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Calculation Method of the Carbon Footprint of Products of Animal Origin Integrated with the Physiological Absorption of Carbon Dioxide: Calculation Example of the CFP of Mozzarella di Bufala Campana DPO

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Abstract

The environmental impact of emissions appears to be increasingly important for food, particularly those of animal origin. The LCA (Life-Cycle Assessment) method, an internationally standardized method used to calculate the environmental impact of goods or services, in the carbon footprint, does not take into account the carbon set and consequently the subtraction of carbon dioxide by the plant biomass whether or not aimed at the production of food of animal origin. This methodology could overestimate the carbon dioxide generated to obtain plant and animal products that require their use. For the production of Mozzarella di Bufala Campana DPO, in this specific case, the masses of the various forage and cereal species used were quantified starting from the food rations of the different categories divided by age and production phase (dry, lactation, young livestock and heifers). The population includes all the animals reared in the areas covered by the DPO specification and with a milk production orientation. The carbon fixed in the forage and consequently the carbon dioxide subtracted from the atmosphere was calculated on the food mass, through the various harvesting speeds and the percentages of dry matter. The purpose of this contribution was to calculate the number of greenhouse gases emitted during the digestive and fermentative processes as well as that produced by the manure and the CO_2 emitted with respiration by comparing it with the sequestration of carbon, and therefore of carbon dioxide, in all plants and all vegetable raw materials, grown in Italy and abroad, used to feed the buffaloes destined for the production of buffalo mozzarella from Campania (Mozzarella MBC) in the DPO area. The amount of greenhouse gases converted into equivalent carbon dioxide emitted during production is lower than the carbon dioxide removed from the atmosphere. For every kg of Mozzarella di Bufala Campana DPO, a total of about 52 kg of CO_2eq is subtracted. Therefore, if this factor were taken into account for agricultural and animal products, the environmental impacts in terms of emissions would be reset.

Keywords
Carbon footprint; environmental impact; greenhouse gases; products of animal origin

1. Introduction

The environmental impact of emissions appears to be increasingly important for food of animal origin. Environmental footprints are created to estimate the environmental impact that a product or service may have on one or more environmental components throughout its life cycle, such as the procurement or extraction of raw materials, transformation, production and consumption. The carbon footprint represents the total amount of CO_2 emitted, that is, the total greenhouse gas emissions associated directly or indirectly with producing food of animal origin [1]. According to the provisions of the Kyoto Protocol, the greenhouse gases responsible for GW: carbon dioxide, methane, nitrogen oxides and hydrofluorocarbons. Each greenhouse gas contributes differently to the greenhouse effect; for this reason, the contribution of each gas has been converted into equivalent CO_2, despite having the highest half-life, and is taken as a unit with less climate-altering power than other gases. Methane has a climate-altering power about 24 times that of CO_2, has a significantly lower half-life of 12 years vs 50-200 than CO_2 and has a 298 value lower than nitrous oxide (N_2O). The phenomenon [2] is expressed with the following formula:

$$\mathrm{Kg\ CO_2eq = kg\ CH_4 \times 24 + kg\ N_2O \times 298 + kg\ CO_2}\ [3, 4].$$

To evaluate the carbon footprint of a product or service, a standard technical standard was developed (UNI et al. "Greenhouse gases - Climate footprint of products - Requirements and guidelines for quantification and communication") which entered into force 11 September 2014 [2]. UNI is the acronym of the Italian National Unification Body, a private association that elaborates and publishes technical standards for all industrial, commercial and tertiary sectors and represents Italy in the European (CEN) and world (ISO) standardization organizations). The methodology used complies with this UNI CEN ISO standard technical standard and is the LCA (Life et al.). This methodology foresees different categories of environmental impact. The impact category regarding emissions is the Carbon Footprint (CFP) or the estimate of greenhouse gas emissions: CO_2, CH_4, N_2O converted into CO_2eq, carbon dioxide equivalent. The Life Cycle Assessment (LCA) has also consolidated in the dairy sector in the last fifteen years. In 2010, the International Dairy Federation (IDF) issued a specific guideline for the dairy sector [2]. This guide focuses on calculating the carbon footprint, this document could be considered a step forward for the harmonization of LCAs in milk production, as it outlines all the criticalities of the sector. Essentially, greenhouse gas emissions attributable to livestock activities can be traced back to three different sources: the first is that of methane of ruminal origin, that is, that emitted during the digestive processes of ruminants and that which derives from emissions due to manure and their management. To these must be added the emissions due to agricultural processing, transport, and production of pesticides and fertilizers for plant products used for animal feed [3]. ISPRA [4] estimates for Italy in 2017 an emission by the livestock system equal to about 22 million tons of CO_2, which represents 5% of the 428 million tons released into the atmosphere by agro-zootechnical activities from our country. However, these data do not consider the enormous potential for carbon sequestration of forage crops, particularly pastures, and the forest-pastoral systems present in Italy. Pulina [5] estimates that about 50% of the more than 10 million ha of Italian wooded areas is grazed mainly by cattle from the cow-calf line to which the one used by small ruminants should be added. Furthermore, farms (ruminants and non-ruminants) and in particular the management of manure, if done correctly, and if extended to all intensive or semi-intensive farms, could be a resource for the production of methane through bioreactors in quantities far higher than that emitted into the atmosphere by rumen fermentations. Since 2002, the increase in methane in the atmosphere has not been directly proportional to that of the increase in ruminants, it can be deduced that the increase in methane in the atmosphere is, only in part, attributable to the increase in the number of ruminants raised [6].

1.1 Bibliographic Review of the Studies Carried Out

Dalla Riva et al. [7], using the LCA methodology compliant with ISO 14040 and ISO 14044, conducted a study on the emissions related to the production of cow's milk mozzarella in Italy and stated that 6.66 kg of CO_2 equivalent developed for each kg of mozzarella produced with milk. In contrast, higher emissions are developed for that obtained with purchased curds, usually of transalpine origin due to transport and the use of special production plants and the electricity necessary to transform the curd into mozzarella.

According to a study by Vergé X.P.C. et al. [8], the calculated carbon footprint of raw milk is between 0.9383 and 1.12 kg CO_2eq/L, depending on climatic conditions and herd management.

Rotz C.A. et al. [9] instead reports values between 0.37 and 0.69 kg of CO_2eq/kg of corrected milk (FCM 4%). Verge X. et al. [8] state that among the carbon footprints (CF) of dairy products, three products have significantly higher CF values: cheese (5.3 kg CO_2eq/kg), butter (7.3 kg CO_2eq/kg) and powdered milk (10.1 kg of CO_2eq/kg).

The results of the carbon footprint calculation resulting from the manufacturing process of each product depend on the amount of milk needed, the co-product allocation process (based on fat and protein content) and the amount of energy used. Verge X. et al. [8], included mozzarella in the LCA of Canadian dairy products. However, the study only estimated GHG emissions. At the same time, all post-dairy planting and solid waste treatment stages were excluded from the count. They did not differentiate between the various cheeses (cheddar, specialty, melted or aged cheeses). In both of the studies cited [8, 9] carbon dioxide from the lung respiration of animals was omitted from the emissions and carbon sequestration was not considered. Emissions related to breeding (manure management, rumen fermentation) and nutrition (agricultural processes, food production and transport) included in the LCA of Dalla Riva et al. contribute respectively 2.50 and 3.04 kg CO_2eq for each kg of mozzarella out of the total of 6.66. These results were compared with the approach developed by the researchers of the "Euro-Mediterranean Center on Climate Change" (CMCC) and the Institute of Services for the Agri-food Market (ISMEA), with the financial support of the "National Rural Network 2014-2020 ", which generated a" web tool "model. If we estimate the emissions exclusively for buffalo breeding and feeding, the results are almost congruent with this.

The emissions attributable to agriculture are, considering the population of the DPO mozzarella di bufala area, approximately 125,000 t of CO_2eq, which divided by about 50,800 t of MBC DPO returns a value equal to 2.46 kg of CO_2eq per kg of MBC. Feeding, on the other hand, produced emissions of approximately 150,000 t of CO_2eq which, divided by approximately 50,800 t of MBC DPO, is equal to 2.95 kg per kg of MBC.

As regards the carbon footprint (CF) of 1 kg of Mediterranean buffalo milk [10] corrected to 4% (FPCM) produced in Italian farms through a simplified Life Cycle Assessment, it was estimated at 3.75 kg of CO_2eq. This quantity is attributable respectively for 45% and 25% to enteric CH_4 and CO_2 eq deriving from agricultural activity which represent 34% of total greenhouse gas emissions.- TGE for the production of agri-food.

In another study Sabia et al. [11] evaluated the environmental loads expressed as CO_2 eq from dairy buffalo heifers confined indoors (4 m^2/head) and in outdoor paddocks (4 m^2/head) compared to those subjected grazing in the Mediterranean environment. Compared to the confined system, that of the free subjects was 35.7% lower due to biogenic methane production followed by CO_2 from fossil fuels and the environmental burdens for acidification potential, eutrophication potential and non-renewable energy consumption. In the confined system, the major pollutant was ammonia, leaching of nitrates into water, and the use of crude oil. This study, however, shows that land take was higher in the free system than in the confined system (20,349 vs 1,381 m^2 per year, respectively). From 7 to 8 months of age up to puberty it has been found that for 1 kg of buffalo milk (FCM 4%), grazing reduces various sources of pollution and production costs but requires greater land use.

Regarding dairy cattle, the environmental impact, through the Life Cycle Assessment (LCA) approach, grazing livestock and soil carbon sequestration [12] could be useful to mitigate the balance of greenhouse gases (GHG).

The assessment of greenhouse gas emissions of small mountain farms, using the LCA approach, highlighted, considering 4% of MCA kg of milk, the Usable Agricultural Surface (UAL) and two different allocation methods, such as small farms (<30 LU = LLU) tended to have higher GHG emissions than larger farms (>30 LU) per kg FPCM (1.94 vs. 1.59 kg CO_2-eq/kg FPCM, $P \leq 0.10$). The results are reversed when considering m^2 of UAL as a functional unit (0.29 vs. 0.89 kg CO_2-eq/m^2, $P \leq 0.05$). The difference between the two groups becomes less evident considering the physical allocation instead. When the contribution of soil carbon sequestration was included in the LCA and no allocation method was applied, smaller farms (LLUs) had higher GHG emissions per kg FPCM than larger farms (large = HLU; 1.38 vs. 1.10 kg CO_2-eq/kg FPCM, $P \leq 0.05$). Also, in this case the situation was reversed by considering the m2 of UAL as a functional unit (0.22 vs. 0.73 kg CO_2-eq/m^2, $P \leq 0.05$). To highlight how the presence of meadows is crucial for the carbon footprint of small farms, this study also simulated the forage self-sufficiency of 100% of farms. In this case, an average reduction of GHG emissions per kg of livestock FPCM without and with physical allocation was estimated at 27.0% and 28.8%.

Sabia et al. [13] showed that biodiversity in the Alpine environment is influenced by livestock breeding. In four different dairy production systems using the LCA approach the carbon footprint (CF) was studied in alpine farms in the Autonomous Province of Bolzano.

The system with the lowest environmental impact in terms of CF was that of the Bruna farms whose cows consumed 7.6 kg of concentrate against 3.7 kg (1.14 kg CO_2-eq/kg of FPCM) while the system with the greatest impact was that of the Grigio Alpino farms whose cows consumed 3.0 kg of feed (1.55 kg CO_2-eq/kg of FPCM).

Including the reduction in FC due to soil carbon sequestered by the meadows, that of the cows of Grigia Alpina herds whose cows consumed 3.0 kg of feed had the least impact when considering biodiversity damage, while that of the Brown breed herds whose cows consumed 7.6 kg of feed, concentrated feed had the greatest impact in terms of damage to biodiversity. This study indicates the importance of including carbon sequestration in grassland soils and its effects on biodiversity when calculating the environmental performance of dairy farms.

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This study indicates the importance of including carbon sequestration in grassland soils and its effects on biodiversity when calculating the environmental performance of dairy farms. In the case of beef cattle, considered the main culprits of greenhouse gas (GHG) emissions in the livestock sector, Stanley et al. [14] demonstrated, using life cycle analysis (LCA), that meat obtained from grass determines higher quantities of greenhouse gases than those obtained from animal feed (FL). Optimal forage utilization, however, can improve animal and forage productivity and potentially sequester more soil organic carbon (SOC) than continuous grazing. Grazing MPA may contribute to climate change mitigation through SOC sequestration and challenges existing conclusions that only livestock intensification reduces the overall GHG footprint of beef through higher productivity. Soil carbon sequestration [15] is responsible for most of the agricultural sector's greenhouse gas (GHG) mitigation potential.

However, since soil C sequestration is reversible and maybe the time of disturbances, loss of variation and climate change, there is a need to reduce CH_4 and N_2O emissions from the livestock sector. It is essential: 1 to avoid tillage and conversion of pasture to arable land, 2 to moderately intensify nutrient-poor permanent grassland, 3 to use light grazing instead of heavy grazing, 4 to increase the duration of grazing; 5 Reduce the conversion of meadows into grassy leguminous clearings or permanent meadows.

Ultimately, the data emerging from the bibliography, although valuable, highlight how to evaluate the environmental impact of livestock activities it is necessary to consider numerous elements such as the use or not of fresh milk rather than curds, the use or not of grazing, the quantity of concentrated feed administered, the type of cheese (fresh vs aged). In all cases, the studies omitted the emission of carbon dioxide from the lung respiration of the animals and the sequestration of carbon in the soil, which is useful for mitigating the balance of greenhouse gases (GHG), was not always considered.

2. Materials and Methods

2.1 Emissions Due to the Entire Processing Cycle

To calculate the carbon sequestration along the entire production chain of Mozzarella di Bufala Campana DPO, we started from the number of buffaloes bred in the areas included in the DPO production specification, present in the national zootechnical register [16]. The DPO area, and therefore the buffaloes raised there, includes all the municipalities of the provinces of Caserta and Salerno, some municipalities in the province of Naples, Foggia, Latina and Frosinone, two of the province of Benevento, a municipality in the province of Isernia and Rome [17]

A food ration was hypothesized (Table 1), considering that each production category has different nutritional needs [18]. From the sum of the estimates of the quantity of food of the main cultivated and used plant species, it was possible to trace the quantity of plant biomass used. From the quantity of cereals/flours used, the vegetative biomass was calculated through the various harvest indices. The term harvest index (HI) is represented by the relationship between the dry matter production of tissues with economic value (in our case, the grain that is harvested) and the dry matter production of the whole plant, excluding the roots [19, 20]. Therefore, the underground vegetative biomass, the crop residues that do not contribute to the removal of carbon dioxide for the fermentation processes during degradation after the burial of agricultural processes, have not been considered. As far as fresh fodder or hay is concerned, the dry matter, the amount of carbon content and the amount of CO_2 fixed by the Calvin-Benson cycle and then sequestered and subtracted from the atmosphere were traced from the biomass produced. The biomass considered also includes crop residues buried during agricultural processing.

Table 1 Main foods administered in the average food rations, calculated dry matter of the total biomass of the plant, carbon content and carbon dioxide sequestered from the atmosphere for single head in DPO area.

Age	Main foods	Average ration, kg/day/head	Dry matter, t/head/year	CO_2 subtracted, t/one head/year
0-6 month	corn silage	3.0	0.383	0.662
	maize grains	3.2	2.920	5.046
	soybeans	0.5	0.730	1.261
	mixed hay	1.0	0.310	0.536
	alfalfa	1.5	0.465	0.804
			Total	**8.310**
6 -12 month	corn silage	4.2	0.537	0.927
	maize grains	3.0	2.738	4.730
	soybeans	0.8	1.168	2.018
	mixed hay	2.0	0.621	1.072
	alfalfa	2.0	0.621	1.072
			Total	**9.820**
12-24 month	corn silage	5.3	0.677	1.170
	maize grains	3.8	3.468	5.992
	soybeans	0.9	1.314	2.271
	mixed hay	2.5	0.776	1.340
	alfalfa	2.5	0.776	1.340
			Total	**11.861**
Lactation	corn silage	18.0	2.300	3.974
	maize grains	4.8	4.380	7.569
	soybeans	3.0	4.380	7.569
	mixed hay	3.0	0.931	1.608
	alfalfa	2.0	0.621	1.072
			Total	**21.791**
Dry, Bulls	corn silage	10.0	1.278	2.208
	maize grains	1.1	1.004	1.734
	soybeans	0.8	1.168	2.018
	mixed hay	8.0	2.482	4.289
	alfalfa	-	-	-
			Total	**10.249**

The physiologically contained quantity of carbon is 48% of the dry matter [21]. From this the quantity of CO_2 subtracted from the atmosphere was calculated, stoichiometrically equivalent to the carbon contained, being the only source of carbon [22]. In particular, the main plant species used in food were taken into consideration: corn grain, cultivated to a state of vitreous ripeness suitable for the production of grains; maize for ensiling grown up to the milky-waxy stage of ripeness; oats, mainly used as hay; sorghum, used green or in the form of silage; alpha, used for the production of hay; soybeans used in the form of various products, flours and other types of by-products. As confirmed by Matthew W. et al. [23] if carbon sequestration is taken into account the balance is favorable for carbon footprint purposes, for example one ton of alfalfa contributes with a negative balance equal to - 213 kg CO_2, i.e. one ton of alfalfa removes 213 kg of CO_2 from the atmosphere. This negative result is net of all emissions which include all agricultural processes and those related to the production of fertilizers and pesticides, electricity, fuels and the operation of machinery. In this way, it was possible to calculate the net contribution of the subtraction of carbon dioxide from the crops of food intended for livestock. If this balance is extended to all animal species reared, for example in Italy, the total CO_2 set exceeds the total CO_2eq produced/emitted by 10% [24].

2.2 Quantification of Rumen Emissions and Manure Emissions

The emissions of the physiological processes of all the buffaloes reared in the area dedicated to the production of Mozzarella di Bufala Campana DPO were quantified. First, the exact number of animals was quantified, divided by category and age. (ANZ), National Zootechnical Registry, Statistics, data as of December 2021. These animals have been converted into standard adult animals in the DPO area. The data on rumen methane emitted by buffaloes were extrapolated and the same procedure was extended for the emissions of methane, carbon dioxide and nitrous oxide deriving from the management of both solid and liquid manure, from manure left on pasture or during spreading in agricultural land as a fertilizer [25]; all emissions have been converted and expressed in carbon dioxide equivalent (CO_2eq). The value of the [26] database, has been extrapolated and proportioned to the number of heads surveyed in the DPO area and therefore only the heads used in the processing cycle of Mozzarella Di Bufala DPO. The sum of the three emissions, expressed in kg of CO_2eq and related to the quantity of mozzarella produced.

2.3 Quantification of Carbon Dioxide Subtracted from the Atmosphere

In addition to the negative sequestration due to crops, another emission kept in mind and calculated in this study is the CO_2 emitted during physiological respiration. The bred subjects were standardized to adult buffalo and the amount of anhydride was calculated based on their number according to estimates by Kinsman R. et al. [27], which estimate for a standard adult bovine (in average environmental conditions) an emission of about 5756 liters of carbon dioxide in conditions of average humidity and temperatures. This amount of carbon dioxide is attributed to an adult standard bovine. To calculate the total carbon dioxide emitted by respiration by all the animals reared in 2018 for the production of MBC DPO, all categories were standardized to adult buffalo: subjects over 24 months of age were considered standard adult cattle; for animals aged between 12 and 24 months, a mass equal to approximately 7/10 of that of an adult animal was estimated; for those aged from 6 to 12 months a mass equal to 1/8 of an adult head, and for animals aged from 0 to 6 months a mass equal to 1/12 of that of an adult. The number of buffaloes reared in 2020 in the areas covered by the buffalo mozzarella of protected origin (MBC) protected designation of origin (DPO production specification was approximately 338,000 by the national livestock registry (ANZ). The number of buffalos reared refers not only to lactating animals but to all categories of the buffalo population in the DPO area. We specify that the population reported by the ANZ [16] is divided not only into males and females, but into four age groups: from 0 to 6 months (heads 23,500), from 6 to 12 months (heads 25,600), from 12 to 24 months (heads 44,500) and over 24 months (heads 244,000). The population over 24 months was divided into buffaloes that gave birth, lactating (167,000 head), those that did not give birth, then probably dry (68,000) and 9,200 breeding males. No human, animal or plant subjects were involved in the study.

3. Results

The milk production destined for Mozzarella di Bufala Campana DPO in 2020 was approximately 287,000 t [28]. In the same year, almost 50,677 t of MBC DPO were produced, presumably deriving from about 204,000 t of milk, considering a 24-25% dairy yield, as the remainder is probably destined for non-DPO buffalo mozzarella.

The export was mainly destined for the market of Germany, France, Great Britain, the United States, Spain and the Netherlands [29]. The% m, m yield was calculated using the Intrieri [30] or Altiero [31] formula. We specify that the two formulas provide comparable results except in the last month of lactation, or when the values of % fat and protein exceed the value of 9.5 and 5.3 respectively [32]. This method, used to calculate the PKM genetic index (Mozzarella et al.), is unreliable because only 33% of the population is correctly estimated [33]. The quantity of carbon dioxide emitted with the physiological lung respiration was calculated per standardized adult buffalo head. In particular, the animals from 0 to 6 months emitted about 26,000 t of CO_2 by breathing, those between 6 and 12 months about 58,000 t, those between 12 and 24 months about 134,000 t, the lactating animals about 631,000 t, 258,000 dry heads and breeding males about 35,000 t. In 2020, with the physiological lung respiration, the animals reared for the production of milk destined for the production of Mozzarella di Bufala Campana DPO emitted approximately 1,144,000 t of CO_2. The respiration of the reared buffalo heads contributes about 23 kg of CO_2 eq for every kg of mozzarella. Table 1 shows the average food ration used, formulated based on the nutritional needs of the various categories [18], the CO_2 value subtracted from the atmosphere for each animal per year of the different categories is then reported. Table 2 shows the number of animals reared in the DPO area and quantity of carbon dioxide seized from the atmosphere and the quantity of carbon dioxide emitted with physiological lung respiration. In 2020, with the physiological lung respiration, the buffaloes reared for milk production to produce Mozzarella di Bufala Campana DPO emitted approximately 1,144,000 t of CO_2 (Table 3). The respiration of the reared buffalo brings about 23 kg of CO_2 eq for every kg of mozzarella. This added value to the 6.66 kg of CO_2eq/kg of mozzarella calculated for the entire production cycle [8] becomes about 30 kg of CO_2eq/kg of mozzarella. To these quantities issued must be added 652.750.366 kg those deriving from agricultural processing for a total of 1.797.031.749 kg, the mass of CO_2eq deriving from ruminal methane and the emissions of manure stored and scattered in agricultural soils is also added, approximately 641.151.600 kg. If the quantities seized by the vegetables used are subtracted from the quantities produced, we obtain kg -3.622.990.396 which divided by the kg of mozzarella produced gives a Carbon Footprint Net value of about - 59 kg for kg of mozzarella. If the emissions for the processing and transformation cycle (LCA) are added, the net CFP is approximately **-52** kg per kg of mozzarella produced (Table 4 and Figure 1).

Table 2 Number of animals reared in DPO area and quantity of carbon dioxide seized from the atmosphere.

Age	Number reared heads in 2020	CO_2 emitted with breathing (t)	CO_2 Subtracted (t/one head/year)	Total CO_2 Subtracted (t)
0-6 month	23,533	26,000	8.310	195,553
6 -12 month	25,683	58,000	9.820	252,215
12-24 month	44,451	134,000	11.861	538,434
Lactation	166,982	631,000	21.791	3,638,771
Dry, Bulls	77,572	35,000	10.249	795,049
Total	**338,221**	**884,000**		**5,420,022**

Table 3 Quantity of carbon dioxide emitted and subtracted and relationship with the quantity of DPO mozzarella produced.

	m CO_2eq (Kg)	m mozzarella (Kg)	kg CO_2eq/kg mozzarella
Breathing	1,144,281,383		22.6
CO_2 sequestration	-5,420,022,145	50,677,000	-107.0
Agriculture emissions	652,750,366		12.9
Rumen and manure emissions	641,151,617		12.7
Emission less manufacturing	**-2,981,838,779**	**CFP**	**-58.8**

Table 4 Emissions (for produced each kg of Mozzarella di Bufala Campana DPO), and CO_2 fixed by vegetation, net carbon footprint.

CO_{2eq} emitted into the atmosphere. kg		CO_2 subtracted from the atmosphere. kg	
Life-cycle assessment	6.66	22.5	CO_2 subtracted from crops abroad
CO_2 emitted by breathing	22.6		
Agriculture emissions	12.9	84.5	CO_2 subtracted from crops in Italy
Rumen and manure emissions	12.7		
Total	54.7	-107.0	Total
Carbon footprint **net**	-**52.2**		Carbon footprint **net**

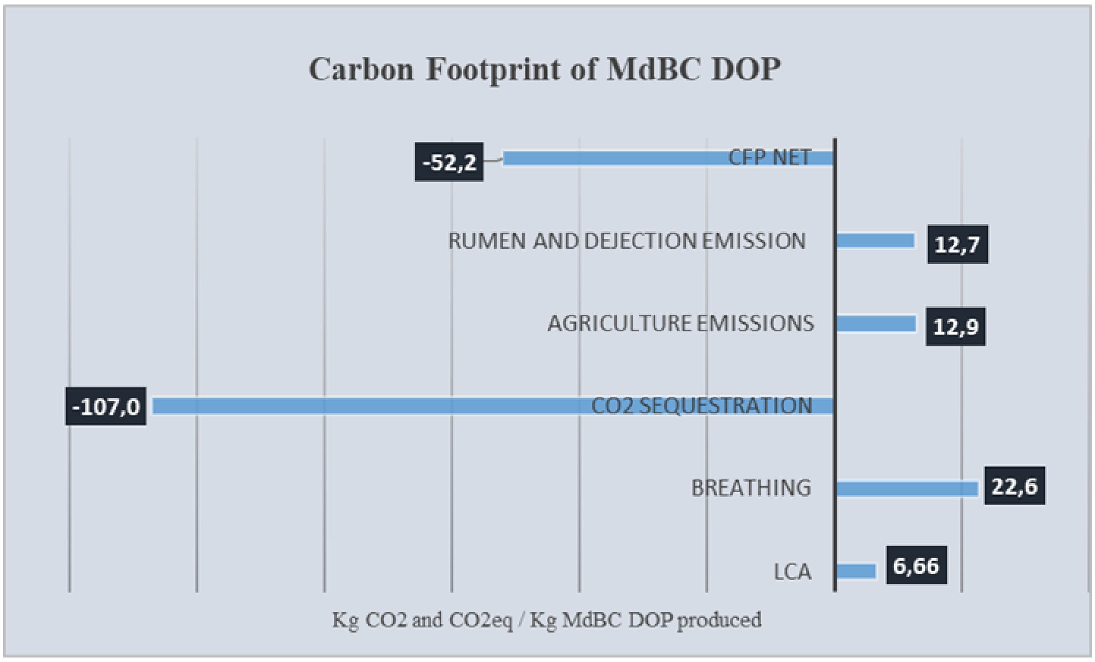

Figure 1 Scheme of the various contributions in the calculation of the CFP of the MdBC DPO.

4. Conclusion and Discussion

From the processed data it emerges that in Italy the CO2 fixed and sequestered in the atmosphere by cultivated and imported plants, for feeding the buffaloes raised in the DPO Mozzarella di Bufala Campana DPO production area, neutralizes the sum of CO2eq emitted by respiration, by agricultural processes, from physiological rumen fermentations, manure management, transport, milk processing, etc... In summary, the entire cycle "from field to table" could be considered not only balanced and therefore null in terms of GHG, but favors a negative balance for GHG purposes.

For each kg of MdBC DPO about 52 kg of CO2 are sequestered from the atmosphere, from the vegetation used to feed the animals bred to produce this product. The results of this study, in agreement with other articles [1, 34, 35], demonstrate that the agricultural sector, on the one hand, generates greenhouse gas emissions, and on the other can reabsorb them, above all with correct sustainable management, thanks to the activity of photosynthesis especially in the dark phase, known as the "Calvin Benson" cycle, which allows neutrality to be achieved.

Therefore, it would probably be appropriate to consider this type of balance when calculating the carbon footprint of agricultural products, especially those of animal origin. Furthermore, the carbon used by farm animals can be considered "recycled" carbon, the biogenic carbon goes through a cycle and is fixed in the forage while the CO2eq produced by fossil fuels is a reserve gas which accumulates in the atmosphere and is not part of a loop, but is a "one-way" source. Therefore, all other sectors (energy, construction, transport, etc...) can work to reduce their emissions, but they cannot remove the excess CO2 already present in the atmosphere.

It must also be taken into account that methane (of ruminal origin and that emitted by manure) has a shorter life in the atmosphere than other GHGs: about 10 years. This means that after a decade it is gone. A process called hydroxyoxidation is triggered which destroys methane and this makes methane very different from other GHG [36].

So, in particular, the currently used methods of estimating the carbon footprint of processed animal products and dairy products should consider carbon sequestration subtraction in addition to emissions. According to this study, the consideration of carbon sequestration and the implementation of this calculation method would demonstrate the sustainability in terms of carbon footprint, of agricultural products, of animal origin such as dairy products, meat and meat products and, in this specific case, for example Mozzarella di Bufala Campana DOP.

Author Contributions

Roberto De Vivo: conception and design of the work; acquisition, analysis, processing and interpretation of data. **Luigi Zicarelli**: adding important intellectual content. **Roberto Napolano**: data acquisition. **Fabio Zicarelli**: data acquisition.

Competing Interests

The authors have declared that no competing interests exist.

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