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Life Cycle Assessment of packaged organic dairy product: a comparison of different methods for the environmental assessment of alternative scenarios

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Abstract

Nowadays Life Cycle Assessment is usually adopted to evaluate the carbon footprint and water footprint of packaged foods considering the whole supply chain, but not many studies compare the results coming from the adoption of different Life Cycle Impact Assessment methodologies. Adopting the IPCC 2013, IPCC 2013 incl. CO_2 uptake, ILCD 2011 Midpoint +, ReCiPe 2016 and AWARE methods, this study aims to investigate the environmental impact of an organic Parmigiano Reggiano cheese produced in Italy. We demonstrated that the application of different LCIA methods gives different impact results for the same product: for example, global warming was lower with ILCD 2011 and IPCC 2013 CO_2 uptake methods than IPCC 2013 and ReCiPe 2016. Moreover, the water footprint resulted different using ILCD 2011 midpoint+ method, since it considers a European consumption of water, the AWARE, based on global average consumption, and the ReCiPe that considers the regionalized impacts. Overall, agricultural and breeding phases had a relevant contribution because of the use of water and greenhouse gas emissions from livestock and their daily feed. However, using renewable energy, such as biogas plants or photovoltaic panels, the paper demonstrated that the water and carbon footprint can be reduced.

***Keywords**:* Dairy Technology, Packaging, Life Cycle Assessment, Life Cycle Impact Assessment

1 Introduction

Climate change is an undeferrable issue: the greenhouse gases emitted to the atmosphere must be decreased urgently, according to the Paris Agreement. Moreover, companies are called to respect the 17 Sustainable Development Goals established by the 2030 Agenda: therefore, many industries are evaluating the hotspots of their processes and products from an environmental point of view, using the Life Cycle Assessment methodology. Many scientific studies have been carried out thanks to the Life Cycle Assessment: cheese is one of the most studied dairy products and results are similar to other industrial products about environmental impacts, both for greenhouse gas emissions and water consumption (Uctug, 2019). Different types of cheese exist, as fresh, mature and semi-hard, which have different characteristics and consequently different environmental impacts: i.e. fresh cheese is less impactful than semi-hard one (Finnegan et al., 2018). However, scientific studies agree to consider milk as the main impact driver and farm activities as the most relevant source of environmental impact, because of agricultural activities and breed emissions (Baldini et al., 2018) (Gonzalez-Garcia et al., 2013). For example, milk production has the major contribution (86%) in cheddar cheese's carbon footprint: the total environmental impact of 1 kg of cheddar is equal to 14 kg CO_2 eq, considering the credits for energy recovery (Gosalvitr et al., 2019).

Some studies tried not only to assess the impact of dairy products, but also to evaluate some strategies to improve their environmental sustainability and increase the shelf life (Stefanini et al. 2021) (Lovarelli et al., 2019). An environmental analysis located in Spain found that 1 kg of a traditional Galician cheese has a carbon footprint equal to 10.4 2 kg CO_2eq and the use of whey as by-product reduces the environmental impact (Gonzalez-Garcia et al., 2013). However, cheese whey represents a source of pollution and it needs to be correctly treated because it has several environmental burdens (Palmieri et al., 2017). In the same country, a small-cheese factory found that the most impactful phase along the supply chain is the raw milk production. On the contrary, packaging manufacturing scarcely influences on the total impact. The global warming potential was calculated using the ReCiPe Midpoint (H) method and it results in 10.2 kg CO_2eq for 1 kg of cheese (Canellada et al., 2018).

An Italian study discovered that 1 kg of mozzarella cheese has an average emission of 6.66 kg CO_2eq and water consumption of 1.58 m^3, which is in the need of 90% to fed production and farm activities; to increase the environmental sustainability, improvement of energy efficiency, packaging use and transport should be done (Dalla Riva et al., 2017). The environmental impact has been calculated also for Asiago cheese, which has a climate change equal to 10.1 kg CO_2eq and a water depletion equivalent to 2.37 m^3; the study suggests identifying plant-specific inefficiencies and other improvements to reduce environmental impact (Dalla Riva et al., 2018).

Since 2000, the sustainability evolution of Protected Designation of Origin (PDO) Parmigiano Reggiano has been assessed (Arfini, et al., 2019) and improvements are needed in the whole dairy supply chain to reduce impact both in farms and cheese factories (Lovarelli et al., 2019).

However, some changes can improve the impacts of dairy products and processes and, for example, organic farming could enhance the responsible use of natural resources and the attention to the biodiversity. Consequently, the market of organic foods is increasing a lot (Orboi, 2013) (ANSA, 2018): in 2017, 12.6 million hectares of European agricultural land were dedicated to organic farming and 15.2% of these lands were located in Italy (Eurostat, 2019).

As far as the packaging is concerned, too much plastic is dispersed in the environment and the oceans causing problems because of their incorrect disposal (Mecho et al., 2020) (Range-Buitrago et al., 2020) (Gong et al.,2020) and it is necessary also a life cycle thinking of products packaging to support a circular economy (Borghesi et al. 2021) (Jang, et al., 2020). As a matter of fact, in the life cycle of dairy foods, also packaging materials and technologies are relevant. Indeed, different materials can represent a different impact assessment, and the final disposal, as landfill, recycling, incineration or reuse, can change the carbon footprint and the energy use (Ghenai, 2012): in particular, the recycling process of packaging materials is advised, thanks to the saving of virgin materials; as the rate of recycled material increases, the environmental impact decreases (Saleh, 2016).

However, plastic is one of the most functional and suitable solutions, able to protect food products from spoilage and pathogenic microorganisms, extending shelf life and preserving nutritional value (Bottani et al. 2014). For this reason, some research assesses that the best solution is not plastic abolition, but the creation of a circular economy, recycling and reusing packaging materials (Stefanini el al. 2021). Many packaging materials are available on the market (Bertolini, Bottani, Vignali, & Volpi, 2016), but each of them has a different environmental impact. For example, in Europe it is possible to create food packaging with 50% of recycled PET, which has the lowest environmental impact in comparison with other food packaging materials (Stefanini el al. 2021).

However, by carrying out a LCA study, it must be noticed that the application of several hypotheses and methods could change the results (Palmieri, et al., 2017), for example the different type of agriculture (conventional intensive or organic) could generate different environmental impacts (Trinh el al., 2020). Some works have been done to compare the impact generated by different Life Cycle Impact Assessment (LCIA) methods (Stravropoulos et al., 2016) (Cavalett et al., 2013) (Dreyer et al., 2003). Moreover, some studies verified the degree of convergence of the methodologies applied for LCA: an Italian research on milk productions found out that measured and estimated calculation approaches, such as the Intergovernmental Panel on Climate Change (IPCC) and European Environmental Agency (EEA), led to different LCA results (Baldini, et al., 2018). In fact, the global warming potential is lower using the IPCC equations. Finally, another hotspot in the environmental assessment of cheese is the burdens allocation with by-products; different choice influences final results (Flysjo, et al., 2011), as a matter of fact for 1 kg of Grana Padano the climate change can be 10.3, 15.2 or 16.9 kg CO_2 eq using dry matter, economic or nutritive allocation factor (Bava, et al., 2018).

Based on all these premises, this study would contribute to explore the environmental aspects related to Italian dairy sector: therefore, the environmental impact of Parmigiano Reggiano and its packaging is investigated along the whole supply chain. Different scenarios are taken into account to highlight which improvements can reduce the environmental impacts, i.e. the use of renewable energy and lower water consumption in the farm, and the use of an alternative packaging material. Carbon footprint and water footprint are determined using different impact methods of Life Cycle Assessment: IPCC 2013, IPCC 2013 incl. CO_2 uptake, ILCD 2011 Midpoint +, ReCiPe 2016 midpoint (H) and AWARE. Thanks to the comparison between these LCIA methods, this study aims to show how results change as well as the implementation's priority of some improvements to make the dairy sector more sustainable.

2 Life cycle assessment methodology

Life Cycle Assessment is a methodology for evaluating a product’s environmental impact by quantifying all associated inputs and output, as materials, energy, wastes and emissions. A product’s life cycle takes into account all production processes, from raw materials extraction to waste disposal, considering a “gate to gate”, a “cradle to gate” or a “cradle to grave” perspective. This study is based on an attributional LCA analysis following UNI EN ISO (ISO 14040, 2006) (ISO 14044, 2006) and it consists of four steps: goal and scope definition, inventory analysis, impact assessment and interpretation of results.

2.1 Goal and scope definition

The aim of the study is to calculate and compare the environmental impacts of an organic Parmigiano Reggiano before and after the implementation of some improvements in the dairy farm and cheese factory, as well as the introduction of renewable energy and new packaging material made of 50%R-PET and technically 100 % recyclable. The analysis is carried out using the Life Cycle Assessment methodology thanks to the Software SimaPro 9.1.1 with EcoInvent 3.6 (allocation, cut-off by classification) and Agri-footprint databases. As explained in the chapter 2.3, different methods of impact calculation are used to calculate carbon and water footprints, in order to evaluate the differences between the same impact category of different impact methods. As mentioned, two different scenarios are considered in the study: the 2018 scenario, in which photovoltaic panels and two biogas plants were already present in the company, and the hypothetical 2019 scenario which considers that production is at full capacity, a larger number photovoltaic panels is adopted, and the use of service water in the cheese factory is set to zero thanks to the new concentration plant for whey. The latter consists of a reverse osmosis treatment in which the final products are concentrated whey (30% of dry matter) and “permeate”, then used as service water. The creation of a concentrated whey, allow to reduce the number of trucks trips for disposal in a foreign country, because they can transport a product with few water inside. Moreover, thanks to the permeate, it is also possible to consider zero the water used during cheese production: consequently, water is used only for bovine drinking in farms and for the salting phase in the cheese factory. This specific organic farming does not include water consumption because only rainwater is used to cultivate fodder, but anyway fodder from SimaPro databases is used.

Functional unit. In LCA studies, the functional unit (FU) is the reference for input and output data to quantify the performance of the product system (ISO 14040, 2006). In this analysis, the FU adopted is 1 kg of organic Parmigiano Reggiano. Fat and Protein Corrected Milk is used to produce the FU as suggested by the International Dairy Federation (International Dairy Federation, 2015):

$$FPCM\left(\frac{kg}{yr}\right) = Production\left(\frac{kg}{yr}\right) * [0.1226 * fat\% + 0.0776 * protein\% + 0.2534] \; (1)$$

where “Production” is the amount of milk produced and the percentages of fat and protein are related to the chemical milk analysis for each cattle farms.

System boundaries. The dairy supply chain is located in Emilia Romagna (Italy) and the study takes into account three dairy farms and a cheese factory. For each dairy farm, organic farming and breed operations are considered, as the crops production, sowing and fertilizing operations, transports, purchased feeds, slurry management with the biogas plant, energy consumptions (electricity, fuels and gas), water consumption for animal feed and milking and, at least, livestock emissions (methane, dinitrogen monoxide and ammonia). Twice a day, milk is transported by a refrigerated truck and is processed in the cheese factory. Cheese production includes all the operations related to the preparation of Parmigiano Reggiano; for curding phase calf rennet and whey are required. After that stage, the curd is cooked in a copper cauldron, moulded and placed in salting tanks. Energy consumptions like electricity, steam and water consumption are considered (Figure 1).

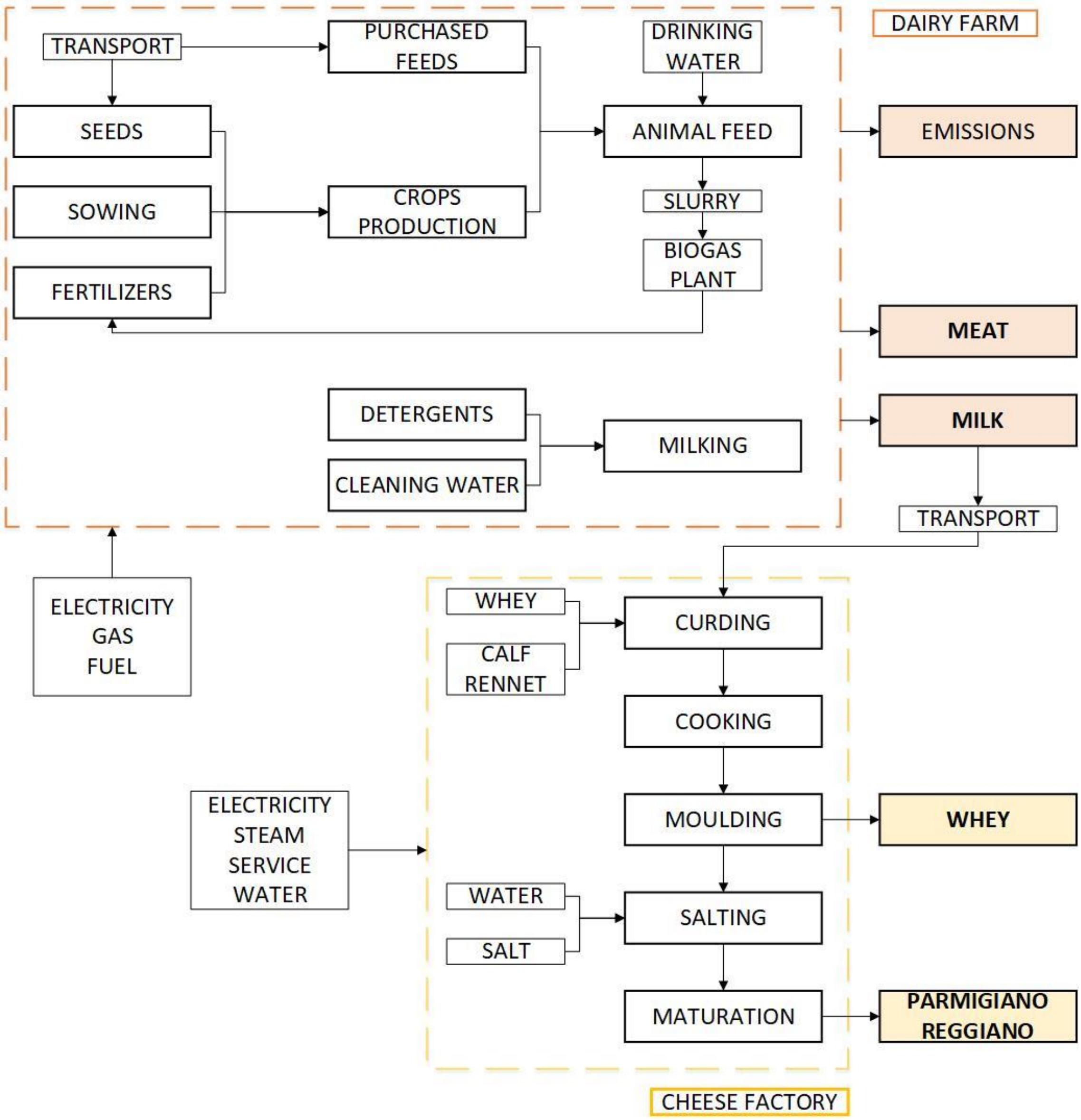

Figure 1 System boundaries

Allocation. According to the ISO 14040, the allocation between product and co-products is a breakdown of input and output flows and it should be avoided, but this is not possible in this study. Two products (milk and meat) are correlated at dairy farms level and two are related to the cheese factory, i.e. Parmigiano and whey; the allocation considers the mass balance and it is made according to the International Dairy Federation. In this study is not possible to avoid allocation, because from a cow the company produce both milk and meat and at the same time the production of cheese generates by-products. We used the mathematical equations to do the allocation according to the standard procedure suggested by International Dairy Federation. The first allocation between milk and meat is made according to the mentioned document, which suggests the following equations (International Dairy Federation, 2015):

$$AF = 1 - 6.04\,BMR \qquad (2)$$

where *AF* represents milk allocation factor and *BMR* is the ratio between the live weight quantity of all animals sold and the amount of sold milk. For each farm, the allocation factors of milk and meat are about 80% and 20% respectively.

The second allocation of this study is between organic Parmigiano Reggiano and its whey:

$$AFi = \frac{DMi * Qi}{\sum_{i=1}^{n}(DMi * Qi)} \qquad (3)$$

where *AF* represents the product allocation factor, *DMi* is the percentage of product dry matter and *Qi* is the produced quantity expressed in kilograms (International Dairy Federation, 2015). Parmigiano Reggiano has 70% of dry matter and considering 1 kg of cheese corresponds to 13.3 kg of whey, 45% is the allocation factor of cheese and 55% for its whey; the milk cream as by-product is excluded from this analysis.

2.2 Inventory analysis

According to the ISO 14040, this stage quantifies resources, energy consumption and environmental releases associated with the examined system, using a mass and energy balance of FU. Data were collected from farms and cheese factory through personal interviews and a checklist. Regarding the raw milk production, which is the main ingredient of Parmigiano Reggiano (i.e. 14 litres of milk are necessary to produce 1 kg of cheese), the daily amount of milk has been recreated considering primary data, except livestock emissions. The daily emissions from animals and farm operations were obtained from the EcoInvent database for cow milk, in particular biogenic methane, nitrous oxide and ammonia, which are, respectively, equal to 0.021, 0.0005 and 0.0025 for kilogram of fat and protein corrected milk.

In table 1 the collection daily data for cattle fed and forages are reported.

EcoInvent processes	**Amount**
Clover seed	25587.5 kg
Wheat seed, organic	2977.5 kg
Maize grain, organic	7474.5 kg
Pea seed, organic	1314.5 kg
Soybean, organic	3206.6 kg
Hay, organic	14137.5 kg
Crude sunflower oil	571 kg
Sugar beet molasses, from sugar production	175 kg
Straw, organic	1286 kg
Barley seed, organic	630 kg

Table 1 Inventory data of daily cows' feeding in farms.

For forages and cattle feed, the operation of sowing, fertilization and transport of suppliers are considered. In particular, transport of suppliers is included in forages and feed recreated on Simapro; suppliers are almost the same for each farms, because they are all part of a specific group. As far as the transport of milk is concerned, farms are close to the cheese factory (14 km, 2.8 km and 16 km) and the same means of transport is used "*Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO4, carbon dioxide, liquid refrigerant, cooling*". Thanks to biogas plants a part of electricity consumed is yet renewable in the first scenario. In table 2 and 3, the data for daily energy consumption in cattle farms are reported for the first and second scenario.

EcoInvent processes	**Amount**
Electricity, high voltage {IT}| heat and power co-generation, biogas, gas engine	1142.5 kWh
Electricity, medium voltage	2016.5 kWh
Natural gas	101.76 m^3
Diesel	1060.5 kg
Liquefied petroleum gas	9.19 kg

Table 2 Inventory data of energy consumption in farms for the first scenario.

EcoInvent processes	**Amount**
Electricity, high voltage {IT}| heat and power co-generation, biogas, gas engine	2328.5 kWh
Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation	840.17 kWh
Natural gas	101.76 m^3
Diesel	1060.5 kg
Liquefied petroleum gas	9.19 kg

Table 3 Inventory data of energy consumption in farms for the second scenario.

Primary data as milk, whey, rennet, electricity, natural gas, water and salt used in the cheese factory were considered to reproduce Parmigiano Reggiano in the LCA software.

Inventory data and annual production refer to 2018 for the first scenario, while the second hypothetical scenario takes into account the maximum production of the cheese factory and the following improvements: all electricity in the dairy supply chain is renewable and the service's water consumption in cheese factory is equal to zero thanks to the new concentration plant for whey. The table 4 shows consumption dataset in cheese factory which refers to the production of 1 kg of Parmigiano Reggiano and its whey.

EcoInvent processes	First scenario	Second scenario
Tap water	43 kg	0 kg
Steam, in chemical industry	3.63 kg	2.59 kg
Electricity, medium voltage	1.56 kWh	0 kWh
Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation	0.26 kWh	1.21 kWh
Heat, district or industrial, natural gas	4.6 kWh	3.24 kWh

Table 4 energy consumption in the Parmigiano Reggiano factory.

As far as the packaging is concerned, only the materials, the extrusion/co-extrusion phase and the final disposal are analysed in this study. A non-recyclable vacuum solution is currently used to package 1 kg of organic Parmigiano Reggiano: a multi-material film made of nylon (OPA) and polythene (PE) made by a co-extrusion operation. However, a recyclable mono-material packaging made of polyethylene terephthalate and recycled polyethylene terephthalate (PET and R-PET respectively) is considered with the scope to replace the existing one. The amount of solventless was excluded. The packaging film weight is assumed to equal to 10 grams.

Packaging Type	Material	EcoInvent process	Weight [g]	% of material
Multi-material	OPA PE	Nylon 6-6 Polyethylene, low density, granulate	1.9 8.1	19 % 81 %
Mono-material	PET R-PET (50% recycled)	Polyethylene terephthalate, granulate, amorphous Polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate	5 5	50 % 50 %

Table 5. Characteristics of packaging materials

End of life of single-material packaging considers three waste treatments for packaging, even if it can be considered 100% recyclable; according to the Italian Sustainability Report (COREPLA, 2018), the waste scenario of PET solutions considers: 44.5% of recycling, 43% incineration and

12.5% landfill. Instead, multi-material packaging is not recyclable and that percentage of recycling is assigned to incineration, so the end of life is modelled considering 87.5% incineration and 12.5% landfill Concerning the municipal incineration of waste in the EcoInvent database, the benefits resulting from energy recovery in incineration (thermal and electric energy), are taken into account. A general distance of 100 km by 16-32 ton, EURO5 truck is assumed for distances between municipal solid waste collection centre and recycling, incineration and landfill sites for both the packaging solutions

2.2.1 Data quality

Data quality is an important issue to establish the type of LCA analysis: according to the ISO 14044 (2006a) data quality refers to "characteristics of data that relate to their ability to satisfy stated requirements". To evaluate the standard of the data it is possible to distinguish two categories: *specific* and *generic data*. The *specific data* are also called primary or site-specific data: they refer to the information directly obtainable from the production site. *Generic data* (or secondary data) are generic information from LCI databases, which meet the criteria of completeness and representativeness; moreover, generic data may refer to *proxies*, data from databases, which do not meet the precision criteria, completeness and representativeness.

The search for data to conduct this study required a lot of effort, both for the collection phase and for the elaboration process; in fact, most of the time to conduct this study was dedicated to the inventory analysis phase. The data were collected thanks to the use of several surveys provided to cattle farms and dairy factory. The data used to conduct the study are taken directly from the production site and then processed to insert them into the software SimaPro 9.1.1 using EcoInvent database. However, some exceptions are made, such as data relating to emissions from livestock:

methane, nitrous oxide and ammonia. It was not possible to directly measure the emissions of enteric fermentations and livestock manure management, thus the emissions of EcoInvent's cow milk are included.

2.3 Life cycle impact assessment methods

This study assesses carbon footprint and water footprint comparing different impact methods: IPCC 2013, IPCC 2013 incl. CO_2 uptake, ILCD 2011 Midpoint +, ReCiPe 2016 midpoint (H) and AWARE.

IPCC 2013 has been developed by Intergovernmental Panel on Climate Change and it lists the climate change factors with a timeframe of 20 and 100 years; the method has only the global warming potential (GWP) as impact category and this study considers a range of 100 years.

IPCC characterization factors for the direct global warming potential, except methane (PRé, 2020):

- Do not cover indirect formation of N_2O from nitrogen emissions;
- Do not consider CO_2 formation from CO emissions;
- Do not consider the range of indirect effects;
- Do not include radiative forcing of No_x, water, sulphate etc emissions in lower stratosphere and upper troposphere.

IPCC 2013 incl. CO_2 uptake contains the climate change factors of IPCC with the timeframe of 100 years, including CO_2 uptake; the results can be calculated cumulatively as Climate Change or per category: Climate change – fossil, Climate change – biogenic, Climate change – CO_2 uptake and Climate change – land use and transformation (PRé, 2020).

According to the method description, IPCC characterisation factors for the direct (except CH4) global warming potential for air emissions are (PRé, 2020):

- Not including indirect formation of dinitrogen monoxide from nitrogen emissions;
- Not accounting for radiative forcing due to emissions of NOx, water, sulphate etc. in the lower stratosphere and upper troposphere;
- Not considering the range of indirect effects given by IPCC
- Not including indirect effects of CO emissions.

ILCD 2011 Midpoint + is the method used for Product Environmental Footprint (PEF) and it presents sixteen impact categories: climate change, ozone depletion, human toxicity cancer effect, human toxicity non-cancer effect, particulate matter, ionizing radiation human health, ionizing radiation, photochemical ozone formation, acidification, terrestrial eutrophication, marine eutrophication, freshwater ecotoxicity, land use, water resource depletion, mineral, fossil and renewable resource depletion. The full name is "ILCD recommendations for LCIA in the European context". Characterization factors are set to zero for long term emissions, as a requirement from the European Commission, which analysed several methodologies for LCIA (PRé, 2020). In this study, climate change and water resource depletion of this method are taking into consideration. According to this method, the climate change is the GWP calculating the radiative forcing over a time horizon of 100 years based on IPCC 2007, but they are not identical, because the method inventory of carbon dioxide is different between them. ILCD method considers for air compartment: carbon dioxide, carbon dioxide – biogenic, carbon dioxide – fossil, carbon dioxide – land transformation and carbon dioxide – peat oxidation. Instead, IPCC 2007 considers only carbon dioxide, carbon dioxide fossil and carbon dioxide land transformation.

As far as **ReCiPe 2016** method is concerned, the ReCiPe 2016 update (Huijbregts, et al., 2016) of the 2008 version (Goedkoop, et al., 2009) provides characterization factors that are representative for the global scale, instead of the European scale, while maintaining the possibility for a number of impact categories to implement characterization factors at a country and continental scale. It has many impact categories, but as far as the GWP and Water Consumption ones are concerned it uses different approaches from other methods; e.g. the factors in Global warming differ from the 100a time horizon in IPCC 2013 because climate-carbon feedback for non-CO_2 GHGs is included, while in Water Consumption the consumption/extraction ratios were provided and country-specific characterization factors were provided as well (many adaptation has been given to this method) (Dekker et al. 2020). Midpoint (H) version has been considered for the assessment in order to compare the result with the other selected methods and because it appears as the most used one (Vitale et al., 2018) (Bottani et al. 2019).

AWARE is the recommended method from WULCA to assess water consumption impact assessment in LCA (WULCA, 2021). It is a water use midpoint indicator representing the Available WAter REmaining per Area in a watershed after the demand of humans and aquatic ecosystems and it assesses the potential of water deprivation considering that the less water remaining available per area, the more likely another user will be deprived. It is a recommended method from WULCA (Water Use in Life Cycle Assessment, a workgroup under UNEP-SETAC for Life Cycle Initiative) to evaluate the impact assessment of water consumption.

3 Results

In the following paragraphs, the results of the study are presented. The environmental impacts of carbon and water footprint are carried out separately using the four different methods.

3.1 Carbon footprint

The total greenhouse gas emissions of organic Parmigiano Reggiano have been calculated employing the IPCC 2013, IPCC 2013 incl. CO_2 uptake, ILCD 2011 Midpoint + and ReCiPe 2016, as shown in Table 6. The kilogram of CO_2 equivalent is used to quantify the impacts. The aim is to show the results using different methods, underlining the difference between the first and second scenario of 1 kg of organic Parmigiano Reggiano.

			1° scenario	**2° scenario**
IPCC 2013	Global warming	kg CO_2 eq	**7.24**	**6.61**
IPCC 2013 incl. CO_2 uptake	Climate change - fossil	kg CO_2 eq	4.15E+00	3.51E+00
	Climate change - biogenic	kg CO_2 eq	3.62E+00	3.70E+00
	Climate change - CO_2 uptake	kg CO_2 eq	-6.08E+00	-6.05E+00
	Climate change - land use and transf	kg CO_2 eq	3.18E-02	3.17E-02
	CUMULATIVE	kg CO_2 eq	**1.72E+00**	**1.19E+00**
ILCD 2011	Climate change	kg CO_2 eq	**1.24**	**0.712**
ReCiPe 2016	Global warming	kg CO_2 eq	**8.12**	**7.49**

Table 6 Carbon footprint of 1 kg of organic Parmigiano Reggiano

IPCC 2013 and ReCiPe 2016 methods refer to global warming potential as an impact indicator, instead climate change is used in the ILCD 2011 midpoint+ and IPCC 2013 incl. CO_2 uptake methods. Milk production is the main contributor to these results. At dairy farms level, transports of suppliers are included in forages and cattle feed impact, but the Table 7 shows the global warming potential of 1 kg of FPCM transported from dairy farms to the cheese factory, pointing out that different distances could change the results.

			Dairy farm 1	Dairy farm 2	Dairy farm 3
IPCC 2013	Global warming	(kg CO_2 eq)	**8.80E-03**	**1.76E-03**	**1.01E-02**
IPCC 2013 incl. CO_2 uptake	Climate change - fossil	kg CO_2 eq	8.80E-03	1.76E-03	1.01E-02
	Climate change - biogenic	kg CO_2 eq	5.82E-05	1.16E-05	6.65E-05
	Climate change - CO2 uptake	kg CO_2 eq	-5.66E-05	-1.13E-05	-6.47E-05
	Climate change - land use and transf	kg CO_2 eq	4.76E-06	9.53E-07	5.44E-06
	CUMULATIVE	kg CO_2 eq	**8.80E-03**	**1.76E-03**	**1.01E-02**
ILCD 2011	Climate change	kg CO_2 eq	**8.77E-03**	**1.75E-03**	**1.00E-02**
ReCiPe 2016	Global warming	kg CO_2 eq	**8.85E-03**	**1.77E-03**	**1.01E-02**

Table 7 Carbon footprint of 1 kg FPCM considering the transport from dairy farms to the cheese factory

Considering the two types of packaging, **Errore. L'origine riferimento non è stata trovata.** shows materials' impact of using different methods.

			OPA + PE		PET + R-PET	
			Materials	EoL	Materials	EoL
IPCC 2013	Global warming	(kg CO_2 eq)	**3.47E-02**	**2.08E-02**	**2.54E-02**	**8.99E-03**
IPCC 2013 incl. CO_2 uptake	Climate change - fossil	kg CO_2 eq	3.47E-02	2.08E-02	2.47E-02	8.99E-03
	Climate change - biogenic	kg CO_2 eq	5.83E-04	1.05E-05	2.52E-03	2.35E-06
	Climate change - CO_2 uptake	kg CO_2 eq	-3.79E-04	-8.70E-06	-1.84E-03	-1.72E-06
	Climate change - land use and transf	kg CO_2eq	9.37E-06	4.45E-07	2.42E-05	7.90E-08
	CUMULATIVE	kg CO_2 eq	**3.49E-02**	**2.08E-02**	**2.54E-02**	**8.99E-03**
ILCD 2011	Climate change	kg CO_2 eq	**3.39E-02**	**2.08E-02**	**2.48E-02**	**8.99E-03**
ReCiPe 2016	Global warming	kg CO_2 eq	**3.59E-02**	**2.08E-02**	**2.60E-02**	**9.01E-03**

Table 8 Carbon footprint of different packaging types

3.2 Water footprint

The total amount of consumed water during a Life Cycle Assessment of organic Parmigiano Reggiano is calculated with AWARE, ILCD 2011 midpoint + and ReCiPe 2016 method and the unit of measurement is cubic meters of water. The aim is to show the volume of water consumed using different methods and underline the difference between the first and second scenario of 1 kg of organic Parmigiano Reggiano. These methods have different impact categories to quantify water consumption: they are respectively water use (AWARE and ReCiPe 2016) and water resource depletion (ILCD 2011 midpoint+). Using AWARE for the first scenario 3.31 m^3 of water are consumed, instead 3.01 m^3 for the second; 0.11 m^3eq and 0.102 m^3eq are used for the first and second case according to the ILCD 2011 method. As far as ReCiPe 2016 method is concerned, in the first scenario 0.102 m^3eq of water are consumed against 0.095 m^3eq for the second scenario. As the carbon footprint, farm activities have the largest water consumption.

Table 9 shows the detail of water footprint for the transportation of milk to the cheese factory.

	Dairy farm 1	**Dairy farm 2**	**Dairy farm 3**
AWARE (m^3)	5.05E-04	1.01E-04	5.77E-04
ILCD 2011 (m^3eq)	2.687E-06	5.37E-07	3.071E-06
ReCiPe 2016 (m^3eq)	1.697E-05	3.395E-06	1.94E-05

Table 9 Water footprint of 1 kg FPCM considering the transport from dairy farms to the cheese factory

Considering the two types of packaging, Table 10 shows water consumption using the different methods.

	OPA + PE		**PET + R-PET**	
	Materials	**EoL**	**Materials**	**EoL**
AWARE (m^3)	3.74E-02	2.49E-04	1.63E-02	2.69E-05
ILCD 2011 (m^3eq)	1.84E-04	8.59E-07	1.11E-04	2.30E-07
ReCiPe 2016 (m^3eq)	7.50E-04	1.06E-05	4.76E-04	2.87E-06

Table 10 Water footprint of different packaging types

4 Discussion

As far as the carbon footprint of organic Parmigiano Reggiano is concerned, IPCC 2013 and ReCiPe 2016 methods have a similar impact value, while ReCiPe has the highest impact; ILCD 2011 midpoint+ and the cumulative IPCC 2013 incl. CO_2 uptake present an extremely low impact. This difference is due to the biogenic and uptake carbon dioxide: biogenic carbon dioxide refers to the emissions linked to the natural carbon cycle, which results from fermentation, decomposition and processing of biological material especially at farms level and in this study it is due to the cows' feeding thanks to different types of fodder such as maize, pea, soya, hay and so on. ILCD 2011 midpoint+ considers biogenic CO_2 to assess climate change, which results lowest because an amount of biogenic carbon is removed from the total global warming impact (depending on the source, the biogenic carbon dioxide could have also a negative number). As a matter of fact, according to the ILCD Handbook (European Commission JRC, 2010), it is important to distinguish biogenic and fossil emissions, because carbon dioxide uptake is a "resource from air" and it assumes a negative value, but on the other hand the carbon dioxide emission (both fossil and biogenic) is considered as positive impact with the same characterization factor. So ILCD Handbook recommends considering the emissions as positive value and the biogenic carbon uptake with negative number (European Commission JRC, 2010). As mentioned before, this method is modelled on Simapro considering for carbon dioxide substance: carbon dioxide, carbon dioxide – biogenic, carbon dioxide – fossil, carbon dioxide – in air, carbon dioxide – land transformation, carbon dioxide – peat oxidation.

As far as the guidelines of the Intergovernmental Panel on Climate Change are concerned, at agricultural level, in the greenhouse gases inventory, the carbon included in the biomass is released when harvested, according a stock change approach in which net emissions are calculated by investigating the net changes in carbon stocks of a biomass carbon pool over time (IPCC, 2006) (Levasseur et al., 2013). According to (Levasseur et al., 2013) to avoid double counting using IPCC guidelines, if biogenic carbon is released later in the life cycle (i.e. combustion of bioenergy), the related carbon dioxide emissions are not taken into account. However, this approach has been criticized, because biomass combustion generates more greenhouse gas emissions than the use to fossil resources (per unit of energy) generating a carbon debt; this gap is filled by the growth of biomass, although this takes a long time to grow and therefore there is an impact on the climate due to the use of fossil resources in the meantime (Levasseur et al., 2013). However, on SimaPro software regarding carbon dioxide substances, IPCC 2013 method considers: carbon dioxide, carbon dioxide – fossil, carbon dioxide – land transformation, carbon dioxide – to soil or biomass stock (the biogenic carbon dioxide uptake is not present). On the contrary, IPCC 2013 incl. CO_2 uptake contains the climate change factors of IPCC (with the timeframe of 100 years), including the CO_2 uptake and the results can be calculate cumulatively as climate change or distinguish per category (fossil, biogenic, CO_2 uptake and land use and transformation), but in environmental studies there is no consensus on how to evaluate the potential life cycle global warming impacts of biogenic carbon emissions in LCA (Breton et al., 2018). This different way to treat biogenic carbon shows a difference between environmental impacts of various methods in life cycle assessment study (Levasseur et al., 2013). Even if methods are similar, it is not possible to consider them equivalent, because the results depend in the type of substances used to create method and mostly the type of data used to recreate the inventory dataset, in particular for biogenic carbon dioxide uptake. This is the reason why this study obtained different results analysing the organic Parmigiano Reggiano, where natural sources are included. Instead, the carbon footprint of milk transports and packaging materials are similar using the four different environmental methods.

Figure 2 and figure 3 represent the carbon footprint of both scenarios highlighting the environmental burdens of dairy farms and the cheese factory. The charts show the different contribution to the climate change (expressed in percentage) for dairy farms and cheese factory, highlighting that for IPCC 2013 and ReCiPe methods dairy farms (the production of milk) have the higher contribution to the final results, because biogenic and uptake carbon dioxide are not directly taken into consideration. On the contrary, for ILCD and IPCC 2013 (CO_2 uptake) dairy farms have the lowest contribution, thanks to the consideration of biogenic and uptake substances with negative sign in the production of milk.

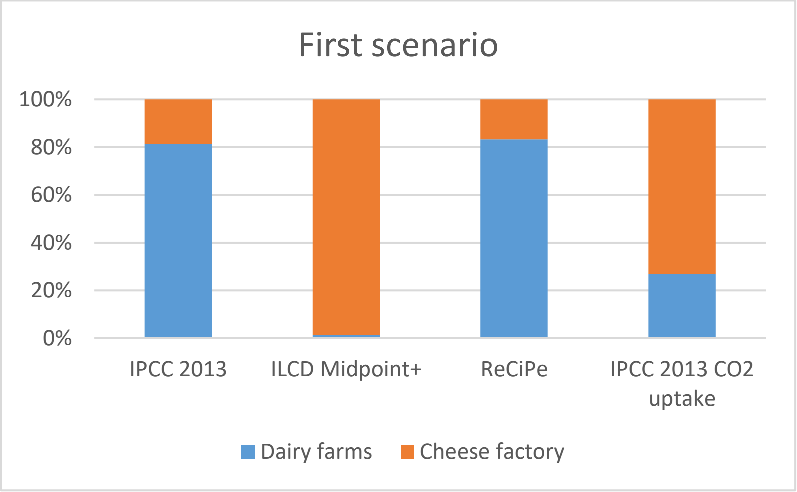

Figure 2 Carbon footprint of dairy farms and cheese factory for the first scenario

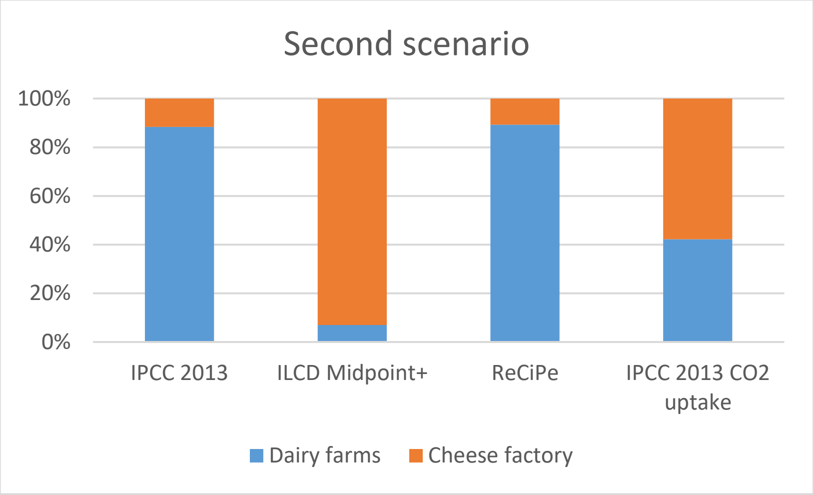

Figure 3 Carbon footprint of dairy farms and cheese factory for the second scenario

Comparing the first and second scenarios it is possible to notice that for each method the impact has decreased in the second case. The reduction in dairy farms and the cheese factory is due to the use of 100% renewable electricity; so this comparison shows also that is possible to increase the sustainability in the whole supply chain thanks to the environmental improvements and the new technologies (Hessle et al. 2017). This means also that Life Cycle Assessment analysis is an optimal tool to evaluate the sustainability management and to understand how it is possible to reduce environmental impact (Ferreira, et al., 2020), even if there are still in a great need to think otherwise and to understand that it is possible to pursue an idea of sustainability in agriculture and food sector (Sala, et al., 2017), but it could be possible and this case study is an example.

Also in the case of packaging carbon footprint, the impact of the ILCD method is similar to others because packaging production does not have biogenic sources. The better solution is the recycled mono-material packaging, which has about halved impact if compared to a multi-material solution. Thanks to this recycle it is possible to increase a circular economy of plastic materials, saving extraction and creation of the virgin one.

As regards the water footprint of the analysed product, ILCD and ReCiPe 2016 present a lower consumption and this is due to the different methods of water calculation. Water use (AWARE) indicator represents the water available remaining per area in a watershed; the latter indicator is calculated at first as the difference between the availability of water and the demand of humans and aquatic ecosystems, building on the assumption that the less water remaining available per area, the more like another use will be deprived (PRé, 2020). Its indicator is first calculated as the water Availability Minus the Demand and is relative to the area, then the result is normalized with the world average value and inverted. The number of cubic meters is the relative value of water consumed in comparison to the average cubic meters consumed in the world. According to the description of this method, the indicator is in a range between 0.1 and 100, where number 1 is the world average and a value of 10 i.e. is the region where there is 10 times less available water remaining per area than the average of world (PRé, 2020). It is also important to notice that the implementation of this method in Simapro includes only the generic factors for unknown water use and it exclude the specific factors regards agricultural and non-agricultural use of water. To assess the water resource depletion in ILCD method, the characterization factors are based on the Ecological Scarcity Method (Frischknecht et al. 2009) and at midpoint level they are calculated by EC-JRC; these characterization factors are calculated for water depletion, considering that a reference water resource flow is based on a weighted average of EU consumption and eco-factors of other water flows are connected to that reference water flow (European Commission JRC, 2012). The ecological method is based on the “distance to target” rather than an impact assessment method which is based on damage; the eco-factors calculation is related to the relation between a critical and a current flows and in this way it is possible to regionalize the results (Frischknecht et al. 2009). According to this method, the freshwater availability is different in the world, because in some regions it is limited and in others there is an excess; so eco-factors are calculated for specific countries (as Switzerland and other OECD states) and for six different scarcity situations: low, moderate, medium, high, very high and extreme. On these bases, it is important to underline that the recommended characterization models and associated characterization factors in ILCD are classified according to their quality (level I, level II and level III) and the impact category of water resource depletion has level III (recommended, but to be applied with caution) (European Commission JRC, 2012).

As far as the ReCiPe method is concerned, all water-related impacts are based on water consumption, that represents freshwater withdrawals which are evaporated, incorporated in products and waste, transferred to other watersheds or disposed into the sea (Falkenmark & Rockstrom, 2004). Consumed water is not available anymore for humans or ecosystems in the watershed of origin; at midpoint level the characterization factor (CF) is cubic meters of water consumed per cubic meters of water extracted. The midpoint CF is equal to 1 if inventory is in cubic meters, while it is equal to the water requirement ration if the inventory refers to the cubic meters of withdrawn (Huijbregts, et al., 2016).

In the end, there is a great difference between AWARE and the other methods, both in the first and the second scenario. As specified before, this difference is due to the way of quantifying the water consumption, because the methods differ in the data sources and the scarcity equations: a demand-to-availability ratio DTA (i.e. AWARE) or a withdrawal-to-availability ratio WTA (i.e. ILCD 2011 midpoint+ and ReCiPe 2016). As a matter of fact, the scarcity equations are the key difference between the midpoint methods; withdrawal-to-availability-ratio measures how refers to how much water in an area is withdrawn in the industrial process than how much is available. Instead, DTA includes the water demand of human and ecosystems, investigating the total amount of water available and it subtracts the demand to calculate how much water is available for use (Prè-sustainability, 2021). These different methods to calculate the water consumption, obviously, do not have in Simapro the same inventory data sources. They differ in the elements number, because investigating the inventory water for AWARE methods it is possible to find 1851 elements, instead 1378 elements for water resource depletion calculation in ILCD and 2091 for ReCiPe water consumption. In Simapro in the all three methods the waters have always the same CAS number (007732-18-15), but the characterization factors are different; e.g. in ReCiPe the CF assumes only "-1", "0", "-0.001" values, instead different numbers for the other two methods, depending on the type of water origin.

Figure 4 and figure 5 illustrate the water footprints, dividing the burdens into dairy farms and cheese factory (expressed in percentage). Despite the organic farming in this study uses only the natural precipitations to irrigate the soil, the milk is the main contributor since it considers animal feeds (water to drink) and milking. As a matter of fact, in several dairy cases, milk and farming stages represent the main contributors to the environmental impact (Vasilaki et al., 2016). Even if the improvement in the water context is done in the cheese factory, in the second scenario the water footprint in farms is lower than the first for all the methods thanks still to the use of renewable energy. However, the major difference is represented by the cheese factory contribution, because in the second scenario the use of service water is set to zero.

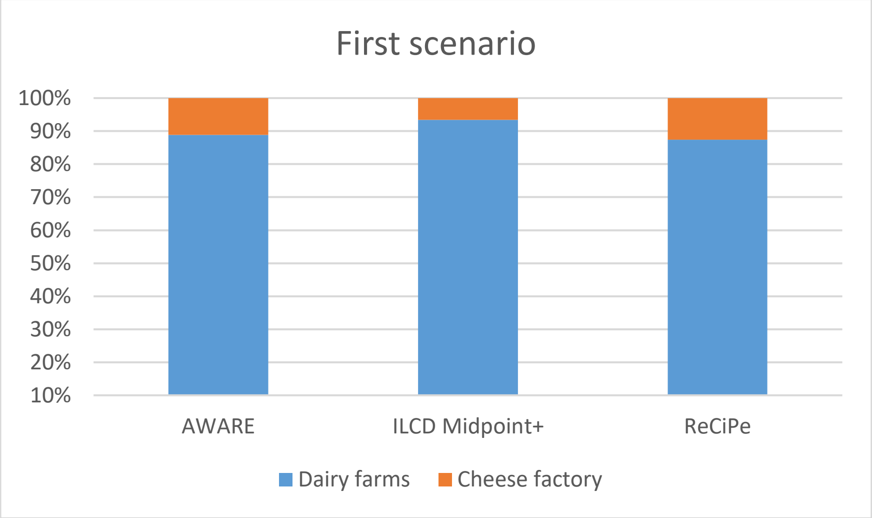

Figure 4 Water footprint of dairy farms and cheese factory in the first scenario

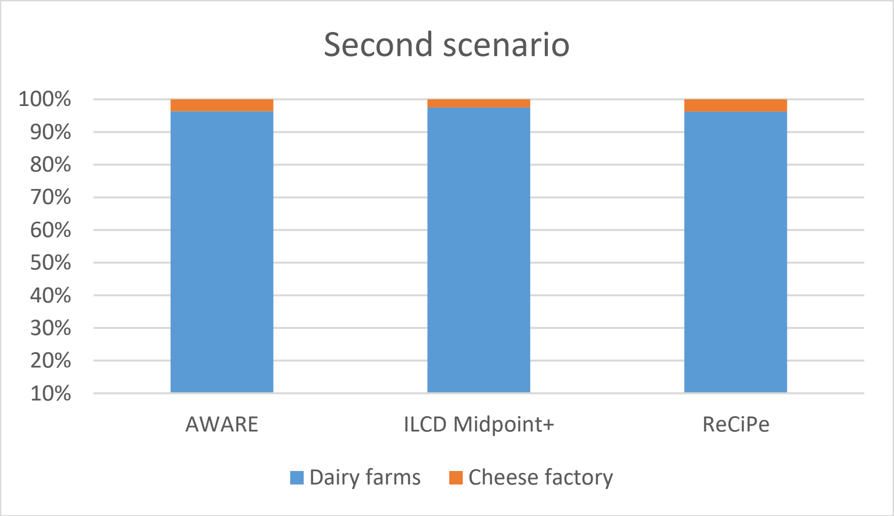

Figure 5 Water footprint of dairy farms and cheese factory in the second scenario

Between the first and second scenarios, the total amount of water footprint decreases both of using AWARE, ReCiPe 2016 and the ILCD 2011 method, while as far as the specific phases are concerned, in the case of AWARE method a strongly decreasing of the "cheese factory" impact is balanced by an increasing of the “dairy Farms” impact.

As regards the packaging type, also considering the water consumption, the recycled packaging materials remain the best solution, thanks to the use of half recycled material, since its water contribution is not accounted for. The multi-material packaging is also lacking in the percentage of recycling at the end of life.

5 Conclusions

This work aimed to assess the environmental impact of an organic Parmigiano Reggiano produced in Emilia Romagna (Italy), comparing a 2018 scenario with a hypothetical 2019 scenario, where a larger number of photovoltaic panels and a new whey’s concentration plant were adopted in the dairy farm, considering also a new material made of R-PET to package the famous Italian cheese. Furthermore, the research wanted to show eventual unevenness in the application of different LCIA methods to evaluate the impact of food products. Indeed, numeric results depend on the different methods used: considering 1 kg of Parmigiano Reggiano the climate change of the ILCD 2011 and IPCC 2013 CO_2 uptake methods resulted lower than IPCC 2013 and ReCiPe 2016, because it considers biogenic CO_2 in its life cycle. On the contrary, the difference in the packaging impacts was not relevant, because in the fossil plastic production biogenic resources are not used. Different results were obtained also by assessing the water footprint, because the ILCD 2011 midpoint+ method considers a European consumption of water, while AWARE are based on global average consumption and ReCiPe considers the regionalized impacts. This can demonstrate that the application of different LCIA methods can give different impact results for the same product.

As far as the LCA results are concerned, the milk production at the farm has the main contribution both for carbon footprint and water footprint according to the literature review. Some improvements in the whole supply chain could bring benefits and reduce greenhouse gas emissions and water consumption, and a recyclable mono-material packaging can further reduce impacts according to all the considered methods. The conclusion of this study can help producers to understand that some improvements should be implemented in order to reduce the products environmental burdens, reaching a more sustainable development. This study could also contribute to the scientific literature about the evaluation of environmental results choosing a method rather than another in Life Cycle Assessment analysis.

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