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1 Life Cycle Assessment of packaged organic dairy
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3 environmental assessment of alternative scenarios

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

15 **Abstract**

16 Nowadays Life Cycle Assessment is usually adopted to evaluate the carbon footprint and water
17 footprint of packaged foods considering the whole supply chain, but not many studies compare
18 the results coming from the adoption of different Life Cycle Impact Assessment methodologies.
19 Adopting the IPCC 2013, IPCC 2013 incl. CO₂ uptake, ILCD 2011 Midpoint +, ReCiPe 2016 and
20 AWARE methods, this study aims to investigate the environmental impact of an organic
21 Parmigiano Reggiano cheese produced in Italy. We demonstrated that the application of different
22 LCIA methods gives different impact results for the same product: for example, global warming
23 was lower with ILCD 2011 and IPCC 2013 CO₂ uptake methods than IPCC 2013 and ReCiPe
24 2016. Moreover, the water footprint resulted different using ILCD 2011 midpoint+ method, since
25 it considers a European consumption of water, the AWARE, based on global average
26 consumption, and the ReCiPe that considers the regionalized impacts. Overall, agricultural and
27 breeding phases had a relevant contribution because of the use of water and greenhouse gas
28 emissions from livestock and their daily feed. However, using renewable energy, such as biogas
29 plants or photovoltaic panels, the paper demonstrated that the water and carbon footprint can be
30 reduced.

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

32 **1 Introduction**

33 Climate change is an undeferrable issue: the greenhouse gases emitted to the atmosphere must be
34 decreased urgently, according to the Paris Agreement. Moreover, companies are called to respect
35 the 17 Sustainable Development Goals established by the 2030 Agenda: therefore, many
36 industries are evaluating the hotspots of their processes and products from an environmental point
37 of view, using the Life Cycle Assessment methodology. Many scientific studies have been carried
38 out thanks to the Life Cycle Assessment: cheese is one of the most studied dairy products and
39 results are similar to other industrial products about environmental impacts, both for greenhouse
40 gas emissions and water consumption (Uctug, 2019). Different types of cheese exist, as fresh,
41 mature and semi-hard, which have different characteristics and consequently different
42 environmental impacts: i.e. fresh cheese is less impactful than semi-hard one (Finnegan et al.,
43 2018). However, scientific studies agree to consider milk as the main impact driver and farm
44 activities as the most relevant source of environmental impact, because of agricultural activities
45 and breed emissions (Baldini et al., 2018) (Gonzalez-Garcia et al., 2013). For example, milk
46 production has the major contribution (86%) in cheddar cheese's carbon footprint: the total
47 environmental impact of 1 kg of cheddar is equal to 14 kg CO₂ eq, considering the credits for
48 energy recovery (Gosalvitr et al., 2019).

49 Some studies tried not only to assess the impact of dairy products, but also to evaluate some
50 strategies to improve their environmental sustainability and increase the shelf life (Stefanini et al.
51 2021) (Lovarelli et al., 2019). An environmental analysis located in Spain found that 1 kg of a
52 traditional Galician cheese has a carbon footprint equal to 10.4 2 kg CO₂eq and the use of whey

53 as by-product reduces the environmental impact (Gonzalez-Garcia et al., 2013). However, cheese
54 whey represents a source of pollution and it needs to be correctly treated because it has several
55 environmental burdens (Palmieri et al., 2017). In the same country, a small-cheese factory found
56 that the most impactful phase along the supply chain is the raw milk production. On the contrary,
57 packaging manufacturing scarcely influences on the total impact. The global warming potential
58 was calculated using the ReCiPe Midpoint (H) method and it results in 10.2 kg CO₂eq for 1 kg of
59 cheese (Canellada et al., 2018).

60 An Italian study discovered that 1 kg of mozzarella cheese has an average emission of 6.66 kg
61 CO₂eq and water consumption of 1.58 m³, which is in the need of 90% to feed production and farm
62 activities; to increase the environmental sustainability, improvement of energy efficiency,
63 packaging use and transport should be done (Dalla Riva et al., 2017). The environmental impact
64 has been calculated also for Asiago cheese, which has a climate change equal to 10.1 kg CO₂eq
65 and a water depletion equivalent to 2.37 m³; the study suggests identifying plant-specific
66 inefficiencies and other improvements to reduce environmental impact (Dalla Riva et al., 2018).
67 Since 2000, the sustainability evolution of Protected Designation of Origin (PDO) Parmigiano
68 Reggiano has been assessed (Arfini, et al., 2019) and improvements are needed in the whole dairy
69 supply chain to reduce impact both in farms and cheese factories (Lovarelli et al., 2019).

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

75 As far as the packaging is concerned, too much plastic is dispersed in the environment and the
76 oceans causing problems because of their incorrect disposal (Mecho et al., 2020) (Range-Buitrago
77 et al., 2020) (Gong et al., 2020) and it is necessary also a life cycle thinking of products packaging
78 to support a circular economy (Borghesi et al. 2021) (Jang, et al., 2020). As a matter of fact, in
79 the life cycle of dairy foods, also packaging materials and technologies are relevant. Indeed,
80 different materials can represent a different impact assessment, and the final disposal, as landfill,
81 recycling, incineration or reuse, can change the carbon footprint and the energy use (Ghenai,
82 2012): in particular, the recycling process of packaging materials is advised, thanks to the saving
83 of virgin materials; as the rate of recycled material increases, the environmental impact decreases
84 (Saleh, 2016).

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

94 However, by carrying out a LCA study, it must be noticed that the application of several
95 hypotheses and methods could change the results (Palmieri, et al., 2017), for example the different
96 type of agriculture (conventional intensive or organic) could generate different environmental

97 impacts (Trinh et al., 2020). Some works have been done to compare the impact generated by
98 different Life Cycle Impact Assessment (LCIA) methods (Stravropoulos et al., 2016) (Cavalett et
99 al., 2013) (Dreyer et al., 2003). Moreover, some studies verified the degree of convergence of the
100 methodologies applied for LCA: an Italian research on milk productions found out that measured
101 and estimated calculation approaches, such as the Intergovernmental Panel on Climate Change
102 (IPCC) and European Environmental Agency (EEA), led to different LCA results (Baldini, et al.,
103 2018). In fact, the global warming potential is lower using the IPCC equations. Finally, another
104 hotspot in the environmental assessment of cheese is the burdens allocation with by-products;
105 different choice influences final results (Flysjö, et al., 2011), as a matter of fact for 1 kg of Grana
106 Padano the climate change can be 10.3, 15.2 or 16.9 kg CO₂ eq using dry matter, economic or
107 nutritive allocation factor (Bava, et al., 2018).

108 Based on all these premises, this study would contribute to explore the environmental aspects
109 related to Italian dairy sector: therefore, the environmental impact of Parmigiano Reggiano and
110 its packaging is investigated along the whole supply chain. Different scenarios are taken into
111 account to highlight which improvements can reduce the environmental impacts, i.e. the use of
112 renewable energy and lower water consumption in the farm, and the use of an alternative
113 packaging material. Carbon footprint and water footprint are determined using different impact
114 methods of Life Cycle Assessment: IPCC 2013, IPCC 2013 incl. CO₂ uptake, ILCD 2011
115 Midpoint +, ReCiPe 2016 midpoint (H) and AWARE. Thanks to the comparison between these
116 LCIA methods, this study aims to show how results change as well as the implementation's
117 priority of some improvements to make the dairy sector more sustainable.

118 **2 Life cycle assessment methodology**

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

126 **2.1 Goal and scope definition**

127 The aim of the study is to calculate and compare the environmental impacts of an organic
128 Parmigiano Reggiano before and after the implementation of some improvements in the dairy
129 farm and cheese factory, as well as the introduction of renewable energy and new packaging
130 material made of 50%R-PET and technically 100 % recyclable. The analysis is carried out using
131 the Life Cycle Assessment methodology thanks to the Software SimaPro 9.1.1 with EcoInvent
132 3.6 (allocation, cut-off by classification) and Agri-footprint databases. As explained in the chapter
133 2.3, different methods of impact calculation are used to calculate carbon and water footprints, in
134 order to evaluate the differences between the same impact category of different impact methods.
135 As mentioned, two different scenarios are considered in the study: the 2018 scenario, in which
136 photovoltaic panels and two biogas plants were already present in the company, and the
137 hypothetical 2019 scenario which considers that production is at full capacity, a larger number

138 photovoltaic panels is adopted, and the use of service water in the cheese factory is set to zero
139 thanks to the new concentration plant for whey. The latter consists of a reverse osmosis treatment
140 in which the final products are concentrated whey (30% of dry matter) and “permeate”, then used
141 as service water. The creation of a concentrated whey, allow to reduce the number of trucks trips
142 for disposal in a foreign country, because they can transport a product with few water inside.
143 Moreover, thanks to the permeate, it is also possible to consider zero the water used during cheese
144 production: consequently, water is used only for bovine drinking in farms and for the salting phase
145 in the cheese factory. This specific organic farming does not include water consumption because
146 only rainwater is used to cultivate fodder, but anyway fodder from SimaPro databases is used.
147 **Functional unit.** In LCA studies, the functional unit (FU) is the reference for input and output
148 data to quantify the performance of the product system (ISO 14040, 2006). In this analysis, the
149 FU adopted is 1 kg of organic Parmigiano Reggiano. Fat and Protein Corrected Milk is used to
150 produce the FU as suggested by the International Dairy Federation (International Dairy
151 Federation, 2015):

$$152 \quad FPCM \left(\frac{kg}{yr} \right) = Production \left(\frac{kg}{yr} \right) * [0.1226 * fat\% + 0.0776 * protein\% +$$

153 0.2534] (1)

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

156 **System boundaries.** The dairy supply chain is located in Emilia Romagna (Italy) and the study
157 takes into account three dairy farms and a cheese factory. For each dairy farm, organic farming
158 and breed operations are considered, as the crops production, sowing and fertilizing operations,

159 transports, purchased feeds, slurry management with the biogas plant, energy consumptions
160 (electricity, fuels and gas), water consumption for animal feed and milking and, at least, livestock
161 emissions (methane, dinitrogen monoxide and ammonia). Twice a day, milk is transported by a
162 refrigerated truck and is processed in the cheese factory. Cheese production includes all the
163 operations related to the preparation of Parmigiano Reggiano; for curding phase calf rennet and
164 whey are required. After that stage, the curd is cooked in a copper cauldron, moulded and placed
165 in salting tanks. Energy consumptions like electricity, steam and water consumption are
166 considered (Figure 1).

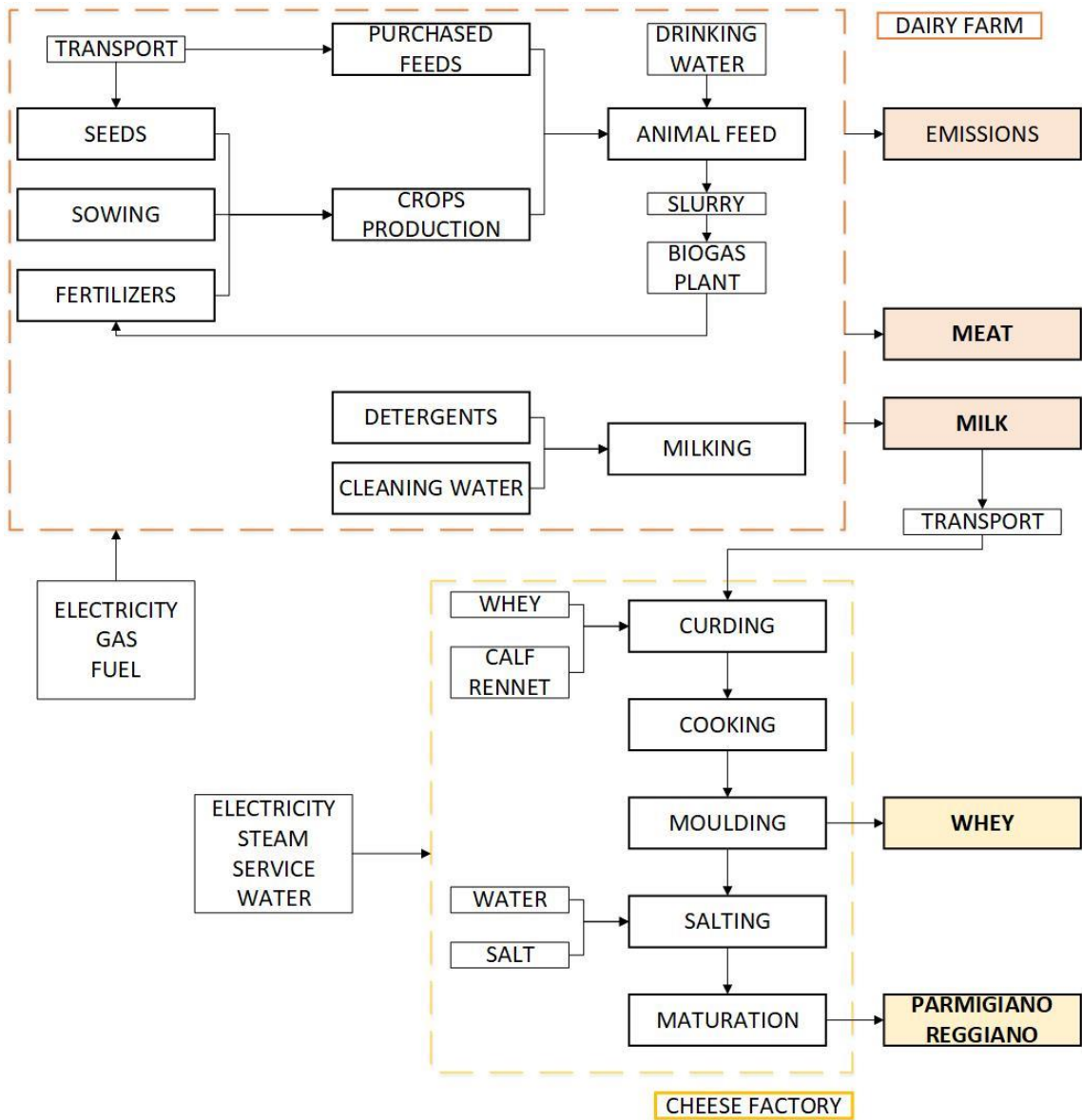


Figure 1 System boundaries

167

168

169 **Allocation.** According to the ISO 14040, the allocation between product and co-products is a
 170 breakdown of input and output flows and it should be avoided, but this is not possible in this
 171 study. Two products (milk and meat) are correlated at dairy farms level and two are related to the

172 cheese factory, i.e. Parmigiano and whey; the allocation considers the mass balance and it is made
173 according to the International Dairy Federation. In this study is not possible to avoid allocation,
174 because from a cow the company produce both milk and meat and at the same time the production
175 of cheese generates by-products. We used the mathematical equations to do the allocation
176 according to the standard procedure suggested by International Dairy Federation. The first
177 allocation between milk and meat is made according to the mentioned document, which suggests
178 the following equations (International Dairy Federation, 2015):

$$179 \quad AF = 1 - 6.04 BMR \quad (2)$$

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

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

$$184 \quad AF_i = \frac{DM_i * Q_i}{\sum_{i=1}^n (DM_i * Q_i)} \quad (3)$$

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

190 **2.2 Inventory analysis**

191 According to the ISO 14040, this stage quantifies resources, energy consumption and
192 environmental releases associated with the examined system, using a mass and energy balance of
193 FU. Data were collected from farms and cheese factory through personal interviews and a
194 checklist. Regarding the raw milk production, which is the main ingredient of Parmigiano
195 Reggiano (i.e. 14 litres of milk are necessary to produce 1 kg of cheese), the daily amount of milk
196 has been recreated considering primary data, except livestock emissions. The daily emissions
197 from animals and farm operations were obtained from the EcoInvent database for cow milk, in
198 particular biogenic methane, nitrous oxide and ammonia, which are, respectively, equal to 0.021,
199 0.0005 and 0.0025 for kilogram of fat and protein corrected milk.

200 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

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

202 For forages and cattle feed, the operation of sowing, fertilization and transport of suppliers are
203 considered. In particular, transport of suppliers is included in forages and feed recreated on
204 Simapro; suppliers are almost the same for each farms, because they are all part of a specific

205 group. As far as the transport of milk is concerned, farms are close to the cheese factory (14 km,
 206 2.8 km and 16 km) and the same means of transport is used “*Transport, freight, lorry with*
 207 *refrigeration machine, 3.5-7.5 ton, EURO4, carbon dioxide, liquid refrigerant, cooling*”. Thanks
 208 to biogas plants a part of electricity consumed is yet renewable in the first scenario. In table 2 and
 209 3, the data for daily energy consumption in cattle farms are reported for the first and second
 210 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

211 *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

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

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

215 Inventory data and annual production refer to 2018 for the first scenario, while the second
 216 hypothetical scenario takes into account the maximum production of the cheese factory and the
 217 following improvements: all electricity in the dairy supply chain is renewable and the service’s
 218 water consumption in cheese factory is equal to zero thanks to the new concentration plant for

219 whey. The table 4 shows consumption dataset in cheese factory which refers to the production of
 220 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

221 *Table 4 energy consumption in the Parmigiano Reggiano factory.*

222 As far as the packaging is concerned, only the materials, the extrusion/co-extrusion phase and the
 223 final disposal are analysed in this study. A non-recyclable vacuum solution is currently used to
 224 package 1 kg of organic Parmigiano Reggiano: a multi-material film made of nylon (OPA) and
 225 polythene (PE) made by a co-extrusion operation. However, a recyclable mono-material
 226 packaging made of polyethylene terephthalate and recycled polyethylene terephthalate (PET and
 227 R-PET respectively) is considered with the scope to replace the existing one. The amount of
 228 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	Nylon 6-6	1.9	19 %
	PE	Polyethylene, low density, granulate	8.1	81 %
Mono-material	PET	Polyethylene terephthalate, granulate, amorphous	5	50 %
	R-PET (50% recycled)	Polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate	5	50 %

229 *Table 5. Characteristics of packaging materials*

230 End of life of single-material packaging considers three waste treatments for packaging, even if
 231 it can be considered 100% recyclable; according to the Italian Sustainability Report (COREPLA,
 232 2018), the waste scenario of PET solutions considers: 44.5% of recycling, 43% incineration and

233 12.5% landfill. Instead, multi-material packaging is not recyclable and that percentage of
234 recycling is assigned to incineration, so the end of life is modelled considering 87.5% incineration
235 and 12.5% landfill Concerning the municipal incineration of waste in the EcoInvent database, the
236 benefits resulting from energy recovery in incineration (thermal and electric energy), are taken
237 into account. A general distance of 100 km by 16-32 ton, EURO5 truck is assumed for distances
238 between municipal solid waste collection centre and recycling, incineration and landfill sites for
239 both the packaging solutions

240 **2.2.1 Data quality**

241 Data quality is an important issue to establish the type of LCA analysis: according to the ISO
242 14044 (2006a) data quality refers to “characteristics of data that relate to their ability to satisfy
243 stated requirements”. To evaluate the standard of the data it is possible to distinguish two
244 categories: *specific* and *generic data*. The *specific data* are also called primary or site-specific
245 data: they refer to the information directly obtainable from the production site. *Generic data* (or
246 secondary data) are generic information from LCI databases, which meet the criteria of
247 completeness and representativeness; moreover, generic data may refer to *proxies*, data from
248 databases, which do not meet the precision criteria, completeness and representativeness.

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

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

258

259 **2.3 Life cycle impact assessment methods**

260 This study assesses carbon footprint and water footprint comparing different impact methods:
261 IPCC 2013, IPCC 2013 incl. CO₂ uptake, ILCD 2011 Midpoint +, ReCiPe 2016 midpoint (H) and
262 AWARE.

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

266 IPCC characterization factors for the direct global warming potential, except methane (PRé,
267 2020):

- 268 • Do not cover indirect formation of N₂O from nitrogen emissions;
- 269 • Do not consider CO₂ formation from CO emissions;
- 270 • Do not consider the range of indirect effects;
- 271 • Do not include radiative forcing of No_x, water, sulphate etc emissions in lower
272 stratosphere and upper troposphere.

273 **IPCC 2013 incl. CO₂ uptake** contains the climate change factors of IPCC with the timeframe of
274 100 years, including CO₂ uptake; the results can be calculated cumulatively as Climate Change
275 or per category: Climate change – fossil, Climate change – biogenic, Climate change – CO₂ uptake

276 and Climate change – land use and transformation (PRé, 2020).

277 According to the method description, IPCC characterisation factors for the direct (except CH₄)

278 global warming potential for air emissions are (PRé, 2020):

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

284 **ILCD 2011 Midpoint +** is the method used for Product Environmental Footprint (PEF) and it

285 presents sixteen impact categories: climate change, ozone depletion, human toxicity cancer effect,

286 human toxicity non-cancer effect, particulate matter, ionizing radiation human health, ionizing

287 radiation, photochemical ozone formation, acidification, terrestrial eutrophication, marine

288 eutrophication, freshwater ecotoxicity, land use, water resource depletion, mineral, fossil and

289 renewable resource depletion. The full name is “ILCD recommendations for LCIA in the

290 European context”. Characterization factors are set to zero for long term emissions, as a

291 requirement from the European Commission, which analysed several methodologies for LCIA

292 (PRé, 2020). In this study, climate change and water resource depletion of this method are taking

293 into consideration. According to this method, the climate change is the GWP calculating the

294 radiative forcing over a time horizon of 100 years based on IPCC 2007, but they are not identical,

295 because the method inventory of carbon dioxide is different between them. ILCD method

296 considers for air compartment: carbon dioxide, carbon dioxide – biogenic, carbon dioxide – fossil,

297 carbon dioxide – land transformation and carbon dioxide – peat oxidation. Instead, IPCC 2007

298 considers only carbon dioxide, carbon dioxide fossil and carbon dioxide land transformation.

299 As far as **ReCiPe 2016** method is concerned, the ReCiPe 2016 update (Huijbregts, et al., 2016)

300 of the 2008 version (Goedkoop, et al., 2009) provides characterization factors that are

301 representative for the global scale, instead of the European scale, while maintaining the possibility

302 for a number of impact categories to implement characterization factors at a country and

303 continental scale. It has many impact categories, but as far as the GWP and Water Consumption

304 ones are concerned it uses different approaches from other methods; e.g. the factors in Global

305 warming differ from the 100a time horizon in IPCC 2013 because climate-carbon feedback for

306 non-CO₂ GHGs is included, while in Water Consumption the consumption/extraction ratios were

307 provided and country-specific characterization factors were provided as well (many adaptation

308 has been given to this method) (Dekker et al. 2020). Midpoint (H) version has been considered

309 for the assessment in order to compare the result with the other selected methods and because it

310 appears as the most used one (Vitale et al., 2018) (Bottani et al. 2019).

311 **AWARE** is the recommended method from WULCA to assess water consumption impact

312 assessment in LCA (WULCA, 2021). It is a water use midpoint indicator representing the

313 Available WATER REMaining per Area in a watershed after the demand of humans and aquatic

314 ecosystems and it assesses the potential of water deprivation considering that the less water

315 remaining available per area, the more likely another user will be deprived. It is a recommended

316 method from WULCA (Water Use in Life Cycle Assessment, a workgroup under UNEP-SETAC

317 for Life Cycle Initiative) to evaluate the impact assessment of water consumption.

318 **3 Results**

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

321 **3.1 Carbon footprint**

322 The total greenhouse gas emissions of organic Parmigiano Reggiano have been calculated
 323 employing the IPCC 2013, IPCC 2013 incl. CO₂ uptake, ILCD 2011 Midpoint + and ReCiPe
 324 2016, as shown in Table 6. The kilogram of CO₂ equivalent is used to quantify the impacts. The
 325 aim is to show the results using different methods, underlining the difference between the first
 326 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
	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
IPCC 2013 incl. CO₂ uptake	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

327 *Table 6 Carbon footprint of 1 kg of organic Parmigiano Reggiano*

328 IPCC 2013 and ReCiPe 2016 methods refer to global warming potential as an impact indicator,
 329 instead climate change is used in the ILCD 2011 midpoint+ and IPCC 2013 incl. CO₂ uptake
 330 methods. Milk production is the main contributor to these results. At dairy farms level, transports
 331 of suppliers are included in forages and cattle feed impact, but the Table 7 shows the global

332 warming potential of 1 kg of FPCM transported from dairy farms to the cheese factory, pointing
 333 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
	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
IPCC 2013 incl. CO₂ uptake	Climate change - CO ₂ 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

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

335 Considering the two types of packaging, **Errore. L'origine riferimento non è stata trovata.**
 336 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
	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
IPCC 2013 incl. CO₂ uptake	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 ₂ eq	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

337 *Table 8 Carbon footprint of different packaging types*

338 3.2 Water footprint

339 The total amount of consumed water during a Life Cycle Assessment of organic Parmigiano
 340 Reggiano is calculated with AWARE, ILCD 2011 midpoint + and ReCiPe 2016 method and the
 341 unit of measurement is cubic meters of water. The aim is to show the volume of water consumed
 342 using different methods and underline the difference between the first and second scenario of 1
 343 kg of organic Parmigiano Reggiano. These methods have different impact categories to quantify
 344 water consumption: they are respectively water use (AWARE and ReCiPe 2016) and water
 345 resource depletion (ILCD 2011 midpoint+). Using AWARE for the first scenario 3.31 m³ of water
 346 are consumed, instead 3.01 m³ for the second; 0.11 m³eq and 0.102 m³eq are used for the first and
 347 second case according to the ILCD 2011 method. As far as ReCiPe 2016 method is concerned, in
 348 the first scenario 0.102 m³eq of water are consumed against 0.095 m³eq for the second scenario.
 349 As the carbon footprint, farm activities have the largest water consumption.
 350 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 (m³)	5.05E-04	1.01E-04	5.77E-04
ILCD 2011 (m³eq)	2.687E-06	5.37E-07	3.071E-06
ReCiPe 2016 (m³eq)	1.697E-05	3.395E-06	1.94E-05

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

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

	OPA + PE		PET + R-PET	
	Materials	EoL	Materials	EoL
AWARE (m³)	3.74E-02	2.49E-04	1.63E-02	2.69E-05
ILCD 2011 (m³eq)	1.84E-04	8.59E-07	1.11E-04	2.30E-07
ReCiPe 2016 (m³eq)	7.50E-04	1.06E-05	4.76E-04	2.87E-06

354 *Table 10 Water footprint of different packaging types*

355 **4 Discussion**

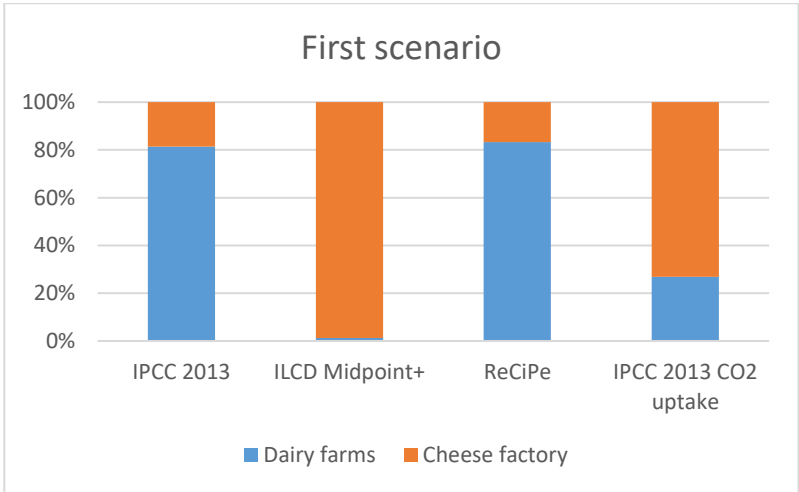
356 As far as the carbon footprint of organic Parmigiano Reggiano is concerned, IPCC 2013 and
357 ReCiPe 2016 methods have a similar impact value, while ReCiPe has the highest impact; ILCD
358 2011 midpoint+ and the cumulative IPCC 2013 incl. CO₂ uptake present an extremely low impact.
359 This difference is due to the biogenic and uptake carbon dioxide: biogenic carbon dioxide refers
360 to the emissions linked to the natural carbon cycle, which results from fermentation,
361 decomposition and processing of biological material especially at farms level and in this study it
362 is due to the cows' feeding thanks to different types of fodder such as maize, pea, soya, hay and
363 so on. ILCD 2011 midpoint+ considers biogenic CO₂ to assess climate change, which results
364 lowest because an amount of biogenic carbon is removed from the total global warming impact
365 (depending on the source, the biogenic carbon dioxide could have also a negative number). As a
366 matter of fact, according to the ILCD Handbook (European Commission JRC, 2010), it is
367 important to distinguish biogenic and fossil emissions, because carbon dioxide uptake is a
368 “resource from air” and it assumes a negative value, but on the other hand the carbon dioxide
369 emission (both fossil and biogenic) is considered as positive impact with the same characterization
370 factor. So ILCD Handbook recommends considering the emissions as positive value and the
371 biogenic carbon uptake with negative number (European Commission JRC, 2010). As mentioned
372 before, this method is modelled on Simapro considering for carbon dioxide substance: carbon
373 dioxide, carbon dioxide – biogenic, carbon dioxide – fossil, carbon dioxide – in air, carbon dioxide
374 – land transformation, carbon dioxide – peat oxidation.

375 As far as the guidelines of the Intergovernmental Panel on Climate Change are concerned, at

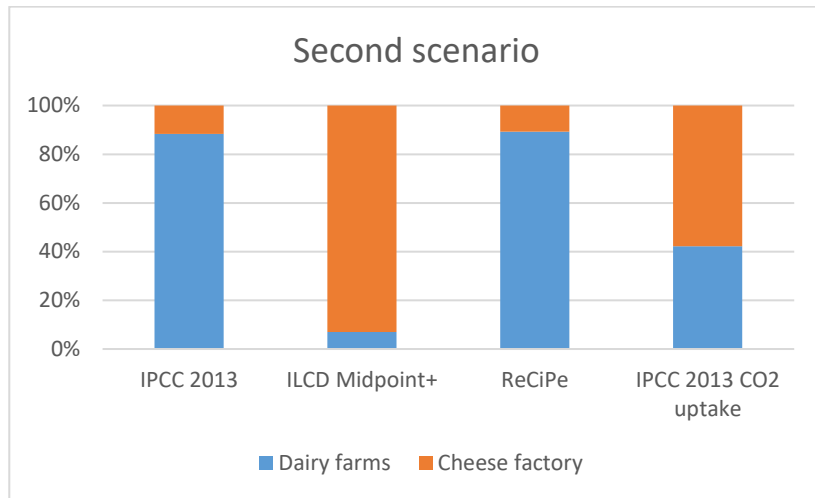
376 agricultural level, in the greenhouse gases inventory, the carbon included in the biomass is
377 released when harvested, according a stock change approach in which net emissions are calculated
378 by investigating the net changes in carbon stocks of a biomass carbon pool over time (IPCC,
379 2006) (Levasseur et al., 2013). According to (Levasseur et al., 2013) to avoid double counting
380 using IPCC guidelines, if biogenic carbon is released later in the life cycle (i.e. combustion of
381 bioenergy), the related carbon dioxide emissions are not taken into account. However, this
382 approach has been criticized, because biomass combustion generates more greenhouse gas
383 emissions than the use to fossil resources (per unit of energy) generating a carbon debt; this gap
384 is filled by the growth of biomass, although this takes a long time to grow and therefore there is
385 an impact on the climate due to the use of fossil resources in the meantime (Levasseur et al.,
386 2013). However, on SimaPro software regarding carbon dioxide substances, IPCC 2013 method
387 considers: carbon dioxide, carbon dioxide – fossil, carbon dioxide – land transformation, carbon
388 dioxide – to soil or biomass stock (the biogenic carbon dioxide uptake is not present). On the
389 contrary, IPCC 2013 incl. CO₂ uptake contains the climate change factors of IPCC (with the
390 timeframe of 100 years), including the CO₂ uptake and the results can be calculate cumulatively
391 as climate change or distinguish per category (fossil, biogenic, CO₂ uptake and land use and
392 transformation), but in environmental studies there is no consensus on how to evaluate the
393 potential life cycle global warming impacts of biogenic carbon emissions in LCA (Breton et al.,
394 2018). This different way to treat biogenic carbon shows a difference between environmental
395 impacts of various methods in life cycle assessment study (Levasseur et al., 2013). Even if
396 methods are similar, it is not possible to consider them equivalent, because the results depend in
397 the type of substances used to create method and mostly the type of data used to recreate the

398 inventory dataset, in particular for biogenic carbon dioxide uptake. This is the reason why this
399 study obtained different results analysing the organic Parmigiano Reggiano, where natural
400 sources are included. Instead, the carbon footprint of milk transports and packaging materials are
401 similar using the four different environmental methods.

402 Figure 2 and figure 3 represent the carbon footprint of both scenarios highlighting the
403 environmental burdens of dairy farms and the cheese factory. The charts show the different
404 contribution to the climate change (expressed in percentage) for dairy farms and cheese factory,
405 highlighting that for IPCC 2013 and ReCiPe methods dairy farms (the production of milk) have
406 the higher contribution to the final results, because biogenic and uptake carbon dioxide are not
407 directly taken into consideration. On the contrary, for ILCD and IPCC 2013 (CO₂ uptake) dairy
408 farms have the lowest contribution, thanks to the consideration of biogenic and uptake substances
409 with negative sign in the production of milk.



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411 *Figure 2 Carbon footprint of dairy farms and cheese factory for the first scenario*
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Figure 3 Carbon footprint of dairy farms and cheese factory for the second scenario

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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,

428 saving extraction and creation of the virgin one.

429 As regards the water footprint of the analysed product, ILCD and ReCiPe 2016 present a lower
430 consumption and this is due to the different methods of water calculation. Water use (AWARE)
431 indicator represents the water available remaining per area in a watershed; the latter indicator is
432 calculated at first as the difference between the availability of water and the demand of humans
433 and aquatic ecosystems, building on the assumption that the less water remaining available per
434 area, the more like another use will be deprived (PRé, 2020). Its indicator is first calculated as the
435 water Availability Minus the Demand and is relative to the area, then the result is normalized with
436 the world average value and inverted. The number of cubic meters is the relative value of water
437 consumed in comparison to the average cubic meters consumed in the world. According to the
438 description of this method, the indicator is in a range between 0.1 and 100, where number 1 is the
439 world average and a value of 10 i.e. is the region where there is 10 times less available water
440 remaining per area than the average of world (PRé, 2020). It is also important to notice that the
441 implementation of this method in Simapro includes only the generic factors for unknown water
442 use and it exclude the specific factors regards agricultural and non-agricultural use of water. To
443 assess the water resource depletion in ILCD method, the characterization factors are based on the
444 Ecological Scarcity Method (Frischknecht et al. 2009) and at midpoint level they are calculated
445 by EC-JRC; these characterization factors are calculated for water depletion, considering that a
446 reference water resource flow is based on a weighted average of EU consumption and eco-factors
447 of other water flows are connected to that reference water flow (European Commission JRC,
448 2012). The ecological method is based on the “distance to target” rather than an impact assessment
449 method which is based on damage; the eco-factors calculation is related to the relation between a

450 critical and a current flows and in this way it is possible to regionalize the results (Frischknecht
451 et al. 2009). According to this method, the freshwater availability is different in the world, because
452 in some regions it is limited and in others there is an excess; so eco-factors are calculated for
453 specific countries (as Switzerland and other OECD states) and for six different scarcity situations:
454 low, moderate, medium, high, very high and extreme. On these bases, it is important to underline
455 that the recommended characterization models and associated characterization factors in ILCD
456 are classified according to their quality (level I, level II and level III) and the impact category of
457 water resource depletion has level III (recommended, but to be applied with caution) (European
458 Commission JRC, 2012).

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

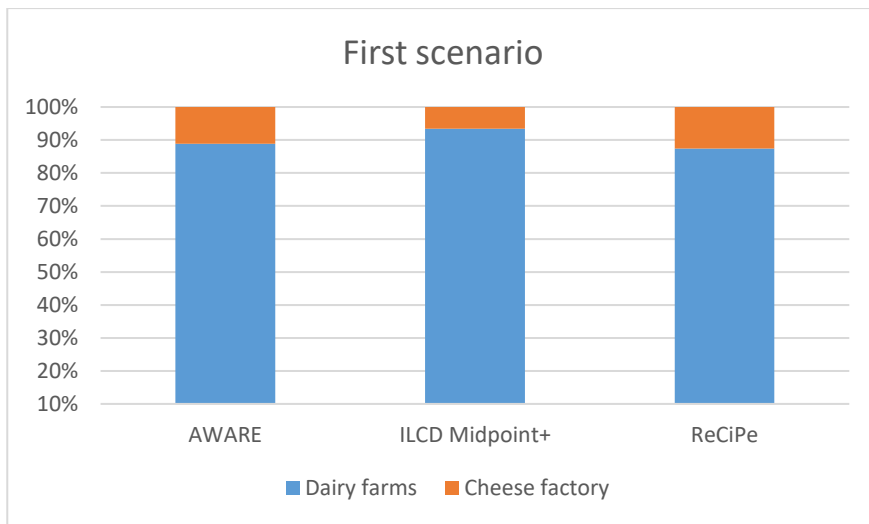
467 In the end, there is a great difference between AWARE and the other methods, both in the first
468 and the second scenario. As specified before, this difference is due to the way of quantifying the
469 water consumption, because the methods differ in the data sources and the scarcity equations: a
470 demand-to-availability ratio DTA (i.e. AWARE) or a withdrawal-to-availability ratio WTA (i.e.
471 ILCD 2011 midpoint+ and ReCiPe 2016). As a matter of fact, the scarcity equations are the key

472 difference between the midpoint methods; withdrawal-to-availability-ratio measures how refers
473 to how much water in an area is withdrawn in the industrial process than how much is available.
474 Instead, DTA includes the water demand of human and ecosystems, investigating the total amount
475 of water available and it subtracts the demand to calculate how much water is available for use
476 (Prè-sustainability, 2021). These different methods to calculate the water consumption, obviously,
477 do not have in Simapro the same inventory data sources. They differ in the elements number,
478 because investigating the inventory water for AWARE methods it is possible to find 1851
479 elements, instead 1378 elements for water resource depletion calculation in ILCD and 2091 for
480 ReCiPe water consumption. In Simapro in the all three methods the waters have always the same
481 CAS number (007732-18-15), but the characterization factors are different; e.g. in ReCiPe the CF
482 assumes only “-1”, “0”, “-0.001” values, instead different numbers for the other two methods,
483 depending on the type of water origin.

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

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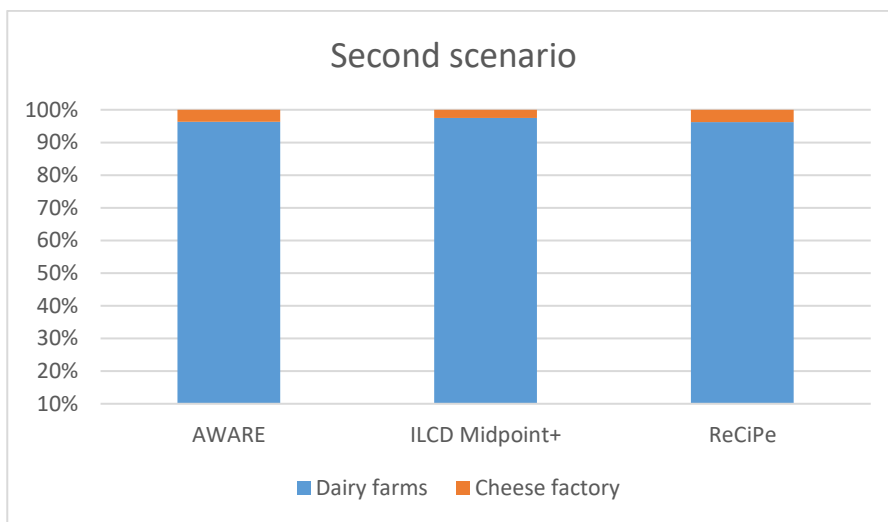


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Figure 4 Water footprint of dairy farms and cheese factory in the first scenario

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

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Between the first and second scenarios, the total amount of water footprint decreases both of using

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AWARE, ReCiPe 2016 and the ILCD 2011 method, while as far as the specific phases are

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concerned, in the case of AWARE method a strongly decreasing of the “cheese factory” impact

503 is balanced by an increasing of the “dairy Farms” impact.
504 As regards the packaging type, also considering the water consumption, the recycled packaging
505 materials remain the best solution, thanks to the use of half recycled material, since its water
506 contribution is not accounted for. The multi-material packaging is also lacking in the percentage
507 of recycling at the end of life.

508 **5 Conclusions**

509 This work aimed to assess the environmental impact of an organic Parmigiano Reggiano produced
510 in Emilia Romagna (Italy), comparing a 2018 scenario with a hypothetical 2019 scenario, where
511 a larger number of photovoltaic panels and a new whey’s concentration plant were adopted in the
512 dairy farm, considering also a new material made of R-PET to package the famous Italian cheese.
513 Furthermore, the research wanted to show eventual unevenness in the application of different
514 LCIA methods to evaluate the impact of food products. Indeed, numeric results depend on the
515 different methods used: considering 1 kg of Parmigiano Reggiano the climate change of the ILCD
516 2011 and IPCC 2013 CO₂ uptake methods resulted lower than IPCC 2013 and ReCiPe 2016,
517 because it considers biogenic CO₂ in its life cycle. On the contrary, the difference in the packaging
518 impacts was not relevant, because in the fossil plastic production biogenic resources are not used.
519 Different results were obtained also by assessing the water footprint, because the ILCD 2011
520 midpoint+ method considers a European consumption of water, while AWARE are based on
521 global average consumption and ReCiPe considers the regionalized impacts. This can
522 demonstrate that the application of different LCIA methods can give different impact results for
523 the same product.

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

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537 PSR 2014 – 2020 – Tipo di operazione 16.2.01 “Supporto per progetti pilota e per lo sviluppo di
538 nuovi prodotti, pratiche, processi e tecnologie nel settore agricolo e agroindustriale. Avviso
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