of cereals were considered separately because these amounts coincide with the sizes of the primary packaging used in the baseline scenarios.

Rice. For the distribution of rice, 8 baseline scenarios were considered, based on the most common types of single-use packaging used for distribution in the Italian market. Such scenarios differ in the material and in the size of primary and transport packages (Table 3).

For the loose distribution, the 2-kg bag waste prevention scenario, currently implemented by 1 Italian supermarket chain, was first considered. In addition, 2 hypothetically improved scenarios that adopt larger primary packaging for filling dispensers (5-kg bag and 25-kg sack) were considered (Table 3). In each waste prevention scenario, the purchase of 1 kg and 2 kg of rice were considered separately.

System description

Baseline scenarios: Single-use packaging. At the manufacturing plant, after production (assumed to be identical in baseline and waste prevention scenarios and therefore not considered in the present study), pasta, breakfast cereals, and rice are first placed into single-use primary packages (plastic bags or cartonboard boxes for pasta, bag-in-box for cereals, and for rice, mixed plastic bags, possibly put inside cartonboard boxes, or only cartonboard boxes). For transportation purposes, the primary packaging is then placed inside corrugated cardboard boxes or wrapped with heat-shrink film and subsequently loaded on reusable wooden pallets. Each load unit is finally wrapped with a plastic stretch film to ensure its stability. Complete load units are transported to the distribution centers of different supermarket chains and, subsequently, to single points of sale. Films and boxes are removed and discarded during the exposure of the product, whereas empty pallets are transported back to the manufacturer and reused to build new load units. After purchase, the product is transported to the point of use: This stage is assumed identical in the baseline and waste prevention scenarios and therefore not considered. After consumption, the empty primary packaging is discarded and managed as municipal waste.

Waste prevention scenarios: Loose distribution. At the manufacturing plant, after production, pasta, breakfast cereals, and rice are first placed into primary packages, subsequently placed into transport packages (plastic bags and cardboard boxes for pasta, sacks for cereals, and plastic bags wrapped with heat-shrink film or sacks for rice) and finally loaded on pallets. Next, each load unit is wrapped with a plastic stretch film and transported to the distribution centers of different supermarket chains and then to single points of sale. Films and boxes are first removed and discarded, whereas empty pallets are transported back to the manufacturer. The primary packaging is then emptied and discarded after the filling of the dispenser. By means of a purchasing bag provided at the point of sale, the consumer can withdraw the desired amount of product directly from the gravity bin dispenser. The bag used for the purchase of the loose product is then transported to the point of use and finally discarded as municipal waste.

Scope definition

The present LCA was carried out according to the principles outlined by the International Organization for Standardization (ISO) 14040 and 14044 standards (ISO 2006a, 2006b).

The function of the compared systems is the distribution of a specific food product to a generic consumer at a large-scale retail store. Therefore, the scenarios were analyzed considering as a functional unit the distribution of 1 kg of food product (dry pasta, breakfast cereals, or rice). This unit, to which data are related, is used as a reference for the calculation of the results.

The system boundary, in both baseline and waste prevention scenarios, first includes the life cycle of the primary packaging (plastic bag, cartonboard box, or sack) and of the transport packages (cardboard box, heat-shrink film, stretch film, and pallet). The system boundary also includes the food packaging operations, the subsequent transportation of the packaged product to the point of sale, and the return trip with empty reusable pallets. In the waste prevention scenarios, the life

Table 3. Baseline and waste prevention scenarios analyzed in this study for the distribution of rice

Scenario		Primary packaging	Size of primary packaging	Transport packaging		Bag for purchase of loose product	Amount of rice withdrawn from dispensers
Baseline	1-kg bag-in-box + film	Mixed plastic bag placed inside a cartonboard box	1 kg	LDPE heat-shrink film		—	—
	2-kg bag-in-box + film		2 kg			—	—
	1-kg bag-in-box + cardboard box		1 kg	Cardboard box		—	—
	1-kg bag + film	Mixed plastic bag	1 kg	LDPE heat-shrink film	Wooden pallet	—	—
	1-kg bag + cardboard box	LDPE heat-shrink film that wraps 2 bags of 1 kg (only in 2 kg bag + cardboard box scenario)	1 kg	Corrugated cardboard box	LLDPE stretch film	—	—
	2-kg bag + cardboard box		2 kg			—	—
	1-kg cartonboard box + film	Cartonboard box	1 kg	LDPE heat-shrink film		—	—
	1-kg cartonboard box + cardboard box		1 kg	Corrugated cardboard box		—	—
Prevention	2-kg bag	LDPE pillow bag	2 kg	LDPE heat-shrink film	Wooden pallet	LDPE bag	1 kg
							2 kg
	5-kg bag	LDPE pillow bag	5 kg				1 kg
							2 kg
	25-kg sack	PP raffia sack	25 kg	—	LLDPE stretch film		1 kg
							2 kg

LDPE = low-density polyethylene; LLDPE = linear low-density polyethylene; PP = polypropylene.

cycle of the bag used for the purchase of loose products and the life cycle of gravity bin dispensers installed at the point of sale were also considered. Figure 1 shows the main processes included in the system boundary for the baseline and the waste prevention scenarios of pasta distribution. System boundaries for breakfast cereals and rice distribution are shown in Figures S1 and S2 of the Supplemental Data.

The production of pasta, breakfast cereals, or rice was excluded because it was assumed to be identical in all compared scenarios. The purchasing round trip, usually performed with a private car, was also excluded because the traveled distance was assumed to be the same in both baseline and waste prevention scenarios. Moreover, the purchase of a loose product replaces that of a single-use packaged one without affecting the purchase of other products. Finally, the life cycle of the capital goods was included in the system boundary only for the processes modeled by using already existent data sets.

With regard to the time horizon and the geographical scope, the present study evaluated the current Italian situation: Actual Italian packaging types, methods of food distribution, and waste management systems were all considered.

According to the goal of the study, the amount of waste generated in each scenario was calculated as the first indicator, including primary and transport packaging. In the waste prevention scenarios, the amount of waste also includes the dispenser and the bag used for the purchase of the loose product. Thirteen impact indicators on the environment and human health, calculated at the midpoint level, were then considered:

- climate change
- ozone depletion
- photochemical ozone formation
- acidification
- eutrophication (terrestrial, freshwater, and marine)
- freshwater ecotoxicity
- human toxicity (cancer effects and noncancer effects)
- particulate matter
- water resource depletion
- mineral and fossil resource depletion

These indicators were selected in an attempt to cover the widest range of environmental issues potentially connected to the examined activities and were calculated with the characterization methods recommended by the Joint Research Centre of the European Commission (EC 2013). For mineral and fossil resource depletion only, the characterization factors calculated on the basis of the "ultimate reserves" of resources (Van Oers et al. 2002) were used instead of the recommended

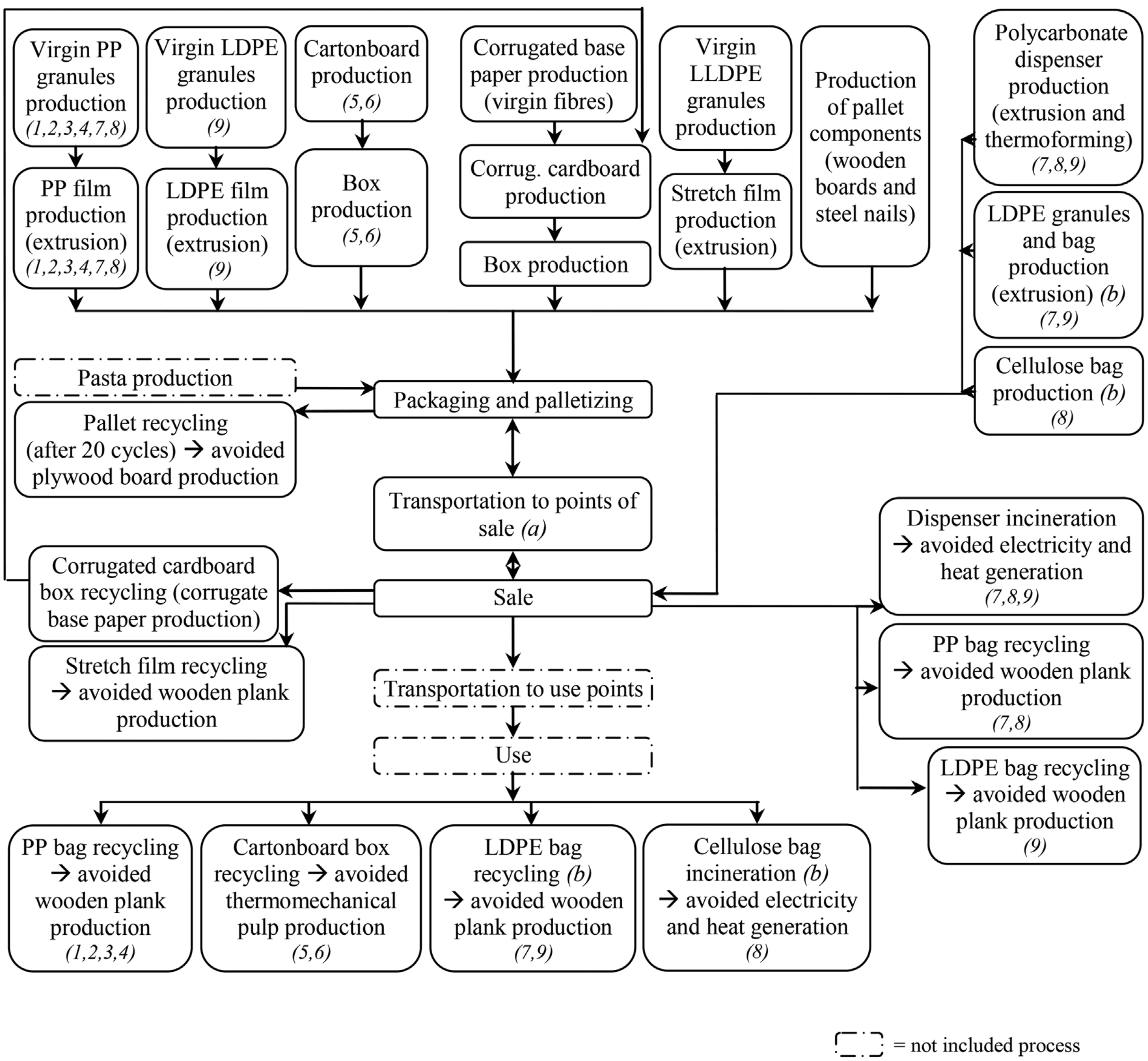

Figure 1. Main processes included in the system boundary for the analyzed baseline and waste prevention scenarios of pasta distribution. (a) Palletized items are firstly transported to distribution centers of supermarket chains. Here, new load units consisting of different products are built and subsequently transported to the single points of sale. In this study, due to the extreme variability of this stage, palletized items were assumed to be directly transported to retail outlets. (b) The bag is used for the purchase of loose pasta. (1) 500-g pillow bag baseline scenario, (2) 1-kg pillow bag baseline scenario, (3) 500-g dsb bag baseline scenario, (4) 1-kg dsb bag baseline scenario, (5) 500-g box baseline scenario, (6) 1-kg box baseline scenario, (7) 1-kg bag waste prevention scenario, (8) 3-kg bag waste prevention scenario, and (9) 5-kg bag waste prevention scenario. For each process, the numbers show the scenarios in which it is included. When no number is indicated, the process is included in all the scenarios. LDPE = low-density polyethylene; LLDPE = linear low-density polyethylene; PP = polypropylene.

factors. The recommended factors are calculated as a function of the "base reserves" of resources, and, because their estimate includes uncertainties related to considerations of the technical and economical availability of resources, their use was deemed less appropriate.

To evaluate the energy performance of the examined distribution systems, the Cumulative Energy Demand (CED) indicator was also calculated, according to the method described in Hischier et al. (2010), considering either direct or indirect (associated with the energetic content of materials) energy utilizations.

The analysis was carried out with the support of the SimaPro software (version 7.3.3, PRé Consultants, The Netherlands), which facilitated the calculation of the potential impacts. Experimental input data were considered in this study (see the *Modeling of scenarios* section); process data sources are also indicated in detail in the *Modeling of scenarios* section.

Modeling of scenarios

Primary packaging life cycle. To assess the impacts of the life cycle of each form of primary packaging, an estimate of the respective average mass per functional unit was required. For this purpose, a sample of primary packages was acquired and weighed for each baseline scenario. Each sample included both major brands and private labels and was based on market shares: A greater number of packages of the major brands was thus acquired. Overall, 230 packages were considered for pasta, 63 for cereals, and 35 for rice. For the waste prevention scenarios based on real experiences, a sample of packages used for the delivery of the product to the points of sale was collected and weighed. Conversely, for the hypothetically improved scenarios, some packages actually used for the food service were considered (5-kg sacks for pasta, 5-kg bags, and 25-kg sacks for rice). Detailed experimental input data are reported in Supplemental Data Table S1 for pasta, in Table S2 for breakfast cereals, and in Tables S3 and S4 for rice.

The production processes of the primary packages, from the extraction of raw materials to the conversion into finished products, were modeled using process data provided in the ecoinvent database (version 2.2). Primary packaging was assumed to be manufactured from virgin raw material, except for cartonboard boxes used for cereals and rice distribution, which are mainly produced by using recycled pulp, according to the information provided by the producers.

Regarding the end of life, all primary packages, excluding mixed plastic bags used in the baseline scenarios of rice distribution and sacks employed for cereals and rice distribution in the waste prevention scenarios, were assumed to be separately collected, sorted, and recycled.

The primary packages used in the baseline scenarios were all assumed to be discarded at the point of use and handled according to the waste management system implemented in northern Italy (Grosso et al. 2012). In particular, plastic bags were assumed to be collected with all other plastic waste (67% curbside collection, 33% street containers collection) and subsequently sorted to separate a mixture of polyolefins (including bags) from rigid containers. This process consumes 26.6 kWh and 84 MJ of diesel per metric ton of input plastic. With regard to cartonboard packages, 70% was assumed to be collected curbside and 30% through street containers. For their sorting, a consumption of 1.5 kWh/t input was considered (Grosso et al. 2012).

The primary packages used in the waste prevention scenarios for the filling of dispensers were instead considered to be discarded at the point of sale, collected by a private operator, and then transported for further treatment (recycling or incineration).

Recycling was modeled on the basis of data reported in Rigamonti and Grosso (2009) and Grosso et al. (2012), assuming that no material losses take place, because the considered waste flows are generally uncontaminated. In detail, plastic bags are processed down by flaking, along with other polyolefins, and are used for the manufacturing of plastic lumber profiled bars, which replace wooden planks with a 1:1 substitution ratio. For this process, the consumption of electricity (429 kWh/t polyolefins), methane (390 MJ/t polyolefins), and water (1068 L/t polyolefins) was considered. Cartonboard boxes are instead recycled for the production of secondary pulp, which substitutes for virgin thermomechanical pulp. Considering the degradation of fiber quality during the recycling process, a 1:0.833 substitution ratio was assumed (Rigamonti et al. 2009). The consumption of electricity (200 kWh/t cartonboard) and diesel (17.9 MJ/t cartonboard) was considered.

Mixed plastic bags, employed in 6 of the baseline scenarios of rice distribution, were assumed to be incinerated in a waste-to-energy plant. Consumed reagents, airborne emissions, and the generation of solid residues (bottom and fly ash) were calculated according to the bag composition (low-density polyethylene [LDPE] and nylon, defined on the basis of information given by a producer) and data provided in Turconi et al. (2011) related to a waste-to-energy plant in northern Italy. Bottom ash was assumed to be used as material for road substrate. Fly ash is made inert and disposed of in salt mines in Germany. The energy recovery was also considered, including the avoided burdens associated with the electricity production through the Italian mix and the thermal energy generation from methane boilers. The same end of life was assumed for raffia sacks used in 1 of the 3 scenarios of loose rice distribution. Finally, the sack employed in the waste prevention scenario of cereals distribution, made of an outer layer of bleached paper and an inner layer of LDPE-coated unbleached paper, was assumed to be recycled with the production of secondary pulp, which substitutes virgin wood pulp. The residues of the recycling process (plastic scraps) are subsequently incinerated.

Transport packaging life cycle. For the transportation of the primary packages, corrugated cardboard boxes or bundles of LDPE heat-shrink film are usually used. The boxes, the bundles, or the primary packaging itself (if boxes or bundles are not used) are placed on a pallet. Finally, a linear low-density polyethylene (LLDPE) stretch film wraps up the pallet load. Some boxes or bundles were acquired and weighed to estimate the mass of each material per functional unit for each scenario in which they are used. Experimental input data are reported in Supplemental Data Tables S1, S2, S3, and S4.

Corrugated cardboard boxes were assumed to be manufactured from secondary pulp, based on the information given by the producers. With regard to the end of life, the boxes were considered to be discarded at the point of sale, collected by a private operator, and then totally recycled to produce corrugated board base paper. Process data on the production and the recycling of the boxes were derived from the ecoinvent database.

At the end of their useful life, heat-shrink films for bundles, manufactured from virgin granules, were assumed to be discarded at the point of sale, collected, and recycled for the production of profiled bars to be used instead of wooden planks. The production process was modeled considering the process data provided in the ecoinvent database, whereas the modeling of the recycling was based on data reported in Rigamonti and Grosso (2009) and Grosso et al. (2012), as described for the plastic primary packaging.

In all the considered scenarios, wooden EUR-Epal pallets are employed for the transportation of the packaged product to the point of sale. This type of pallet, made of sawn timber boards and particle blocks, is the most common type according to Creazza and Dallari (2007). For each item for which the composition of the load unit (number of boxes, bundles, or sacks for pallet) was known, the amount of pallet per functional unit was calculated by dividing the mass of the pallet by the net weight of the load unit. In this calculation, each pallet was assumed to be used for 20 transportation cycles before being discarded, according to Creazza and Dallari (2007). At the end of its useful life, the wood was assumed to be ground (with a consumption of 33.5 kWh/t) and used for the manufacturing of particle boards, which substitute for plywood boards from virgin raw material. A 1:0.6 substitution ratio was assumed, based on the lower mechanical flexion strength of particle boards with respect to plywood boards (Rigamonti and Grosso 2009). Because pallets sent to recycling are generally uncontaminated, no material losses were considered in this process. The production of pallet components and the end of life of the wood were modeled on the basis of process data reported in the ecoinvent database.

Finally, regarding the stretch film employed to wrap up the pallet load, the amount needed per functional unit was calculated considering the information given by a producer of stretch-wrapping robots and the average height of the load units. Its life cycle was modeled as described for the heat-shrink film.

Packaging operations. For each analyzed scenario, the operations carried out for pasta, cereals, or rice packaging were modeled on the basis of features of the machinery most typically used for this purpose. In particular, electricity consumption was estimated for the entire packaging line. The production, transmission, and transformation of the electricity were inventoried on the basis of data provided in the ecoinvent database for the Italian energy mix.

Transportation to points of sale. For both distribution systems, after the packaging operations, the load unit is transported to the points of sale of the large-scale retailer. Pasta and cereals were assumed to be transported by trucks along a haul equal to the average distance, weighted on the basis of market shares, between the packaging plants of all the brands considered in the study and the city of Milan, the most important business center of northern Italy with a central position in this region. The estimated distance, equal to 550 km for pasta and 800 km for cereals, was considered for both baseline and waste prevention scenarios, because the same producers can provide both packaged and loose products. In this way, the results of the comparison are not dependent on the distance between the packaging plant and the point of sale. For rice, because recent market shares were not available, the average distance between the packaging plants and the city of Milan was not weighted and resulted 90 km. This value was used in both baseline and waste prevention scenarios. Process data regarding the transportation stage with a truck (average gross weight > 16 t) were derived from the ecoinvent database.

Product sale and purchase. In the waste prevention scenarios, gravity bin dispensers are used for the distribution of the loose product. The impacts associated with the life cycle of the main components of the dispenser (made of polycarbonate) were therefore taken into account. The dispenser was assumed to be filled 3 times per week with 10.6 kg of pasta, 5.0 kg of cereals, or 17.7 kg of rice. These masses were calculated on the basis of the volume of the dispenser used in one of the examined experiences of loose distribution and an estimate of pasta, cereals, and rice density (kg of product/m^3). The estimated useful life of the dispenser is 10 y. Its production process (thermoforming) was modeled considering process data provided in the ecoinvent database. At the end of its useful life, the dispenser was assumed to be incinerated. This process was modeled as described for the plastic primary packaging.

In the waste prevention scenarios, a bag available at the points of sale is used for the purchase of the loose product. Based on the actual practice of the examined points of sale, excluding the 3-kg bag scenario (purchase of loose pasta with cellulose bags), LDPE bags are used in all actual cases of loose distribution. The use of LDPE bags, which are more common

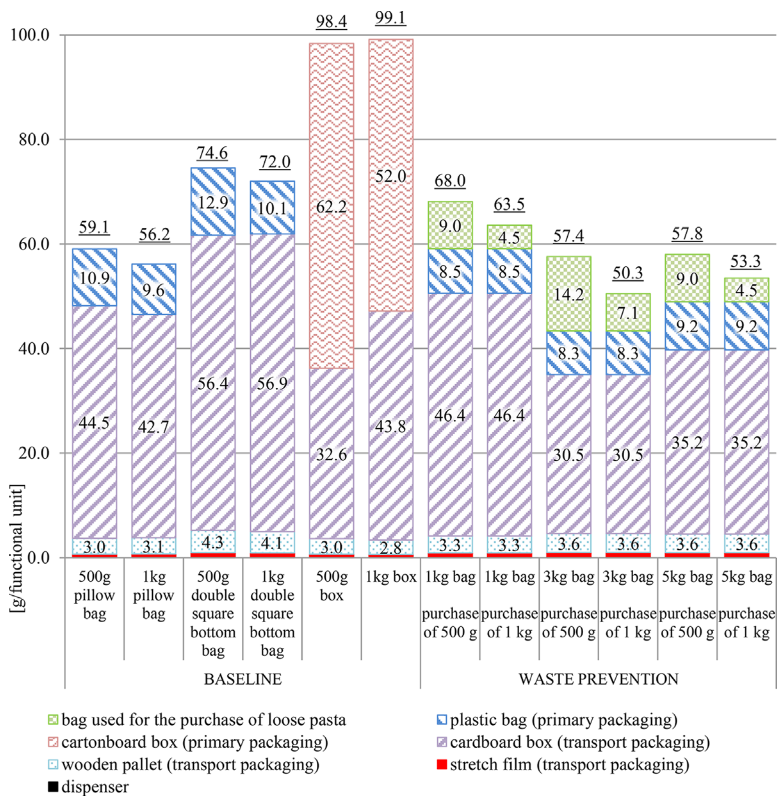

Figure 2. Waste generated per functional unit for pasta distribution. For each scenario, the total amount and the subdivision among the types of packaging are indicated.

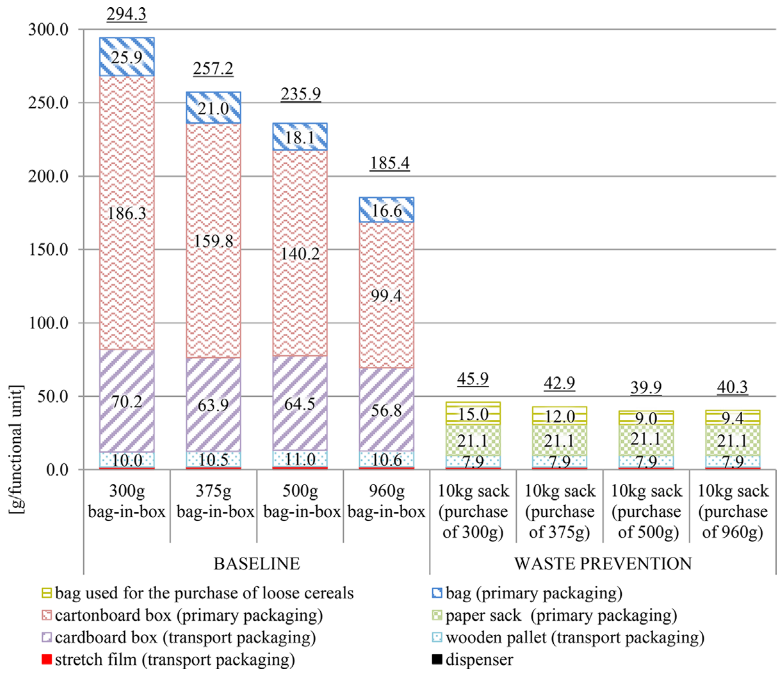

Figure 3. Waste generated per functional unit for breakfast cereals distribution. For each scenario, the total amount and the subdivision among the types of packaging are indicated.

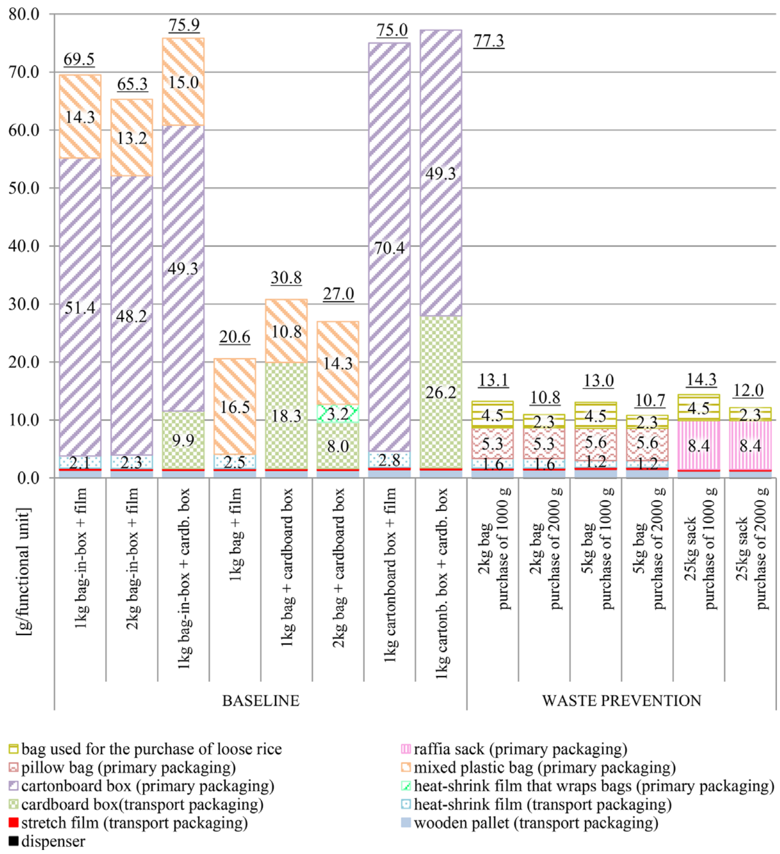

Figure 4. Waste generated per functional unit for rice distribution. For each scenario, the total amount and the subdivision among the types of packaging are indicated.

than cellulose bags, was also considered for the hypothetically improved scenarios. For both types of bag, produced by using virgin raw materials, some items were acquired and weighed. Process data regarding their production were derived from the ecoinvent database. At the end of their useful life, LDPE bags were assumed to be separately collected, sorted, and recycled for the manufacturing of profiled bars, as described for the plastic primary packaging. Cellulose bags, which are not mechanically recyclable according to the information given by the producer, were instead assumed to be incinerated.

RESULTS AND DISCUSSION

Waste generation

As explained in the *Scope definition* section, the waste generation indicator includes the primary and transport packages, as well as the dispenser and the bag used for the purchase of the loose product in the waste prevention scenarios. The waste generated during the production, transformation, and transportation of materials and goods was not included.

Dry pasta. The amount of waste generated per functional unit (FU) in each scenario of pasta distribution is represented in Figure 2. The distribution of loose pasta does not always imply a smaller amount of waste than the one based on single-use packages. In fact, the 1-kg bag waste prevention scenario implies an increase in waste (+13.0% equal to +7.3 g/FU) with respect to the best baseline scenario (1-kg pillow bag). The same type of primary and transport packaging is indeed used in the 1-kg bag waste prevention scenario and in the baseline scenarios with pillow bags, but the waste prevention scenario also includes the additional contribution of the bag for the purchase of loose pasta. Conversely, in the other waste prevention scenarios, the waste per functional unit is less than in the best baseline scenarios, even including the contribution of the purchasing bag, but the reduction is never larger than 10%. Finally, in all the prevention scenarios, the loose distribution of pasta allows a reduction in waste when compared to the traditional distribution by double square-bottom bags and by cartonboard boxes. Focusing on the waste prevention scenario with the least generated waste (3-kg bag), the maximum reduction takes place with respect to the 1-kg box baseline scenario (–49.2% equal to –48.8 g/FU). However, this benefit is only slightly higher than the benefit achieved with the best baseline scenario (1-kg pillow bag), which is 43.4% (–43.0 g/FU).

Table 4. Percentage change of potential impacts in waste prevention scenarios of pasta distribution compared to the baseline one with the lowest impact for all categories: 1-kg pillow bag[a]

Impact category		1-kg pillow bag (baseline scenario) impacts	Impact change (%) 1-kg bag (waste prevention scenario) purchase of 1 kg	3-kg bag (waste prevention scenario) purchase of 1 kg	5-kg bag (waste prevention scenario) purchase of 1 kg
Climate change	kg CO_2 eq/FU	0.173	10.0%	–1.7%	3.4%
Ozone depletion	kg CFC-11 eq/FU	2.02E–08	5.8%	–4.9%	–0.9%
Photochemical ozone formation	kg NMVOC eq/FU	1.11E–03	5.5%	–1.6%	3.6%
Acidification	molc H^+ eq/FU	1.01E–03	7.7%	–1.7%	4.3%
Terrestrial eutrophication	molc N eq/FU	3.93E–03	4.1%	–1.6%	0.7%
Freshwater eutrophication	kg P eq/FU	3.46E–05	10.7%	–9.0%	–6.3%
Marine eutrophication	kg N eq/FU	3.96E–04	4.6%	–3.0%	–1.0%
Freshwater ecotoxicity	CTUe/FU	0.225	13.3%	–8.5%	7.1%
Human toxicity (cancer effects)	CTUh/FU	8.77E–09	8.9%	–3.0%	5.9%
Human toxicity (noncancer effects)	CTUh/FU	1.82E–08	7.5%	–8.1%	–9.5%
Particulate matter	kg $PM_{2.5}$ eq/FU	8.51E–05	10.8%	14.7%	5.6%
Water resource depletion	m^3 water eq/FU	5.28E–04	17.8%	8.6%	11.4%
Mineral and fossil resource depletion	kg Sb eq/FU	5.83E–04	12.7%	–8.6%	8.0%
Cumulative Energy Demand	MJ eq/FU	3.55	12.2%	–2.3%	6.8%

CFC = Chlorofluorocarbon; CTUe = Comparative toxic unit for ecosystems; CTUh = Comparative toxic unit for humans; FU = functional unit; PM = Particulate matter; MJ = Megajoule; NMVOC = Non-methane volatile organic compounds.
[a]The comparison refers to the purchase of the same amount of pasta.

Breakfast cereals. The amount of waste generated per functional unit in each scenario of cereals distribution is shown in Figure 3. In the waste prevention scenario, the amount of waste generated by primary and transport packages is constant, while the contribution of the purchasing bag per functional unit varies depending on the amount of product purchased loose (300, 375, 500, or 960 g). The purchase of 500 g produces the lowest amount of waste simply because 2 bags are required when buying 960 g. Compared to the baseline scenarios, the loose distribution of cereals allows a waste reduction up to 84.4% (–248.4 g/FU) for the purchase of 300 g. The reductions are also substantial when considering the purchase of 375, 500, and 960 g.

Rice. Figure 4 shows the amount of waste generated per functional unit in each scenario of rice distribution. All the waste prevention scenarios show a lower amount of waste with respect to all baseline scenarios: The reduction is always larger than 30%. Such a waste reduction is greater than 80% when compared to the worst baseline scenario (1-kg cartonboard box + cardboard box for the purchase of 1-kg and 2-kg bag-in-box + film for the purchase of 2 kg). In general, the highest reductions are achieved with respect to the baseline scenarios that include a cartonboard box as primary packaging.

Life cycle impact assessment results

Supplemental Data Tables S5, S6, and S7 show the potential environmental impacts of all scenarios. In the comparison, impact differences lower than 10% were not considered significant because of LCA uncertainties.

Dry pasta. The results for dry pasta show a reduced difference between the impacts of the baseline scenarios with pillow bags as primary packaging and the impacts of the waste prevention scenarios. This is due to the characteristics of the used primary and transport packages that are similar in type and mass per functional unit. As an example, a 1-kg pillow bag (i.e., the baseline scenario with the lowest impact for all the considered indicators) was compared to each waste prevention scenario (1-kg bag, 3-kg bag, 5-kg bag with the purchase of 1 kg; Table 4). Under the condition that impact differences lower than 10% were not considered significant, scenarios resulted comparable for the majority of the indicators. The comparison also shows that the hypothetically improved 5-kg bag waste prevention scenario does not allow larger reductions than the real scenarios. Similar results were obtained when considering the purchase of 0.5 kg. The contribution analysis (Figures 5a and 5c) shows a very similar profile. Similar packages cause, in fact, very similar impacts; in both scenarios,

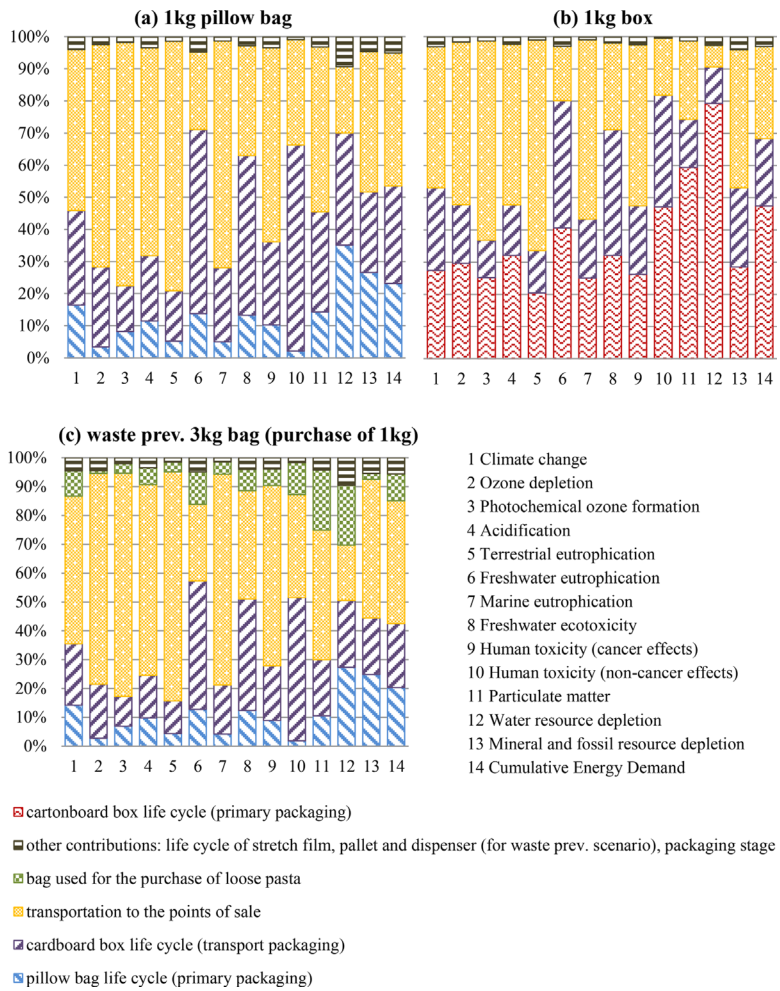

Figure 5. Contributions to the total impact, for the 14 examined indicators, of the scenarios for pasta distribution. 1-kg pillow bag (**a**); 1-kg box (**b**); waste prevention 3-kg bag (**c**).

Table 5. Percentage change of potential impacts in waste prevention scenario of cereals distribution compared to the baseline ones[a]

Impact category	300-g bag-in-box vs 10-kg sack purchase of 300 g	375-g bag-in-box vs 10-kg sack purchase of 375 g	500-g bag-in-box vs 10-kg sack purchase of 500 g	960-g bag-in-box vs 10-kg sack purchase of 960 g
Climate change	–66.0%	–64.1%	–63.2%	–55.9%
Ozone depletion	–63.2%	–60.9%	–59.0%	–51.5%
Photochemical ozone formation	–51.4%	–49.9%	–48.6%	–41.1%
Acidification	–58.3%	–56.4%	–55.1%	–47.3%
Terrestrial eutrophication	–49.3%	–47.8%	–46.3%	–39.2%
Freshwater eutrophication	–83.1%	–81.8%	–81.2%	–76.2%
Marine eutrophication	–54.6%	–52.8%	–51.3%	–44.2%
Freshwater ecotoxicity	–73.0%	–71.5%	–71.3%	–65.0%
Human toxicity (cancer effects)	–60.9%	–58.6%	–57.5%	–49.8%
Human toxicity (noncancer effects)	–79.2%	–77.2%	–76.0%	–70.8%
Particulate matter	–63.8%	–62.0%	–60.4%	–51.7%
Water resource depletion	–66.9%	–64.7%	–63.9%	–54.5%
Mineral and fossil resource depletion	–63.2%	–61.8%	–61.6%	–54.3%
Cumulative Energy Demand	–67.1%	–65.4%	–64.8%	–57.2%

[a]The comparison refers to the purchase of the same amount of cereals.

the transportation to the point of sale causes the highest contribution for 10 of the 14 examined indicators. For freshwater eutrophication, freshwater ecotoxicity, and human toxicity (noncancer effects), most of the impact is because of the cardboard-box life cycle, whereas for water resource depletion, the contribution of the pillow-bag life cycle was significant.

Impact reductions are much larger when the waste prevention scenarios are compared to the baseline scenarios with cartonboard boxes as primary packaging. For instance, waste prevention scenarios were compared with the 1-kg box baseline scenario, considering the purchase of the same amount of pasta. Excluding 1-kg bag and 5-kg bag scenarios for the mineral and fossil resource depletion, all the waste prevention scenarios are preferable for all the calculated indicators. In particular, the following reductions were observed: From 5.9% to 63.2% for the 1-kg bag scenario, from 12.5% to 66.0% for the 3-kg bag scenario, and from 11.9% to 65.1% for the 5-kg bag scenario. However, these benefits are comparable to that achievable with the best baseline scenario (1-kg pillow bag). The 1-kg pillow bag scenario, when compared to the 1-kg box scenario, allows, in fact, an impact reduction for all the categories, ranging from 4.3% to 68.7%.

The contribution analysis shows that in the baseline scenarios with a cartonboard box as primary packaging, its life cycle causes the highest impact for 5 (1-kg box, Figure 5b) or 8 indicators (500-g box). Cartonboard boxes have, in fact, a mass per functional unit 5 times higher than plastic bags. As can be inferred from Figure 5, the packaging operations and the life cycle of the stretch film, the pallet, and the dispenser (only for waste prevention scenarios) have a reduced contribution to the impacts.

Breakfast cereals. Considering the purchase of the same amount of cereals, loose distribution is preferable to that based on single-use packages for all the examined indicators (Table 5). The impact indicators with the largest benefits are freshwater eutrophication and human toxicity (noncancer effects). The lowest reductions, although higher than 39%, are instead observed for the terrestrial eutrophication indicator. The reductions are associated mainly with the change in packaging, as shown in the contribution analysis results (Figure 6). The life cycle of the bag-in-box and of the corrugated cardboard boxes (employed only in baseline scenarios) makes important contributions to the impacts. These packages have, in fact, a mass per functional unit 1 order of magnitude higher than the paper sack in the waste prevention scenario: For the 375-g bag-in-box scenario (Figure 6), the cartonboard box (containing the HDPE bag) causes the highest impact for 10 of the examined indicators.

For the waste prevention scenario, the transportation to the point of sale has the highest burden for all the examined indicators, excluding water resource depletion, for which a relevant contribution of the sack paper production is observed.

Rice. For all the examined impact indicators excluding ozone depletion, all the waste prevention scenarios are preferable to all the baseline scenarios (Table S7). In Table 6, each waste prevention scenario, when purchasing 1 kg, was compared to the baseline 1-kg bag + cardboard box scenario (the best for 10 categories). The comparison shows that the hypothetically

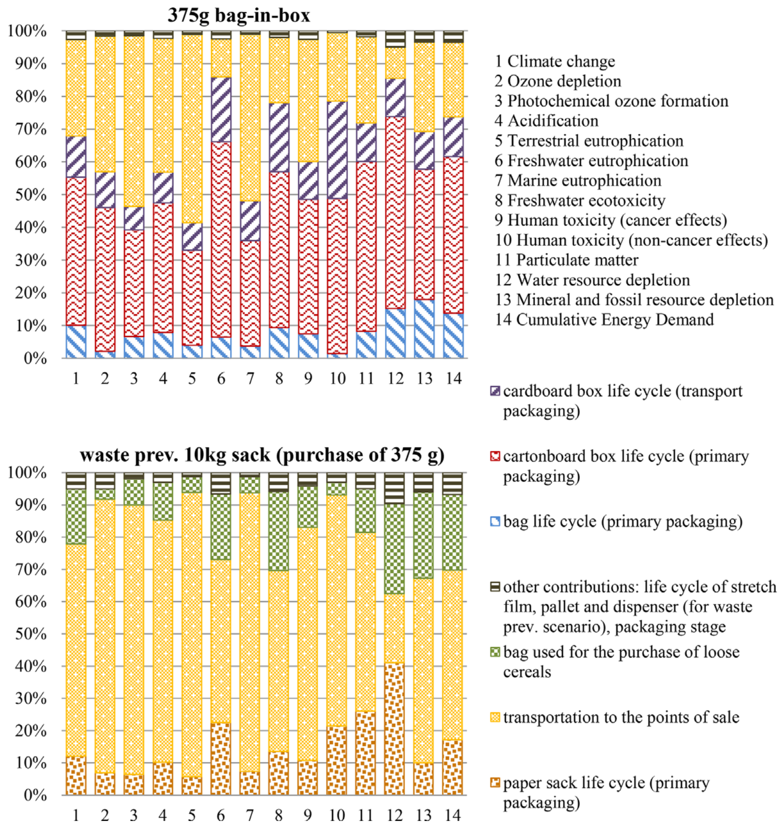

Figure 6. Contributions to the total impact, for the 14 examined indicators, for 375-g bag-in-box and 10-kg sack scenarios of breakfast cereals distribution.

improved 5-kg bag and 25-kg sack waste prevention scenarios allow larger impact reductions than the actual bag (2-kg bag scenario).

Moreover, in the comparison between each waste prevention scenario and the 1-kg bag-in-box + film scenario (the most common in the Italian market), all the waste prevention scenarios produce preferable results, for the 14 impact indicators, with a reduction ranging from 53% to more than 86%.

For the distribution of 2 kg of rice, all the waste prevention scenarios are preferable to the best baseline scenario (2-kg bag + cardboard box) for all the impact categories excluding the 2-kg bag and 5-kg bag scenarios for ozone depletion. In particular, the environmental benefits range from 34.9% (mineral and fossil resource depletion) to 63.0% (human toxicity, noncancer effects) for the 2-kg bag scenario; from 42.1% (mineral and fossil resource depletion) to 69.1% (human toxicity, noncancer effects) for the 5-kg bag scenario; and from 35.6% (ozone depletion) to 66.7% (freshwater ecotoxicity) for the 25-kg sack scenario.

In general, the impact reductions are larger when the waste prevention scenarios are compared to the baseline scenarios with a primary packaging including a cartonboard box (regardless of whether it contains a plastic bag). The mass per functional unit of the box is indeed 1 order of magnitude higher than that of the primary packaging of the waste prevention scenarios. Accordingly, the contribution to the impacts of the cartonboard box ranges from 39% to 83% if containing a plastic bag or from 51% to 91% if not containing a bag.

For rice, the contribution to the impacts of the transportation to the point of sale is less important than in case of pasta and cereals distribution due to the shorter distance. The burden of the packaging stage is instead more important especially for the scenarios in which vacuum packaging machines or heat-shrinking packers are used, due to their high electricity consumption.

CONCLUSIONS

The present study allows us to understand the importance of LCA methodology in verifying the actual effectiveness of a waste prevention measure in reducing both waste generation and impacts on the environment and human health. Only after a positive confirmation from a study such as this, can the implementation of a waste prevention activity be encouraged and supported. Subjective feelings about the goodness of an action should be put aside in favor of the results of a scientific study.

The comparison between the traditional and the loose distribution of dry food products shows that the latter is not necessarily the most environmentally friendly. The results are significantly different for dry pasta, breakfast cereals, and rice and depend on how the traditional and the loose distributions are implemented. If the size and the material of the packages are very similar, as for pasta plastic bags, the loose distribution will hardly permit waste and impact reductions and can even cause an increase in waste generation (up to 15%) and in potential impacts. Nevertheless, it is hard to suppose the use of bigger pasta bags for filling dispensers: The 5-kg bag (considered in the hypothetically improved 5-kg bag scenario)

Table 6. Percentage change of potential impacts in waste prevention scenarios of rice distribution compared to the baseline 1-kg bag + cardboard box[a]

Impact category		1-kg bag + cardboard box impacts (baseline scenario)	Impact change (%) (waste prevention scenarios)		
			2-kg bag purchase of 1 kg	5-kg bag purchase of 1 kg	25-kg sack purchase of 1 kg
Climate change	kg CO_2 eq/FU	0.110	–44.0%	–51.6%	–42.7%
Ozone depletion	kg CFC-11 eq/FU	3.69E–09	12.9%	–5.7%[b]	–55.3%
Photochemical ozone formation	kg NMVOC eq/FU	3.95E–04	–27.5%	–33.1%	–35.8%
Acidification	molc H+ eq/FU	4.53E–04	–27.0%	–37.5%	–44.2%
Terrestrial eutrophication	molc N eq/FU	1.26E–03	–34.2%	–39.9%	–42.0%
Freshwater eutrophication	kg P eq/FU	1.72E–05	–40.9%	–54.4%	–56.1%
Marine eutrophication	kg N eq/FU	1.38E–04	–44.2%	–49.2%	–51.0%
Freshwater ecotoxicity	CTUe/FU	0.143	–47.2%	–51.9%	–56.6%
Human toxicity (cancer effects)	CTUh/FU	4.17E–09	–32.4%	–40.6%	–45.8%
Human toxicity (noncancer effects)	CTUh/FU	7.09E–09	–74.2%	–78.2%	–75.2%
Particulate matter	kg $PM_{2.5}$ eq/FU	4.63E–05	–37.4%	–44.5%	–48.0%
Water resource depletion	m^3 water eq/FU	4.03E–04	–19.3%	–31.2%	–36.5%
Mineral and fossil resource depletion	kg Sb eq/FU	2.86E–04	–6.9%[b]	–15.7%	–24.8%
Cumulative Energy Demand	MJ eq/FU	1.80	–17.3%	–25.3%	–29.9%

CFC = Chlorofluorocarbon; CTUe = Comparative toxic unit for ecosystems; CTUh = Comparative toxic unit for humans; FU = functional unit; PM = Particulate matter; MJ = Megajoule; NMVOC = Non-methane volatile organic compounds.
[a]The comparison refers to the purchase of the same amount of rice.
[b]Lower than 10% and therefore not significant.

is already very large (70 cm × 35 cm), and its management at the point of sale is difficult. This suggests that the loose distribution of pasta can provide benefits only when applied in substitution of single-use cartonboard boxes: In this case, the loose distribution allows for a 50% waste reduction and a decrease in almost all potential impacts.

If dispensers are filled with much bigger packages that are made of different materials with respect to the primary packaging used in the baseline scenarios, the loose distribution allows for a significant reduction in both the amount of waste and potential impacts, mainly when compared to baseline scenarios with “complex” and heavy packages (i.e., bag-in-box). For example, the use of a 10-kg paper sack for filling the dispenser with breakfast cereals allows a significant reduction in both the amount of waste (up to 84%) and the potential impacts compared to the traditional sale with single-use packages (an HDPE bag placed inside a cartonboard box). Additionally, the examined loose distribution of rice permits a reduction in waste generation up to 86% and a reduction in the majority of potential impacts. However, the loose distribution of rice could raise several hygienic concerns due to possible insect infestation. For this reason, some points of sale that have sold loose rice in the past have discontinued this alternative method of distribution.

Finally, further studies could investigate the effectiveness of the examined waste prevention activity with respect to the total amount of waste generated in a certain area. Specifically, based on the market share of each baseline scenario and on the consumption rate of pasta, breakfast cereals, and rice, the total amount of waste actually connected to the traditional distribution of these products should be quantified. Subsequently, the amount of prevented waste due to the implementation of each method of loose distribution could be calculated.

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SUPPLEMENTAL DATA

Figure S1. Main processes included in the system boundary for the analyzed baseline and waste prevention scenarios of breakfast cereals distribution.

Figure S2. Main processes included in the system boundary for the analyzed baseline and waste prevention scenarios of rice distribution.

Table S1. Experimental input data employed for the modeling of pasta distribution scenarios

Table S2. Experimental input data employed for the modeling of breakfast cereals distribution scenarios

Table S3. Experimental input data employed for the modeling of rice distribution baseline scenarios

Table S4. Experimental input data employed for the modeling of rice distribution waste prevention scenarios

Table S5. Environmental potential impacts of pasta distribution

Table S6. Environmental potential impacts of cereals distribution

Table S7. Environmental potential impacts of rice distribution

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