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Environmental implications of food loss probability in packaging design

A. Conte [a], G.M. Cappelletti [b], G.M. Nicoletti [b], C. Russo [b], M.A. Del Nobile [a,*]

[a] Services Center of Applied Research, University of Foggia, Via Napoli, 25-71122 Foggia, Italy
[b] Department of Economics, University of Foggia, via R. Caggese, 1-71121 Foggia, Italy

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ABSTRACT

In this paper, a new perspective of food packaging design is proposed by using the Life Cycle Assessment (LCA) approach, in which shelf life and food loss probability were taken into account. The study focused on twenty-four scenarios of packaging of a ripened cheese obtained from sheep milk, in order to analyze the environmental implications of different packaging systems in terms of potential food loss. The aim is to provide an eco-indicator able to quantify the environmental indirect effects related to the different choices in the food packaging. Results highlighted that, by considering only the direct inputs and outputs of the packaging system, thinner and recyclable packaging materials sealed in air are more sustainable from an environmental point of view. On the contrary, if indirect effects of food loss probability are also taken into account (e.g. production and transport of cheese in order to reconstruct the stockpile), multilayer systems under modified headspace conditions are preferred packaging solutions. This is consequence of the fact that cheese production brings about high environmental impacts if compared to the other phases of the life cycle, therefore, the environmental implications of the choices adopted for the packaging phase are more affected from the capacity of reducing food losses than from the production and disposing of packaging materials.

1. Introduction

Product shelf life is defined as the period of time during which the quality of the packaged food remains acceptable. This period may range from a few days to more than one year because each category food has its specificity in quality kinetic deterioration. For this reason, the packaging must have properties to assure that the desired shelf life is not compromised (Kilkast & Subramaniam, 2000; da Cruz, Faria, & Van Dender, 2007; Del Nobile, 2001; Del Nobile, Licciardello, Scrocco, Muratore, & Zappa, 2007). There are numerous variables that can play a significant role in establishing package performance, such as the initial food quality, the processing operations, the size and shape of package. Considering the importance of packaging in determining product shelf life, the correct approach allows considering on the same level of importance the product development and its packaging system (Cleland, 1996). Packaging design has gained great importance over the last decades due to the numerous available packaging options that offer various alternatives for cost and time reduction (Rodriguez-Aguilera & Oliveira, 2009). On the other hand, it is necessary to consider that even though packaging plays an important role in food preservation (Conte, Scrocco, Brescia, & Del Nobile, 2009), it also represents an environmental issue, being considered one of the most wastes of industrialized countries. The main criteria taken into account for packaging optimization have been referred to the balance between packaging performance, in terms of shelf life, and its costs, without considering the environmental implications. Generally, materials that assure long shelf life show a higher impact on the environment (Luz, 2012; Williams, Wikström, & Löfgren, 2008). However, in the management system, packaging has been individuated as one of the nine causes able to reduce losses in the supplier–retailer interface (Mena, Adenso-Diaz, & Yurt, 2011).

In fact, the environmental assessment of food packaging focused only on the materials and their recyclability (Harding, Dennis, von Blottnitz, & Harrison, 2007), without considering the overall impacts caused by food losses (i.e. food products that cannot be distributed because expired). If the evaluation aims to investigate also the indirect environmental implications, the best packaging system should balance between the environmental impact of the package itself and the impact deriving from the potential loss of the packaged product, which in turn is strictly related to its shelf life (McMillin, 2008; Williams & Wikström, 2011). As a matter of fact, shelf life extension plays a very important role on food losses reduction by increasing the usability of food (Marsh & Bugusu, 2007) and also allowing their distribution on a larger scale (Luz, 2012). For example, the capability of the active packaging to prolong the shelf life and reduce food losses has already been widely recognized by the packaging and food industry (Williams & Wikström, 2011; Wikström & Williams, 2010). In the same context, Zhang, Hortal, and Dobón (2015) provided a link between food loss saving and the food packaging system's overall environmental performance. The authors compared the eco-profiles of beef using conventional modified atmosphere packaging (MAP) and novel MAP (active coating), demonstrating

* Corresponding author at: University of Foggia, Via Napoli, 25-71122 Foggia, Italy.
E-mail address: matteo.delnobile@unifg.it (M.A. Del Nobile).

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that using active packaging solution a substantial reduction of beef losses at the retail of market could potentially be realized and a more significant food loss reduction could be expected at household level. Nevertheless the numerous efforts to study the environmental impact of food, a real quantification of the environmental indirect effects related to the different choices in food packaging is still lacking. This is mainly due to the lack of a direct relationship between food loss probability and packaged food shelf life. In addition, it is also worth considering that in the coming years, consumer preference for fresh products ready to eat, which reduce time for preparation and cooking (Lundqvist, de Fraiture, & Molden, 2008) could further provoke an increasing amount of food losses.

LCA considers the environmental impacts of all the phases of the life cycle of a product, from raw materials through production, use and finally to waste management (Russell, Ekvall, & Baumann, 2005; Baumann & Tillman, 2004; Guinée et al., 2001). This methodology was standardized according to the ISO 14040 (2006) and ISO 14044 (2006) standards, in four steps: goals and scope definition, inventory analysis, impact assessment and interpretation (ISO 14040, 2006 and ISO 14044, 2006). Despite of the fact that LCA methodology was traditionally used to assess the environmental performance of food products (Roy et al., 2009; Schau & Fet, 2008; Mattson & Sonesson, 2003), it is also applied to study food waste and more recently the food losses (Laurent et al., 2014; Kim & Kim, 2010; Lundie & Peters, 2005).

In this study, the case of "Canestrato di Moliterno" cheese was used to simulate the effects of various packaging systems on both product shelf life and food loss probability, and performing an eco-indicator able to highlight the environmental indirect implications related to the potential food loss. In the perspective to balance convenience, protection, shelf life and environmental impact of the package (Verghese, Lewis, Lockrey, & Williams, 2013), which also account for the environmental indirect effects, the current work aims to propose a packaging design that takes into account the environmental impact of both packaging (in terms of materials and technology) and food loss, by using the Life Cycle Assessment (LCA). In particular, three different equations between food loss probability and packaged food shelf life are proposed to quantitatively determine the environmental indirect effects.

2. Materials and methods

2.1. LCA approach

According to the ISO 14040 and 14044 standards, and the guidance provided by the ILCD — International Reference Life Cycle Data System (EC-JRC — Institute for Environment and Sustainability, 2010) the LCA methodology was applied by following two approaches:

— The first one follows the rules of an *Attributional approach* (AA), in order to obtain information about the impacts of the adoption of the different packaging solutions, by considering only the phase of packaging, including the production and disposal of packaging materials.
— The second one is a new approach similar to a *Consequential approach* (CA), because it aims to gather information about the consequences of decisions in packaging choices. Despite of the fact that no large-scale change could be occurred, the CA that we used wants to investigate the environmental implications of decisions in changes of the plastic films and gaseous atmospheres. Both inside effects (production and disposal of plastic materials) and outside effects (shelf-life and food losses) were examined.

For both the approaches, the Functional unit (FU) was set at 100 g of packaged portioned sheep's milk cheese. As concerning the reference flow, for AA it was set at the amount of input and output linked to FU. As for the CA the reference flow refers not only to the input and output linked to the production, packaging and distribution of the FU, but also all flows needed to the stockpile reconstruction as consequence of food losses (production of other cheese and transport).

As for the system boundaries, the differences between the two approaches are represented in Fig. 1. In order to highlight the environmental indirect effects of the different shelf life in terms of food losses, the following assumptions were established:

— The packaging with the longest shelf life entails the lowest food loss, which was set to 8% (Lebersorger & Schneider, 2011);
— The longest shelf life is the time scale in which the supply of cheese must be guaranteed;
— Three trends over time of food losses were analyzed: sigmoid, first-order function and straight line;
— Within the settled time scale, the loss of packaged cheese with shorter shelf life entails the reconstruction of the stockpile, and so, the production and transportation of other packaged cheese.

2.2. Life cycle inventory

The life cycle inventory was performed according to the Production Regulation of the PDO "Canestrato di Moliterno" (Table 1). The geographical context is referred to the two provinces of the Basilicata region (Matera and Potenza, South of Italy), in which this production is allowed. As for the sheep breeding phase the following assumptions were considered:

- an average daily milk production per head of sheep 0.5 l;
- a period of milk production of 180 days;
- an average production of wool per sheep per year of 3 kg;
- an average production of lamb (live weight) per year of 15.75 kg.

According to the assumption listed above, an allocation procedure was performed by considering the mass; the percentages attributed to main product (milk) and co-products are the following:

- Sheep milk 83%;
- Lamb 14%;
- Wool 3%.

The co-product lamb and wool are considered as input for other processes, while manure was modeled as waste spread in the soil.

Data referred to sea salt and health products were excluded from the analysis, due to the fact they are not available from databases or scientific literature; furthermore, as for medicines, they are employed

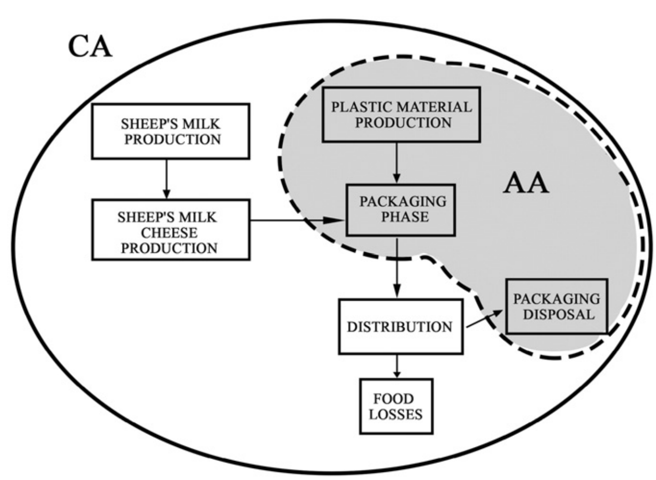

Fig. 1. System boundaries of the LCA methodology applying the two approaches, the Attributional approach (AA) and Consequential approach (CA)

Table 1
Inventory data referred to 100 g of sheep's milk cheese.

Phase	Input	Unit	Quantity	Data quality	Database	Output	Unit	Quantity	Data quality	Database
Sheep's breeding	Protein peas	kg	0.005	Primary	Ecoinvent v.2.2	Manure	kg	2.5	Primary:	Ecoinvent v.2.2
	Grain maize	kg	0.01	Primary	Ecoinvent v.2.2	Lamb	kg	0.117	Primary:	GaBi database
	Wheat	kg	0.005	Primary	Ecoinvent v.2.2	Wool	kg	0.022	Primary:	GaBi database
	Hay intensive	kg	0.06	Primary	Ecoinvent v.2.2					
	Hay extensive	kg	0.03	Primary	Ecoinvent v.2.2					
	Wheat straw extensive	kg	0.02	Primary	Ecoinvent v.2.2					
	Fava beans	kg	0.01	Primary	Ecoinvent v.2.2					
	Barley	kg	0.005	Primary	Ecoinvent v.2.2					
	Health products (antibiotic, anticoccidial, anthelmintic)	kg	0.000032	Primary	Omitted					
	Lime	kg	0.3	Primary	GaBi database					
	Electricity	kWh	0.004	Primary	GaBi database					
	Surface water	l	1.0	Primary	GaBi database					
Milking	Electricity	kWh	0.008	Primary	GaBi database	Sheep's milk	liter	0.7	Primary	GaBi database
	Water	l	0.192	Primary	GaBi database					
Cheese-making	Sheep's milk	l	0.7	Primary	GaBi database	Sheep's milk cheese "Canestrato di Moliterno" (dried)	kg	0.1	Primary	GaBi database
	Water	l	1.8	Primary	GaBi database	Whey	kg	0.028	Primary	GaBi database
	LPG	l	0.002	Primary	GaBi database	Ricotta	kg	0.02	Primary	GaBi database
	Electricity	kWh	0.007	Primary	GaBi database	Waste water	kg	1.28	Primary	GaBi database
	Rennet	kg	0.0002	Primary	GaBi database	Waste (cheese)	kg	0.012	Primary	GaBi database
	Sea salt	kg	0.003	Primary	Omitted					

in very low quantity. As for the cooled transportation of the sheep milk from the farm to dairy industry, and of the cheese from dairy company to retailer, average distance of 50 km was considered, and GaBi database was used for the calculation of the vehicle emissions (IKP and PE, 2002).

For the packaging phase four plastic films were considered:

1. HB: a multi-layer high-barrier film composed by polyethylene terephthalate (13% PET) co-extruded with polyethylene (78% PE), anti-fog treatment (9% AF), thickness: 90 μm;
2. MB: a common multi-layer film composed by polyamide (21% Nylon), polyethylene (74% PE) and ethylene vinyl acetate (5% EVA), thickness: 95 μm;
3. OPP 60: oriented polypropylene (100%), thickness: 60 μm;
4. OPP 35: oriented polypropylene (100%), thickness: 35 μm.

The energy required per FU to seal the package was:

- HB: kWh 0.008;
- MB: kWh 0.004;
- OPP 60: kWh 0.01;
- OPP 30: kWh 0.016.

For each heat-sealed bag, composed by the plastic films described above, six gaseous atmospheres were considered: air, vacuum and four modified atmospheres obtained by mixing N_2 and CO_2 at various percentage. For the production of N_2 and CO_2 information were gathered from GaBi databases. With regard to the disposal of packaging, two scenarios were considered: the multilayer systems are recovered for energy use (incineration) whereas the PP was completely recycled. As regard the avoided impacts of plastic incineration, Italian electricity mix and thermal energy from natural gas were considered. For the recycled packaging, the recycling and pelletizing processes were taken into account.

In a previous test carried out in the laboratory of the University of Foggia, the shelf life of packaged cheese was calculated on the basis of microbiological and sensory quality assessment (Costa, Lucera, Lacivita, Saccotelli, Conte, & Del Nobile, in press). Table 2 shows the 24 combinations of packaging and headspace conditions, by highlighting for each system, the relative shelf life and the indirect effects in term of food loss.

As for the quality of data, all primary data were collected by consulting local farmers and sheep's dairy industries (Table 1). As far as the secondary data, Ecoinvent database v. 2.2 was used to model information about cattle feed production and agricultural practices (Frischknecht & Jungbluth, 2007). Data referred to the production of the plastic films derived from Plastics Europe database. Also GaBi databases were employed in order to obtain data about emissions of the Italian electricity grid mix, and the production and disposal of the other resources considered in the system. In particular, as for the packaging disposal after the use-phase, according to data of National Packaging Consortium for plastic recovery (COREPLA, www.corepla.it) a percentage of 60% of the total weight was adopted for OPP35 and OPP60 recycling, while the total weight of HB and MB was considered for incineration.

2.3. Life cycle impact assessment

The software GaBi was used to model the life cycle and carrying out the impact analysis. The CML2001 was the evaluation method employed, by considering the following impact categories:

- abiotic depletion (kg sb eq);
- potential acidification (kg SO_2 eq);
- potential eutrophication (kg phosphate eq);
- potential freshwater aquatic eco-toxicity (kg DCB eq);
- potential global warming (kg CO_2 eq);
- potential human toxicity (kg DCB eq);
- potential marine aquatic eco-toxicity (kg DCB eq);
- potential ozone layer depletion (kg R11 eq);
- potential photochemical ozone creation (kg ethene eq);
- potential terrestrial eco-toxicity (kg DCB eq).

The normalization and weighting of the results were performed by using the standard values in GaBi functionalities in order to determine an eco-indicator for each scenario.

2.4. Relationship between food loss probability and shelf life

As can be inferred from Table 2, different values of shelf life were recorded, in particular, it can be highlighted that both vacuum and MAPs (Modified Atmosphere Packaging) generally improved the efficacy of each film. Thus for the systems under vacuum and MAPs higher shelf life with respect to control samples in air were found. By comparing

Table 2
Shelf life of sheep's milk "Canestrato di Moliterno" cheese with calculated Food Loss Probability (FLP) values (functional unit: 100 g of packaged cheese).

Packaging film	Headspace conditions		Shelf life (day)	FLP_1 (%) (first order)	FLP_2 (%) (sigmoid)	FLP_3 (%) (straight line)
HB	AIR		30	36.41	19.70	63.19
	VP		60	13.26	9.98	26.38
	MAP1	30%CO_2 70%N_2	60	13.26	9.98	26.38
	MAP2	50%CO_2 50%N_2	70	9.47	8.57	14.11
	MAP3	70%CO_2 30%N_2	75	8.00	8.00	7.98
	MAP4	90%CO_2 10%N_2	15	60.34	37.58	81.60
MB	AIR		25	43.09	23.47	69.33
	VP		40	26.00	14.89	50.92
	MAP1	30%CO_2 70%N_2	30	36.41	19.70	63.19
	MAP2	50%CO_2 50%N_2	40	26.00	14.89	50.92
	MAP3	70%CO_2 30%N_2	40	26.00	14.89	50.92
	MAP4	90%CO_2 10%N_2	18	54.54	31.90	77.91
OPP60	AIR		21	49.30	27.66	74.23
	VP		28	38.95	21.06	65.64
	MAP1	30%CO_2 70%N_2	28	38.95	21.06	65.64
	MAP2	50%CO_2 50%N_2	28	38.95	21.06	65.64
	MAP3	70%CO_2 30%N_2	18	54.54	31.90	77.91
	MAP4	90%CO_2 10%N_2	18	54.54	31.90	77.91
OPP35	AIR		14	62.41	39.91	82.82
	VP		18	54.54	31.90	77.91
	MAP1	30%CO_2 70%N_2	28	38.95	21.06	65.64
	MAP2	50%CO_2 50%N_2	28	38.95	21.06	65.64
	MAP3	70%CO_2 30%N_2	28	38.95	21.06	65.64
	MAP4	90%CO_2 10%N_2	18	54.54	31.90	77.91

HB: high-barrier multilayer film made up of polyethylene terephthalate, ethylene–vinyl–alcohol and polyethylene, with 90 μm thickness.
MB: medium-barrier multilayer film made up laminating a nylon layer and a polyolefin film with a thickness of 95 μm.
OPP 60 and OPP 35: oriented polypropylene film with a thickness of 60 μm and 35 μm.
AIR: atmospheric conditions, VP: vacuum packaging; MAP: modified atmosphere packaging.

the various polymeric films it can be noticed that the shelf life values increased as the barrier properties of film to gases increased (Del Nobile & Conte, 2013). The proper combination of material and headspace gas concentration to maintain the sensory characteristics of cheese was found with the most high barrier polymeric matrix under a specific MAP (30:70 CO_2:N_2) (Costa et al., in press).

The determination of the relationship between the food loss probability (FLP) and the shelf life is based on the following two hypotheses: a) the FLP is 1 if the shelf life is zero (the packaged food will be surely lost); and b) FLP goes to 0 if the shelf life goes to infinity (the packaged food will be never lost); therefore, FLP has to decrease as the shelf life increases. Unfortunately, besides the above-mentioned two hypotheses, there are very few experimental data available in the literature. The only one found is that reported by Lebersorger and Schneider (2011), where it is stated that packed food amounts to 8% by mass of avoidable food waste. Based on the above-mentioned hypothesis and on the limited experimental available data, we have proposed three different empirical equations: first order kinetic, a sigmoid and a straight line. They all span between 0 and 1, and are reported in the following:

$$FLP_1 = \exp.(-k_a \cdot SL) \tag{1}$$

$$FLP_2 = (1/(1\text{-}\exp.(-1)))\cdot(\exp(-\exp.(1/(-k_b \cdot SL)))\text{-}\exp.(-1)) \tag{2}$$

$$FLP_3 = k_c . SL \tag{3}$$

where: SL is the packaged food shelf life; and k_a, k_b, and k_c are the kinetic constants for the proposed equations: first order kinetic, sigmoid and straight line, respectively.

In order to evaluate the kinetic constants, the three proposed equations were fitted to the two available points:

FLP = 1 at SL = 0;

FLP = 0.08 at SL = 75 (the longest shelf life recorded from data in Table 2).

Results from the fitting procedure are the following:

$k_a = 3.37\ 10^{-2}\ day^{-1}$;

$k_b = 9.67\ 10^{-2}\ day^{-1}$;

$k_c = 1.23\ day^{-1}$.

The calculated kinetic constants along with the proposed equations were used to calculate the FLP for each system proposed in this work. All the FLP values are listed in Table 2. As one could expect, as the shelf life values increased, lower FLP values were recorded, regardless the equation used. Comparing FLP data from the three equations it can be possible to underline that the highest values were recorded from the straight line Eq. (3) and the lowest results were obtained from the sigmoid Eq. (2). Moreover, the range of FLP among the twenty-four systems is very marked if the Eq. (3) is considered, spanning from about 8 to over 82. On the other hand, the FLP calculated with the Eq. (2) span from a minimum of 8 to about 40, whereas the FLP values with Eq. (1) go from 8 to over 62. Therefore, considering the different effects of the various packaging solutions on cheese shelf life it is interesting to observe that more than one combination of material and headspace condition result in low FLP values.

3. Results and discussion

As reported beforehand, a new perspective of food packaging design is proposed in this work. It is based on the environmental impact of both packaging system and food loss probability. Moreover an attempt was made to relate food loss to the performance of the package in terms of shelf life.

3.1. Environmental impact evaluation: packaged food and packaging

As regard the environmental impact of the various scenarios calculated according to the LCA methodology, Table 3 shows the values of the eco-indicator for each system (PEI). Table 3 highlights that among the different plastic films, the polypropylene with thickness 35 μm exerted the best environmental performance. This is due to the low amount of plastic material needed to produce the plastic bag. Furthermore, it is a plastic material completely recyclable (Duval, 2014). On the contrary, the multi-layer films need higher quantity of different plastic materials and their recycle is not easy. Indeed, they are principally recovered for energy use (incineration) (Siracusa, Ingrao, Lo, Mbohwa, & Dalla, 2014). By analyzing the environmental performance of the different MAPs, the electricity consumption is the most relevant hotspot. The

Table 3
Packaging eco-indicators values for a functional unit of 100 g of cheese packaged under different conditions.

Packaging film	Headspace conditions	Packaging eco-indicator [PEI]
HB	AIR	3.39E-13
	VP	4.05E-13
	MAP1	4.06E-13
	MAP2	4.06E-13
	MAP3	4.06E-13
	MAP4	4.06E-13
MB	AIR	3.91E-13
	VP	4.19E-13
	MAP1	4.20E-13
	MAP2	4.20E-13
	MAP3	4.20E-13
	MAP4	4.20E-13
OPP60	AIR	1.91E-13
	VP	2.83E-13
	MAP1	2.83E-13
	MAP2	2.83E-13
	MAP3	2.83E-13
	MAP4	2.84E-13
OPP35	AIR	1.06E-13
	VP	2.36E-13
	MAP1	2.36E-13
	MAP2	2.37E-13
	MAP3	2.36E-13
	MAP4	2.37E-13

HB: high-barrier multilayer film made up of polyethylene terephthalate, ethylene–vinyl–alcohol and polyethylene, with 90 μm thickness.
MB: medium-barrier multilayer film made up laminating a nylon layer and a polyolefin film with a thickness of 95 μm.
OPP 60 and OPP 35: oriented polypropylene film with a thickness of 60 μm and 35 μm.
AIR: atmospheric conditions, VP: vacuum packaging; MAP: modified atmosphere packaging.

technologies which foresee the under vacuum-seal or the MAP require higher amount of electricity than the packaging in air. In the first case it needs to expel the air from the package, while in the case of MAP, the air must be substituted with a gas mixture. So, if vacuum or MAP are used, higher electricity is consumed than packaging in air. Therefore, in an AA perspective, because of only the packaging phase was considered, from an environmental point of view, the best combination of materials and headspace conditions is the use of polypropylene film (thickness 35 μm) without modifying the headspace atmosphere. Similarly, Banar and Cokaygil (2009) proved the best packaging for cheese by a comparative LCA between three different cheese packages (P1: completely polypropylene, P2: tin and polyethylene, and P3: carton and polyethylene). The study was carried out for production, distribution and waste disposal (100% landfill) phases. According to the assessment, the order of the packaging types based on the total magnitude of their environmental damage was P2, P1, and P3 for the production, the distribution and for the waste disposal phase, thus highlighting that when the sole material was taken into account cheese packaging containing a carton box and polyethylene inside the pack (P3 type package) damaged the environment less than packages composed of plastic or packages containing metals.

Results of indirect implications of packaging choices are reported in Table 4 where the values of the packaged food eco-indicator (PFEI) were listed for each system. In order to calculate PFEI, the impacts coming from the animal breeding and cheese production (eco-indicator: $2.10 * 10^{-12}$) and transport (eco-indicator: $5.05 * 10^{-14}$) are separately indicated. Successively, starting from the assumption that the impact of transport is referred to the system with the longest shelf life (75 days), the impact of pondered transport is calculated by multiplying the number of the transports needed to ensure the supply of cheese for a period of 75 days. Therefore, the total environmental impact of the packaged food (PFEI) is obtained by the sum of the impact of cheese production and the relative impact of the pondered transport calculated for each system. Considering the ratio between the impact of the packaged food and the total impact (PFEI and PEI), it is worth noting that the cheese production is responsible for over 80% of the total impact, due to the high amount of materials and energy in the input of the production phase than in the other phases of the analyzed life cycle. Furthermore, among the sub-phases of cheese production, the sheep breeding plays an important role with respect to the other phases (sheep breeding 86.2%, cheese-making 8.5%, transport 3.5%, milking 1.8%). In particular, the sheep breeding is principally referred to the feed production. The total environmental impact of the sheep feed is affected by the production of forage (hay intensive, over 40%), fava beans (15%), grain maize (almost 10%), protein peas (over 7%), hay extensive (7%), wheat (6%), barley (over 5%), and wheat straw (almost 4%). The environmental impact of electricity consumption and use of lime for sanitary use is negligible. As regard the cheese making, the contribution of the electricity consumption is almost 60% of the total environmental impact, while the LPG consumption contributes to over 20%; the use of tap water entails almost 10% of the total impacts. The contribution of the other input is negligible.

3.2. Environmental driven food packaging design

In order to define a new whole eco-indicator able to quantify the environmental indirect effects related to the different choices in the cheese packaging in terms of food losses, the following equation is proposed:

$$\mathrm{WEI_i = PEI + PFEI * FLP_i} \qquad \mathrm{i = 1, 2, 3}$$

where WEI is the above-mentioned whole eco-indicator, PEI is the environmental impact of the package (Table 3), PFEI is the environmental impact of the packaged food (Table 4) and FLP is the Food Loss Probability (Table 2). Table 5 shows the values of WEI, by distinguishing for each trend of FLP. If FLP values are taken into account, the results highlight that, the environmental performance of the different systems are quite different from those obtained considering only the materials and processes involved in the life cycle of the FU. Indeed, by considering the FLP in the LCA, the advantages deriving from the use of the OPP films are completely overwhelmed by the indirect effects deriving from the shorter shelf life. Otherwise, the use of multi-layer films (HB and MB) guarantees longer shelf life and lower FLP (Luz, 2012; Williams et al., 2008), thus causing better environmental performance in a life cycle perspective, especially with the use of an anti-fog multi-layer film. So, the adoption of the high barrier film (HB) with a proper MAP (MAP3) becomes the most sustainable combination.

Similarly, the different gaseous atmospheres also influence in different ways the shelf life and consequently the FLP. In particular, MAP4 entails high impact in each combination, but as for the other combinations, there is not a direct correlation between the environmental performance and the use of a specific headspace. Ultimately, the results show that food losses greatly affect environmental performance of each system due to the high environmental impact caused by the production of cheese with respect to the other stages of the life cycle. For this reason, the environmental implications of the choices adopted for the packaging phase of the foodstuff are more affected from the capacity of reducing food losses than from the production and disposing of packaging materials.

4. Conclusions

In this study, the case of the sheep's milk cheese “Canestrato di Moliterno” was analyzed in order to quantify by an eco-indicator, the environmental implications of the indirect effects of the choices of packaging, in terms of shelf-life and food losses. In this analysis a direct relation between shelf life and food loss was underlined. According to LCA analysis, the results show that thinner and recyclable packaging materials are more sustainable from an attributional LCA approach. On the

Table 4
Impact of production and transport process (functional unit: 100 g of packaged cheese).

Packaging film	Headspace conditions	Production	Transport			Packaged food eco-indicator [PFEI]
		Impact of sheep breeding and cheese production	Number of transports to be repeated during the longest shelf life period	Impact of transport	Impact of pondered transport	
HB	AIR	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	VP	2.10E-12	1	5.05E-14	5.05E-14	2.15E-12
	MAP1	2.10E-12	1	5.05E-14	5.05E-14	2.15E-12
	MAP2	2.10E-12	1	5.05E-14	5.05E-14	2.15E-12
	MAP3	2.10E-12	1	5.05E-14	5.05E-14	2.15E-12
	MAP4	2.10E-12	5	5.05E-14	2.52E-13	2.35E-12
MB	AIR	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	VP	2.10E-12	2	5.05E-14	1.01E-13	2.20E-12
	MAP1	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	MAP2	2.10E-12	2	5.05E-14	1.01E-13	2.20E-12
	MAP3	2.10E-12	2	5.05E-14	1.01E-13	2.20E-12
	MAP4	2.10E-12	4	5.05E-14	2.02E-13	2.30E-12
OPP60	AIR	2.10E-12	4	5.05E-14	2.02E-13	2.30E-12
	VP	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	MAP1	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	MAP2	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	MAP3	2.10E-12	4	5.05E-14	2.02E-13	2.30E-12
	MAP4	2.10E-12	4	5.05E-14	2.02E-13	2.30E-12
OPP35	AIR	2.10E-12	5	5.05E-14	2.52E-13	2.35E-12
	VP	2.10E-12	4	5.05E-14	2.02E-13	2.30E-12
	MAP1	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	MAP2	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	MAP3	2.10E-12	3	5.05E-14	1.51E-13	2.25E-12
	MAP4	2.10E-12	4	5.05E-14	2.02E-13	2.30E-12

HB: high-barrier multilayer film made up of polyethylene terephthalate, ethylene–vinyl–alcohol and polyethylene, with 90 μm thickness.
MB: medium-barrier multilayer film made up laminating a nylon layer and a polyolefin film with a thickness of 95 μm.
OPP 60 and OPP 35: oriented polypropylene film with a thickness of 60 μm and 35 μm.
AIR: atmospheric conditions, VP: vacuum packaging; MAP: modified atmosphere packaging.

contrary, if a type-consequential approach is adopted, the packaging able to guarantee a longer shelf life, thus reducing the food loss probability becomes the most sustainable. The environmental impact caused by cheese production is high if it is compared to the other stages of life cycle, and as a consequence the ability of the packaging to reduce food losses is the key factor to make a proper choice, more than considering packaging production or packaging disposing. Probably, in the supply chain management process, a correct stockpile planning and some

Table 5
Packaged food loss eco-indicator calculated multiplying the packaged food eco-indicator (PFEI) by the Food Loss Probability (FLP) and the whole eco-indicator values as sum of the packaging eco-indicator and the packaged food loss eco-indicator (functional unit: 100 g of packed cheese).

Packaging film	Headspace conditions	Packaged food loss eco-indicator (PFLEI) $PFLEI_i = PFEI * FLP_i \quad i = 1,2,3$			Whole Eco-Indicator $WEI_i = PEI + PLFEI_i \quad i = 1,2,3$		
		$PFLEI_1$	$PFLEI_2$	$PFLEI_3$	WEI_1	WEI_2	WEI_3
HB	AIR	8.20E-13	4.44E-13	1.42E-12	1.16E-12	7.83E-13	1.76E-12
	VP	2.85E-13	2.15E-13	5.68E-13	6.90E-13	6.20E-13	9.73E-13
	MAP1	2.85E-13	2.15E-13	5.68E-13	6.91E-13	6.20E-13	9.73E-13
	MAP2	2.04E-13	1.84E-13	3.04E-13	6.09E-13	5.90E-13	7.09E-13
	MAP3	1.72E-13	1.72E-13	1.72E-13	5.78E-13	5.78E-13	5.77E-13
	MAP4	1.42E-12	8.85E-13	1.92E-12	1.83E-12	1.29E-12	2.33E-12
MB	AIR	9.71E-13	5.29E-13	1.56E-12	1.36E-12	9.20E-13	1.95E-12
	VP	5.73E-13	3.28E-13	1.12E-12	9.92E-13	7.47E-13	1.54E-12
	MAP1	8.20E-13	4.44E-13	1.42E-12	1.24E-12	8.64E-13	1.84E-12
	MAP2	5.73E-13	3.28E-13	1.12E-12	9.93E-13	7.48E-13	1.54E-12
	MAP3	5.73E-13	3.28E-13	1.12E-12	9.92E-13	7.48E-13	1.54E-12
	MAP4	1.26E-12	7.35E-13	1.79E-12	1.68E-12	1.15E-12	2.22E-12
OPP60	AIR	1.14E-12	6.37E-13	1.71E-12	1.33E-12	8.28E-13	1.90E-12
	VP	8.78E-13	4.74E-13	1.48E-12	1.16E-12	7.57E-13	1.76E-12
	MAP1	8.78E-13	4.74E-13	1.48E-12	1.16E-12	7.58E-13	1.76E-12
	MAP2	8.78E-13	4.74E-13	1.48E-12	1.16E-12	7.58E-13	1.76E-12
	MAP3	1.26E-12	7.35E-13	1.79E-12	1.54E-12	1.02E-12	2.08E-12
	MAP4	1.26E-12	7.35E-13	1.79E-12	1.54E-12	1.02E-12	2.08E-12
OPP35	AIR	1.47E-12	9.40E-13	1.95E-12	1.58E-12	1.05E-12	2.06E-12
	VP	1.26E-12	7.35E-13	1.79E-12	1.49E-12	9.71E-13	2.03E-12
	MAP1	8.78E-13	4.74E-13	1.48E-12	1.11E-12	7.11E-13	1.72E-12
	MAP2	8.78E-13	4.74E-13	1.48E-12	1.11E-12	7.11E-13	1.72E-12
	MAP3	8.78E-13	4.74E-13	1.48E-12	1.11E-12	7.11E-13	1.72E-12
	MAP4	1.26E-12	7.35E-13	1.79E-12	1.49E-12	9.72E-13	2.03E-12

HB: high-barrier multilayer film made up of polyethylene terephthalate, ethylene–vinyl–alcohol and polyethylene, with 90 μm thickness.
MB: medium-barrier multilayer film made up laminating a nylon layer and a polyolefin film with a thickness of 95 μm.
OPP 60 and OPP 35: oriented polypropylene film with a thickness of 60 μm and 35 μm.
AIR: atmospheric conditions, VP: vacuum packaging; MAP: modified atmosphere packaging.

precaution in the merchandising could limit the loss in the distribution phase. However, if the attention focuses on consumer's behavior, the shelf life plays a very important role to limit the food loss. This is even more evident if we consider the ever-increasing need to have packaged foods in small ready-to-use portions.

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