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Developing a model for the Life Cycle Assessment of the Parmigiano-Reggiano cheese

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Titolo
Sviluppo di un modello per l'analisi del ciclo di vita del formaggio Parmigiano-Reggiano

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LCA, Parmigiano-Reggiano food chain, Greenhouse gases, Monte Carlo simulations

Parole chiave
LCA, Filiera del Parmigiano-Reggiano, Gas ad effetto serra, Simulazioni Monte Carlo

Summary
The actors involved within the Parmigiano-Reggiano food chain are growing their interest about environmental issues related to this important PDO product. This study aimed to develop a model for applying Life Cycle Assessment (LCA) methodology to this product system, and through this model, to identify major impacts and hot spots. Applying this model to a specific organic dairy farm, and the related product system, this study showed that major environmental impacts for all impact categories considered are related to the agricultural phase, mainly land occupation for fodder production, and greenhouse gases (methane and nitrous oxide) from enteric fermentation and manure management. Infrastructure, mainly buildings, showed to have great importance in some impact categories.

Riassunto
All'interno della filiera del Parmigiano-Reggiano sta emergendo un crescente interesse da parte degli operatori per le problematiche ambientali legate a questa importante produzione DOP. Questo studio ha l'obiettivo di sviluppare un modello di Life Cycle Assessment (LCA) da applicare al sistema produttivo del Parmigiano-Reggiano, per identificare gli impatti più rilevanti e le principali criticità. L'applicazione del modello al caso di studio di un'azienda lattiero-casearia biologica ha mostrato che gli effetti ambientali più significativi per tutte le categorie di impatto analizzate sono da attribuire alla fase agricola, con particolare riguardo all'uso delle superfici agricole per la produzione di foraggio e all'emissione dei gas ad effetto serra (metano e ossidi di azoto) da fermentazione enterica e gestione dei reflui zootecnici. I fabbricati aziendali hanno evidenziato una certa rilevanza per alcune categorie di impatto.

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Introduction

In our society the complexity of the production and consumption systems is incredibly different and greater than those present some decades ago, mainly due to new consumption dynamics that affected the entire food marketing process. This led to incorporate in food products relevant services requested by consumers through a massive use of energy. These complex and energy-consuming product systems are creating great impacts on environment, and public concerns about these impacts are growing. The need of knowledge about interactions between the use of products and services and the environment constitutes a relevant objective to reach for private and public organisms.

Life cycle assessment (LCA) has been proposed as a useful tool to assess environmental product impacts, considering not only physical characteristics of the products itself, but the whole life cycle of the product, from raw material extraction to final waste disposal. The concept of LCA evolved since the 1960s, reaching a wide diffusion and usage in 1990s, under various names and applications (1). Then the efforts of various organizations like the Society of Environmental Toxicology an Chemistry (SETAC) and the International Organization for Standardization (ISO) gathered to a standardization of the LCA methodology, codified by ISO 14040, 14041 and 14043 (2). Then the methodology evolved again, and a new series of standards has been published [ISO 14040:2006 and ISO 14044:2006 (3, 4)].

Several LCA on dairy sector have been conducted, particularly in northern Europe, and the main evidence is that the major hot spot of the product systems is the agricultural phase, followed by dairy processing (5, 6). Since agricultural and food processes often have multiple output, an appropriate allocation procedure should be chosen (7). Comparison between conventional and organic farming showed that organic farming has lower eutrophication potential and pesticide use, but higher per-ton of milk land use (8, 9). However, at present few LCA studies exist on cheese products: one on a Swedish semi-hard cheese confirmed that milk production has the greatest environmental impact, followed by dairy processing (10). Nowadays, very few studies have been made on the Italian dairy sector.

Parmigiano-Reggiano is one of the most recognized quality cheese in the world produced in a well defined area of Italy. Parmigiano-Reggiano production is controlled by the consortium "Consorzio del Formaggio Parmigiano-Reggiano", which sets the rules of production of cheese and milk, particularly the admitted cattle feeding, and protects the brand against usurpation and unfair concurrence at national and international level. Due to its popularity all over the world and the great volumes of production, Parmigiano-Reggiano food chain greatly affects the agrifood sector of its area of production.

Now, some actors of this food chain are growing interest about environmental implications of their own activity. For these reasons, LCA could represent an important and useful tool for clarifying the linkage between the Parmigiano-Reggiano production sector and the environmental effects.

This study aims to develop a model for the application of LCA methodology to Parmigiano-Reggiano and other "grana" cheeses[1], by finding processes that contribute mostly to environmental impacts ("hot spots") and most important impact categories. The model is applied to a representative organic dairy farm in Parmigiano-Reggiano system, integrated downstream with the cheese production.

[1] *"Grana" cheese includes all those cheeses, generally obtained by cow milk and with a long period of seasoning, like Grana Padano, mainly produced in Po Valley, or Trentigrana, mainly produced within the province of Trento.*

Product system under study

The object of this study is the Parmigiano-Reggiano production system. Parmigiano-Reggiano is a hard cheese PDO product, with a total production of 3,231,915 wheels of cheese in 2011 (11). They are about 40 cm in diameter per 23 cm in thickness (around 39 kg in weight). It is sold in various ways: as whole wheels, cut in pieces and packed in food paper at vendor, pre-cut and packaged in vacuum sealed plastic film. Also, there are packs of grated cheese or snacks.

Parmigiano-Reggiano is sold all over the world: 87% in Italy (53% in northern Italy, 19% in central Italy and 15% in southern Italy) and the rest is exported. In this study we consider only the portion of Parmigiano-Reggiano sold in Italy. Ways of distribution are mainly the great distribution, but also specialized shops and, recently, directly at the dairy or by internet (bought online and shipped to the consumer).

Production of cheese is governed by production rules issued by the consortium, after UE approval. The Parmigiano-Reggiano production is allowed only in an area of origin that covers the provinces of Parma, Reggio Emilia, Modena, Bologna at the left of Reno river and Mantova at the right of Po river. Parmigiano-Reggiano is made with milk milked twice a day, and immediately gathered to dairy. Milk collected during evening is left to rest along the night, to separate the cream that is generally sold for butter production. Such skimmed milk is mixed with whole morning milk and then, untreated, is pumped in 900 L copper pots. Here, after the addition of calf rennet and natural whey starter (obtained only with part of the residual whey of the day before), the milk coagulates. The curd is manually broken, and the pot is heated to 55°C, to let the broken curd to sediment. Then the resulting mass is cut, and the two masses are extracted and putted in plastic molds, with a small casein plate for piece identification. The residual whey is usually sold, used for production of "ricotta" cheese or used as feed for pigs. The wheels are left to rest for the first day, and periodically turned. The plastic mold is then substituted with a metal one, and a marking stamp that impress on the wheel surface marks indicating the dairy and the characteristic dotted "Parmigiano-Reggiano" marks. After a few days rest, wheels are putted in brine until 30th day. Finally, they are stored in warehouse for their long ripening. Here, they are periodically turned and cleaned, mainly with automated machinery. Ripening can occur at dairy, or at specialized ripeners. After 12 months (the minimum ripening length) wheels are analyzed by experts: those reaching quality standards are fire-marked, those of lesser quality are striped or whitened to distinguish them. The cheese, that at this stage can be denominated Parmigiano-Reggiano, can be sold, but more often the ripening is prolonged to 24, 30 months or more.

Milk for Parmigiano-Reggiano production is also subject to the rules of consortium. Farms that provide milk for Parmigiano-Reggiano have usually large herds (200 heads or more (12)) hosted in loose housing systems; only older farms have smaller herds hosted in tied housing systems. The excrements can be collected both in form of solid manure or liquid slurry. For reproduction is usually used artificial insemination, but some farms anyway have got one bull or two, used in cases where artificial insemination does not work. A portion of female calves are retained to grow new heifers; male calves and old cows are sold for fattening and/or slaughtering. Cattle feed is strictly regulated: at least 50% of dry matter must be provided by hay or fresh fodder of admitted crops, usually alfalfa, ryegrass or permanent meadow. The diet could be completed with concentrates, but silage is strictly prohibited. In addition, for all dairy cows, and heifers from 6th month of pregnancy, animal derivates in feeding stuffs are prohibited. Fresh fodder, hay and straw are usually produced in farm, in crop rotation (like four years of alfalfa followed by two years of grain cereals), or in permanent meadow. Manure or slurry produced is usually applied on farm's crops as fertilizer. Concentrates are usually purchased at regional feed mills.

There are different types of dairy management: most dairies are owned by cooperatives of farmers, but some private dairies exist, purchasing milk from farmers. Some dairies are farm dairies (owned by a single farmer, which provides all the milk needed). In many cases, after the minimum 12 months ripening, the cheese is sold by dairies to wholesalers, which conclude the ripening and sell the product to final consumers or big retailers.

The sample dairy under study is located on first hills at the western end of the zone of origin of Parmigiano-Reggiano. It is a family managed organic farm dairy, with a production of 3-4 wheels per day. The farm, that produces all the milk needed from the dairy, has a herd of about 160 heads, including 90 lactating dairy cows. All products follow organic agriculture standards, and farmers are taking care to environmental issues: for example, almost all their electricity consumption is covered by photovoltaic plants installed on stable and dairy roofs. Cheese is usually sold using plastic film vacuum sealed, shipped to the consumer previously contacted by internet; only a small part of the production is sold directly at dairy shop. Ripening occurs at dairy for the first 6 months, next the cheese is transported to a third-parties ripener to complete the ripening, and then transported back to dairy. The by-products of the cheese making process, cream and ricotta cheese, are sold to other industries or consumers, and whey is used internally in closed-loop, as feed for heifers not yet inseminated.

The farm has a loose housing system, with collection of solid manure used as fertilizer on farm crops. The straw used is produced by farm crops. Cattle is fed with organic alfalfa, in form of hay and fresh fodder, from farm crops, and with purchased organic concentrates. Alfalfa is grown in crop rotation with wheat and maize (4-5 years of alfalfa and 2 years of grain crop); however, the crop rotation is not considered in this study (only the alfalfa production is considered). Because the farm follows organic agriculture, no artificial fertilizers or pesticides are used, only manure is applied to fields. In these fields, alfalfa does not require irrigation. Hay is harvested in round bales.

Method

LCA standards (ISO 14044:2006 (4)) require a reference function and a functional unit to be defined. The reference function is the good or service provided by the product system. In this case, the reference function is the consumption of Parmigiano-Reggiano, seasoned 24 months, packaged in vacuum sealed plastic film, in three Italian cities (Bologna, Roma and Bari) representing consumption patterns among Italy. The functional unit is the quantity by which LCA results are normalized. In this study, we chose the consumption of 1 kg or Parmigiano-Reggiano as functional unit. This means that results are flows emitted by or needed for the consumption of 1 kg of Parmigiano-Reggiano.

The model has been constructed following an iterative process, started considering only the reference function (consumption of Parmigiano-Reggiano):

1. individuation of inputs and outputs of the process considered;
2. individuation of data needed, and preparation of data collection sheets;
3. data collection, on site or from literature;
4. life cycle inventory (LCI) calculation (calculation of elementary flows associated to 1 functional unit);
5. calculation of category indicators;
6. individuation of processes that need to be more investigated, or to be excluded. This is done ap-

plying cut-off criteria: if the flow is related to less than 0.1% in mass, energy and all category indicators (on the product system total), the flow can be excluded from the model; if the flow is related to more than 10% in mass, energy or at least one category indicator, the flow must be investigated creating one ad-hoc process representing the specific situation; otherwise (if related mass, energy and category indicators lie between 0.1% and 10%) the flow can be approximated with one of the flows present in the database used.
7. If new ad-hoc processes are created, applying cut-off criteria, for these processes must be done the same procedure, returning to step 1.

Collected data should meet some data quality requirements. The goal of the study was to collect data with adequate temporal coverage (relative to years 2010 and 2011), geographical and technological coverage (site-specific data when possible, otherwise data representing Italian situation), and with relative uncertainty less than 10%. Because of the quantity of data needed, in some cases these goals were not met; for such data which does not reach data quality goals an uncertainty analysis has been performed.

Like in many agricultural product systems, some processes have multiple outputs, for example the dairy produces not only cheese but also butter and ricotta cheese, and the farm produces not only milk but also meat from calves and cows. For these problems, Cederberg (7) proposed a system expansion as the best method for avoiding allocation, but it requires big efforts for collecting additional data, and in some cases it is hard to apply (e.g. cream and whey are always byproducts, even in other product systems). An allocation based on physical parameters seems not applicable, because an allocation by mass can bring to wrong conclusions for the presence of great masses of low-value co-products (e.g. mass of whey is great compared to mass of cheese). So, in this study an economic allocation has been chosen. This is a common choice in food systems (10).

After calculating LCI results, a life cycle impact assessment (LCIA) has been performed, using the Eco-indicator 99 model (13). This model has been chosen because it is a very well known model, ranging over different impact categories, and it is suitable for an initial identification of major issues. The LCIA consists in classification (associating LCI elementary flows to impact categories), characterization (for each category, multiplication of flows by a characterization factor, then sum of the products together to get the category indicator), normalization (dividing the category indicator of the product system by a category indicator related to annual European per-capita impacts) and weighting (multiplication of the normalized category indicator by a weight representing the relative importance of the impact category, then sum the product across categories to get a single indicator).

Because some of these steps require assumptions and value-choices, this method provides different cultural perspectives, related to different characterization factors, normalization values and weights. In this study we use "hierarchical" characterization, "hierarchical" normalization and "averaged" weights; and other perspectives ("I,I" and "E,E", see model report for details (13)) are used as a robustness test.

The categories considered are grouped in three groups:

Human health, measured in DALY (disability adjusted life years):

- Carcinogenics, indicating DALY lost for carcinogenic emission;
- Climate change, indicating DALY lost for heat/cold effects, variation of climate-related diseases and displacement due to climate change;
- Ionizing radiation, indicating DALY by exposition to radioactive emissions;
- Ozone layer depletion, indicating DALY lost for diseases related to ozone layer depletion;

- Respiratory effects, indicating DALY lost for respiratory diseases due to product system's emissions.
 Ecosystem quality, measured as PDF (potentially disappeared fraction of species) times area times time:
- Acidification and eutrophication, indicating loss of target species due to acidification and eutrophication from air emissions;
- Ecotoxicity, indicating species affected by the increase of ecotoxic substances concentration;
- Land occupation, indicating loss of vascular plant species (relative to a reference) due to land use or land use change.

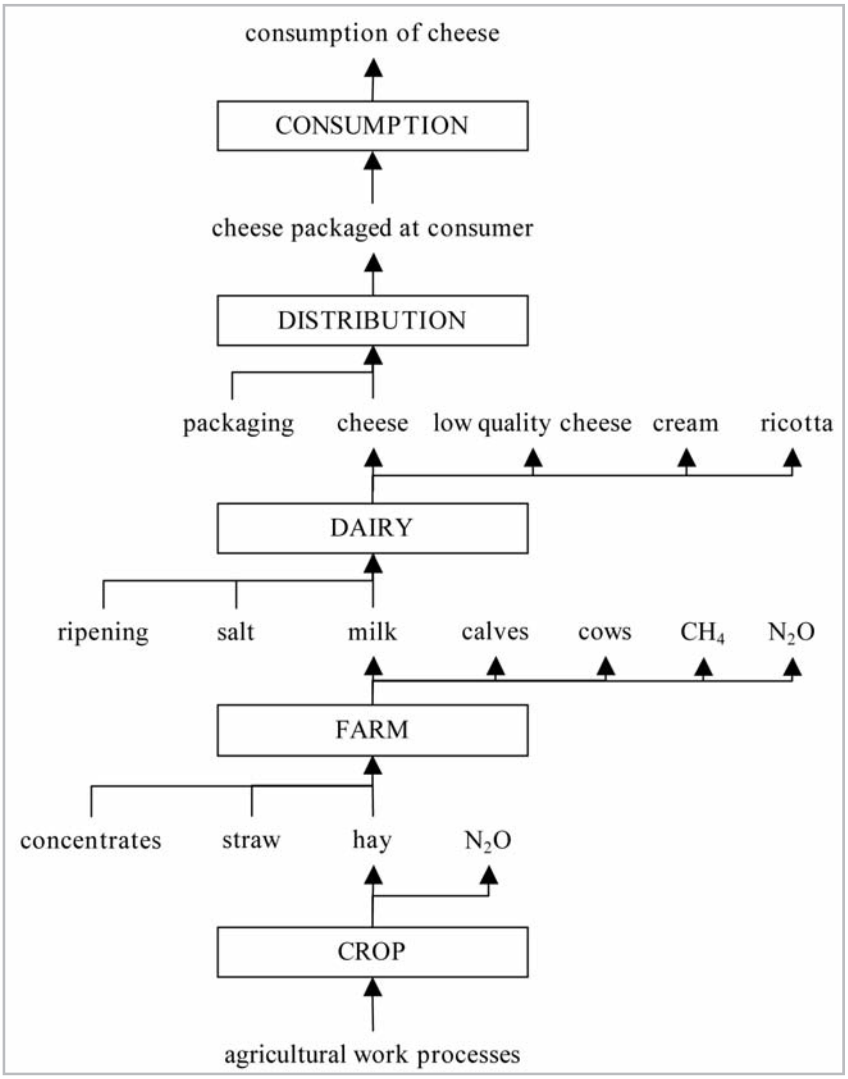
Resources, measured in MJ of surplus energy (difference of energy required to extract the amount of resource, between the actual situation and an hypothetical future situation with more scarce resources):
- Fossil fuels;
- Mineral extraction.

Finally, two types of uncertainty analysis have been performed. For data not reaching data quality goals, or for missing data, a single-data uncertainty analysis has been conducted, by varying the value of the data by a value clearly greater than the possible variability of the data, and then recalculating LCI and LCIA, and the relative variation of the results compared to the original results. To estimate the uncertainties on category indicators, we used Monte Carlo simulations. Data were, mostly, without uncertainty, so we assigned to each data an uncertainty (assuming a log-normal distribution) using the pedigree matrix (14), for coherence with Ecoinvent database. Then, we ran 300 runs of Monte Carlo simulation.

Model

Developed model is summarized in Figure 1. For each process in diagram, we also considered transports, waste treatment (for main wastes), energy consumption and associated emissions (grid or photovoltaic elec-

Figure 1 - Model



tricity, natural gas or diesel), water consumption and wastewater treatment, surface occupied, buildings and machinery production and dismantling. Whey is not present in model because it is entirely re-used in a closed loop.
Elements not considered are: transport of employers from home to work and back; transport of salt, cattle, diesel and lubricants; waste collection and transport to disposal, packaging other than primary package of cheese; rennet; medicals; detergents; leaching of cooling media; natural gas burned for fire marking of the wheels; ammonia emissions from manure and water fluxes of crops. Nitrate and phosphate leaching and run-off from crops are not modeled in eco-indicator 99. CO_2, O_2 and water vapor fluxes from cattle metabolism, and CO_2, O_2 and N_2 related to crops are not considered, because they are non-influent on category indicators. Assumptions made are: no transport from the delivery of the cheese and its consumption, because it is shipped directly to consumers; all cheese is ripened 24 months; all wastes are incinerated; the cheese is consumed in three Italian cities according to Italian consumption patterns.

Data sources

For this study, site-specific data have been used, where possible, for main processes; for data not retrievable on-site, and for minor processes, data from literature (mainly (15) and (16)) and from Ecoinvent database (17) has been used. Table 1 shows major data sources for each sector.

Main results

After LCI and LCIA calculation, category indicators, together with normalized and weighted values, referred to 1 functional unit (the consumption of 1 kg of Parmigiano-Reggiano), are summarized in table 2.
Standard deviations are calculated from Monte Carlo simulations. Normalized indicators are expressed as ratio between product's characterized indicators on characterized indicators referred to per-capita annual consumptions of Europe. Weighted indicators are expressed in points. 1 point represents 1/1000 of European per capita annual impacts.

Comparison between processes

Table 3 shows, for each impact category, relative contribution of each main process. The result shows that distribution and consumption phases contributes by a very little proportion (<5% of total impacts). Ripening phase has little impacts, mainly in mineral extraction and carcinogenics categories, due to warehouse building and dismantling. At dairy, some important impacts are present: for dairy building construction and dismantling (for mineral extraction, carcinogenics and ecotoxicity) and for natural gas burned for steam production (fossil fuels and ozone depleting potential). Main hot spots are in the agricultural phase (60% for all categories): concentrates production has important impacts in almost all categories, like alfalfa cultivation (in this case, impacts are distributed among all work processes); construction and dismantling of building have also important im-

Table 1 - Data sources

Step	Data sources
consumption	Ecoinvent database (16) and estimates
distribution	Ecoinvent database (16) and estimates
dairy	on site
ripening	on site
farm	on site, Ribaudo (14), IPCC (15)
cultivation	on site, Ribaudo (14), IPCC (15)
others	Ecoinvent database (16)

Table 2 - Results

LCIA Category Amount	Crude amount	Standard deviation	Unit	Normalized amount	Weighted
e.q. - acidification & eutrophication	4.75E-01	8.56E-02	PDF m^2 y	9.25E-05	3.70E-02
e.q. - ecotoxicity	2.78E-01	5.84E-01	PDF m^2 y	5.42E-05	2.17E-02
e.q. - land occupation	2.31E+01	3.85E+01	PDF m^2 y	4.50E-03	1.80E+00
ecosystem quality - total	**2.46E+01**	**3.85E+01**	**PDF m^2 y**	**4.80E-03**	**1.92E+00**
h.h. - carcinogenics	3.55E-06	2.04E-06	DALY	2.31E-04	9.23E-02
h.h. - climate change	3.41E-06	4.91E-07	DALY	2.22E-04	8.86E-02
h.h. - ionising radiation	1.40E-08	1.00E-08	DALY	9.08E-07	3.63E-04
h.h. - ozone layer depletion	5.67E-10	1.23E-10	DALY	3.68E-08	1.47E-05
h.h. - respiratory effects	6.60E-06	9.90E-07	DALY	4.28E-04	1.71E-01
human health - total	**1.36E-05**	**2.32E-06**	**DALY**	**8.82E-04**	**3.53E-01**
resources - fossil fuels	8.17E+00	1.10E+00	MJ	9.71E-04	1.94E-01
resources - mineral extraction	6.67E-01	1.45E-01	MJ	7.93E-05	1.59E-02
total - total					**2.48E+00**

Table 3 - Contributions

	A. & E.	Ecotox.	Land occ.	Carc.	Climate Ch.	Ion. rad.	Oz. L. Depl.	Resp.	F. fuels	Mineral
distribution and consumption	0.5%	0.6%	0.0%	0.3%	0.4%	0.9%	1.4%	0.9%	1.8%	0.1%
ripening	0.3%	4.0%	0.0%	5.1%	1.0%	1.4%	3.3%	0.9%	4.0%	5.4%
dairy	1.9%	26.3%	0.2%	30.4%	7.2%	12.3%	21.1%	5.8%	25.0%	34.4%
building	0.9%	20.1%	0.1%	26.7%	1.0%	4.4%	1.8%	3.5%	2.0%	28.0%
natural gas	0.6%	0.3%	0.0%	0.2%	4.7%	1.2%	17.5%	1.0%	21.9%	0.1%
farm	97.3%	69.2%	99.8%	64.1%	92.4%	86.8%	74.2%	92.5%	69.2%	60.1%
concenrates	73.7%	17.3%	35.3%	31.5%	13.3%	42.9%	28.0%	41.0%	24.1%	8.6%
hay	6.5%	7.7%	61.4%	3.7%	8.4%	12.9%	14.0%	14.9%	16.6%	8.9%
buildings	3.6%	38.2%	1.4%	22.5%	4.9%	20.0%	17.4%	13.0%	14.3%	37.2%
enteric fermentation	0.0%	0.0%	0.0%	0.0%	66.2%	0.0%	0.0%	0.0%	0.0%	0.0%

pacts in various categories. Diesel consumption in agricultural works has an important impact in fossil fuels depletion and respiratory effects. Greenhouse gases (methane and N_2O) produced during enteric fermentation and manure management have a great importance for the climate change category, contributing by 66% to the total production system.
According to cut-off criteria (stating that if a process contributes more than 10% in mass, energy or at least one impact category, it should be more thoroughly studied) further improvements of the model can be implemented: the production of concentrates, the construction of dairy and farm buildings, and the combustion of natural gas at dairy exceed the 10% threshold, but for lack of data no insights have been made.

Comparison between categories

Although comparisons between categories are necessarily based on subjective weights and value-choices, some facts can be put in evidence:
land use is, by far, the most important category, but it is affected by great uncertainty;
ionizing radiation and ozone layer depletion have much less importance than the other categories;
other categories have similar importance; among them ecotoxicity, carcinogenics and mineral extraction seem related to building construction; acidification comes mainly from concentrates production, climate change is strongly dependent from enteric fermentation gases and respiratory effects are linked to fossil fuels combustion.
Even using different cultural perspectives (“I,I” and “E,E”) results are similar; the only major difference is that, in the “Individualist” perspective, greater importance is assigned to mineral extraction, in spite of fossil fuels (fossil fuels in the Individualist perspective are not considered, because of the assumption that fossil fuels reserves will not run out in the near future).

Uncertainty analysis

Monte Carlo simulations showed moderate uncertainties (considering the great intrinsic uncertainties of such complex study), except for land use category, which has an uncertainty greater than 100%, making difficult to interpret this result.
From the uncertainty analysis on data not reaching quality goals, can be seen that, in the worst case, variation of some data can cause variation on result as great as a factor of 2. Data whose uncertainty showed to influence more the results are mainly quantities of products (number of wheels, tons of milk) and of fodder.

Conclusion

In this study, a model for LCA of Parmigiano-Reggiano cheese has been developed, and successfully applied to the product system associated to a representative organic dairy, from cradle (growing of fodder) to grave (disposal of packaging).
The impact assessment done, using the Eco-indicator 99 characterization model, highlighted the most and the least important impact categories for this product system: land occupation has proven to be the main impact category (mainly related to hay and concentrates production), whereas low importance was related to ionizing radiation and ozone layer depletion.
Results also permit to identify hot spots: most of the impacts come from agricultural phase, mainly from fodder (concentrates and hay) production, for almost all impact categories, and from GHG emitted by cattle enteric fermentation. Both these two impacts are strictly related to cattle diet, so this is a key parameter for impact management.
Other hot spots are the consumption of fossil fuels (diesel and natural gas) and related emissions, in the agricultural phase and at dairy, and the construction and dismantling of buildings (mainly the farm and dairy ones). The distribution phase showed low importance, but this could be related to the particu-

lar selling system applied by the dairy under study (product shipped to the consumer). If the product were to be sold though large retailers, impacts could be greater.

These results suggest some improvements to product system that can reduce or control impacts: first of all, control cattle diet, choosing fodder with low impacts, could manage main impacts of whole product system. For defining the best diet, also accounting nutritional requirements, a comparative LCA between diets should be conducted; but from this study we can state that existing rules on cattle feeding could be an effective tool for control impacts of the whole Parmigiano-Reggiano sector. Other improvements can be made in more efficient energy use, reducing fossil fuel consumption, and choosing "green buildings" with low environmental impact. The rigid process of cheese production leaves low margin of reducing impacts by improve productivity: the coagulation process cannot be changed without loss of quality, and wastes are already near to zero.

The developed model can be further improved, and applied to comparisons (for example, as stated above, between cattle diets). A more appropriate LCIA model should be used, with a better land use assessment, and inclusion of effects of leaching and runoff of nitrate and phosphate.

Application of this model can give scientific basis for explaining to the public the complexity and environmental implication of the Parmigiano-Reggiano production system, and the trade-offs of the choices applied during milk and cheese production, and for make public concerned about environmental differences that may exist beyond products apparently similar.

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