Influence of carbon fixation on the mitigation of greenhouse gas emissions from livestock activities in Italy and the achievement of carbon neutrality

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ABSTRACT: Among the greenhouse gas emissions due to livestock activities there is, in addition to rumen methane, that which derives from the fermentation and management of manure from farmed animals. To feed the farmed animals, plants are used that fix carbon and therefore subtract carbon dioxide from the atmosphere. The emissions related to rumen fermentations, those related to manure, management, and spreading of animals of species reared in Italy, as well as manure released by grazing animals were quantified and summed. The emissions due to the respiration of animals were calculated and the carbon dioxide fixed by the main crops of zootechnical interest was calculated and then subtracted from the atmosphere. In addition, the emissions from the cultivation of plant species, attributable to the working of the soil, the production of fertilizers and pesticides, electricity, fuels, and the operation of machines, were also taken into account. The results of this elaboration show that in Italy the CO_2 fixed in the vegetation cultivated to feed animals is about 10% higher than the sum of that emitted by the animals reared and by the entire process that is part of it. It could therefore be argued that the influence of carbon fixation should probably be taken into account to calculate the environmental impact in terms of carbon footprint of agricultural and animal products. In this way, carbon neutrality would be demonstrated, which characterizes the production processes of agricultural products and animal productions unlike other production cycles.

Key words: environmental impact, greenhouse gases, livestock emissions

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INTRODUCTION

The debate on the environmental impact attributed to animal husbandry is usually focused on greenhouse gas emissions as well as on water consumption. According to the 2017 FAO report, total global greenhouse gas emissions from all economic sectors amounted to 51 billion tons (t) of CO_2eq (Gt CO_2eq yr^{-1}), emissions coming directly from agriculture (including activities livestock) amounted to 6.1 Gt CO_2eq yr^{-1}. The percentage contribution of agriculture and animal husbandry to world CO_2eq emissions from all human activities was 11% and 9% from related land use. The main contribution to total CO_2eq emissions in the world is represented by the energy sector, which emitted two-thirds of the total, due to the use of fossil fuels for energy production. Industrial processes, on the other hand, were responsible for 8% of the total (FAO, 2020). From ISPRA data (ISPRA is

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the Higher Institute for Environmental Protection and Research) in the yearbook of atmospheric emissions of 2018, agricultural activities represent 7% of total anthropogenic emissions (75% of 7% relating to agriculture is represented from animal husbandry), 25% for transport, 45% for energy production, 20% for industrial processes, and waste management for 4%. ISPRA 2018 data show that the contribution to emissions due to agriculture, which includes the component due to livestock, has remained practically stable in recent decades (from 1990 to today), with a slight downward trend. The energy sector, on the other hand, numerically the most consistent, showed an increase starting from 2000 and then began a reduction after 2005 and still continues to decrease. Obviously, if the same data are seen in percentage terms, the share of the agricultural sector (including animal husbandry) rises slightly, but this is not due to a real increase in agricultural emissions, but rather to a decrease in emissions from other sectors. Extrapolating data from the ISPRA (2017, 2018, 2019) yearbooks, in the total greenhouse gas emissions in Italy, agriculture represented 6.8%, 6.7%, 6.3%, 5.6%, 6.0%, 6.9%, 7%, respectively, in 1990, 1995, 2000, 2005, 2010, 2015, 2020 and with a projection in 2030 of 7.8%. This growing trend is essentially due to the substantial decrease in emissions from the energy production sector, which is giving way to energy from renewable sources. According to FAO (2020), the impact of agriculture is also decreasing over time. It was 29% on average in the 1990s (1990 to 1999), 25% in the 2000s (2000 to 2009), and 20% in the current decade (2010 to 2017). This reduction is due to two main trends: increases in total anthropogenic greenhouse gas emissions, from 1990 to 2017 were greater in the energy sector than in the agricultural and livestock sectors and emissions from agricultural land use decreased substantially in the same period 1990 to 2017. Among the greenhouse gas emissions due to livestock activities there is, in addition to ruminal methane, i.e., produced during the digestive processes of ruminants, the gas released by the manure of farmed animals (ruminants and nonruminants) whose management must be considered. Manure in an aerobic state produces nitrous oxide (N_2O) while during storage in tanks under anaerobic conditions they also produce CH_4. The nitrogen and carbon content, storage methods, duration, and type of manure treatment affect N_2O emissions. For farmed ruminants, ruminal methane must be added to the emissions produced in the management of manure (emissions), which has a climate-altering power about s/b 24 times that of carbon dioxide even if its half-life is considerably lower, about 50 to 200 vs. 12, respectively, for CO_2 and CH_4 (IPCC). Nitrous oxide, on the other hand, has an even greater climate-altering power, about 298 times that of carbon dioxide and a half-life of 114 yr. This half-life has been defined as a "regulation time" which takes into account the indirect effect of the gas on its residence time (IPCC). Methane emissions from livestock manure originate mainly from anaerobic degradation of the organic substance contained in them during storage prior to agronomic use. Furthermore, manure management, if done correctly, could be a resource for the production of "clean" methane, if the farm were equipped with a biogas plant. Obviously, it could only be used for breeding with animal facilities and reared animals, excluding pasture breeding. After the year 2002, compared with the values of 1978, the percentage increase of methane in the atmosphere was lower than that of the percentage increase in ruminants, this shows that the association between methane in the atmosphere and the increase in number of ruminants is to be considered an unlikely association (Zicarelli, 2018). ISPRA estimates for Italy in 2017 an emission by the livestock system of approximately 22 million t of CO_2, which represent 5% of the 428 million tons released into the atmosphere by our country.

The objective of the study was to evaluate how much the quantity of CO_2 fixed in the forage differs from the sum of that produced by the animals raised and by the cultivation of forages.

MATERIALS AND METHODS

This study is divided into two phases: in the first phase, an estimate of the greenhouse gas emissions deriving from the activities of livestock farms is carried out and their carbon footprint is calculated according to a mass counting method. In the second phase, some agricultural activities related to breeding (production of forage and other feed) are evaluated, which mitigate the impact of the estimated emissions thanks to the photosynthetic activity of plants.

Emissions Related to Animal Husbandry

The emissions related to rumen fermentations of all ruminants raised in Italy have been quantified, obviously cattle were the species that contributed most to the emission of rumen methane (Table 1). The number of animals reared was obtained from the (BDN, National Data Bank),

Table 1. Greenhouse gas emissions, converted into carbon dioxide equivalent, deriving from the different phases of the management of animal waste, reared in Italy in 2018

Species	Storage emissions in CO_2eq, t[a]	Spreading emissions in CO_2eq, t[b]	Manure emissions left on pasture in CO_2eq, t[c]	Total CO_2eq, t
Cattle	2,684,183	1.431.753	1,240,064	5,356,000
Buffaloes	208,204	83.229	—	291,433
Sheep	71,736	96.848	655,702	824,286
Goats	4,447	4.956	118,931	128,334
Pigs	1,559,966	473.512	—	2,033,478
Poultry	641,128	806.472	28,080	1,475,680
Total				10,109,211

[a]Includes emissions, all converted into carbon dioxide equivalent (CO_2eq), incurred during storage of both solid manure and slurry, expressed in tonnes, source FAO (2020).

[b]Includes emissions that are released during spreading for agronomic purposes, converted into CO_2eq, source FAO (2018).

[c]Includes emissions from manure left by animals during grazing, converted into CO_2eq, source FAO (2018).

National Zootechnical Registry, Statistics, data as of December 2018. This database, from which information on the consistency of the animals was obtained, does not distinguish sheep and goats for milk and meat. According to Johnson et al., cattle can produce 250 to 500 liters of methane for 1 d and there are many factors that influence cattle's methane emissions. Cicerone and Oremland (1988) have shown that the methane produced by ruminants is influenced by numerous factors related to the animal itself (age, production level, and physiological state) and the quantitative and qualitative characteristics of the diet that is administered to them. For example, a more digestible diet may result in lower methane production when compared with a lower quality diet Johnson et al. (2007) and Johnson and Johnson (1995) report that with diets rich in concentrates about 2% of the raw energy ingested is converted into methane, while with diets based on low-quality fodder for the production of methane about 12% of the raw energy is lost. According to FAO 2018 data, data on rumen methane emitted by different species of ruminants raised in Italy have been extrapolated, and the same procedure has been extended for the emissions of methane, carbon dioxide, and nitrous oxide deriving from the management of manure of the same animals. For CH_4 emissions, the management, storage, and spreading of manure on the farm and those of grazing animals were taken into consideration (FAO, 2019); all emissions were expressed in carbon dioxide equivalent. The methane of rumen origin generated by cattle was the most relevant. In addition to rumen methane and the emissions of manure, the carbon dioxide emissions emitted during respiration were calculated. As regards all ruminants reared in Italy, they have all been standardized in standard adult cattle. Buffaloes were equated with cattle equivalents, sheep and goats considered to be 1/8 of a standard adult bovine. Furthermore, within the same species, the number of adult animals was standardized according to the ISTAT estimates on the consistency of the various age groups of the animals. Once everything was standardized in adult cattle, the amount of carbon dioxide emitted with physiological lung respiration was calculated according to the estimates of Kinsman et al. (1995), according to which an adult standard bovine (on average and in intermediate environmental conditions) emits approximately 5,756 liters of carbon dioxide in humid conditions and average temperatures every day. This gas volume value was transformed into mass to make it comparable to the other greenhouse gases involved, revised into annual values and multiplied by the number of standard adult cattle obtained from the standardization of all ruminants reared in Italy in 2018 (BDN, 2018), which were equal to about 5,824,836. The pigs reared in Italy in 2018, converted into standard adult heads, were instead about 5,993,944, were converted according to ISTAT estimates for the various weight categories to standardize the data. According to a study by Philippe and Nicks (2015), the exhalation of carbon dioxide for reared pigs is on average about 1.55 kg for day, for an average pig with a live weight of 70 kg the variability is given by many factors, age, grade crowding density, temperature, humidity, and general well-being. By processing these data, the amount of carbon dioxide exhaled and then emitted by the pigs was estimated, adjusting the estimates to the live weight of the estimated standard pigs. The number of poultry reared (broilers, laying hens, and turkeys; geese and ducks were neglected because they were small in number) according to ISTAT in 2018 was approximately 148,349,000. The main source of carbon dioxide in livestock is the respiration of animals, the combustion of natural gas for heating and cooking, and the decomposition of organic matter (Knížatová et al., 2010). There is a link between metabolism and CO_2 production via respiration (Mihina et al., 2012). The production of carbon dioxide by birds is proportional to their production of metabolic heat, and therefore to their live body weight, which in turn is affected by the temperature and activity of the birds. Production under normal farming conditions normally has a diurnal variation of ±20% (Pedersen et al., 2008). According to Calvet et al. (2011), on average carbon dioxide emission rates were estimated at 3.84 and 4.06 g per h per bird in summer and winter, respectively. After evaluating many parameters and measuring carbon dioxide, it can be concluded according to Brouček and Cermák (2015) that there is an average release of 73.11 kg of CO_2 per bird per year. The quantity of carbon dioxide emitted, expressed in tons per year, was therefore estimated for all species. After having quantified all the emissions related to the life of the animals, we moved on to quantify all the subtraction of carbon dioxide by the plants they fed on.

Carbon Dioxide Fixed in Feed

Some international scientific standards do not consider CO_2 fixed in feed. Only the increase of CO_2 in soil as organic matter and that of woody growths of trees and shrubs are considered stocks. Furthermore, CO_2 from respiration is normally not considered in the calculation of animal emissions. In this study, however, an alternative method is used, and both the CO_2 fixed by all the plants used in the diet and the emissions of lung respiration, both in stock, are taken into account. The carbon dioxide fixed by the main crops of zootechnical interest was calculated through the Calvin–Benson cycle and then subtracted from the atmosphere. The CO_2 fixed by cultivated fodder and cereals mitigates the emission produced by the farms themselves, so it is grown to produce food for the animals, according also Guyader et al. (2016). Statistical data revealed the quantity of forage (ISTAT, 2018a, 2018b) and also pastures, according to Acutis et al. (2013), and cereals (ASSALZOO, 2018) produced in Italy and abroad and used for Italian animal husbandry. The quantity of carbon physiologically contained in herbaceous plants turns out to be about 48% of the dry matter and (Lasserre et al., 2006) from this the quantity of CO_2 removed from the atmosphere was calculated, stoichiometrically equivalent to the carbon contained, being the only source of carbon (Costa and La Mantia, 2005). From the quantity of cereals produced, the vegetative biomass was traced through the various harvest indices (Sinclair, 1998; Dai et al., 2016), and then the underground part, i.e., the crop residues that do not contribute, was subtracted from the vegetative biomass. The subtraction of carbon dioxide for fermentation processes during degradation after the burial of agricultural processes. In addition, emissions from the cultivation of plant species were taken into account, attributable to the working of the soil, the production of fertilizers and pesticides, electricity, fuels, and the operation of machines. All emissions relating to the cultivation of raw materials and feed processed through various sources in the literature were quantified, to make clear the subtraction of carbon dioxide from cultivated vegetation. In a study by Valli et al. (2013), coefficients were developed that can calculate in terms of greenhouse gas emissions, converted into carbon dioxide equivalent per quantity of dry matter of cereal produced. Emissions include all agricultural processes and those related to the production of fertilizers and pesticides, electricity, fuels, and machine operation. For example, 1 kg of dry matter of alfalfa hay corresponds to 0.07 kg of carbon dioxide equivalent emitted, 1 kg of dry matter of corn silage at 0.14 kg of CO_2eq, 1 kg of dry matter of soy at 0.32 kg of CO_2eq, and 1 kg of dry matter of grasses hay emits 0.15 kg of CO_2eq. Little et al. (2017) in a study comparing greenhouse gas emissions in different types of silage, they studied the various emissions due to the processes and cultivation of various cereals and hays. It was possible to calculate the net contribution of the carbon dioxide subtraction of forage and cereal crops in the livestock sector following the suggestion of Matthew et al. (2014). Matthew et al. (2014) in fact, they quantified the emissions related to the production of alfalfa and its hay production. Finally, after having quantified the emissions and subtractions relating to the animal husbandry phase alone, without taking into account the emissions related to the transport and processing of raw materials of animal origin, a balance was made. For annual crops, the variations according to the time of the biological cycle and the necessary agricultural processes, different for each plant species, were taken into consideration. The rotation and the alternation of the various crops, winter and summer, cultivated on the same soil in the same year was also taken into consideration.

Emissions Related to Animal Husbandry and Carbon Dioxide Fixation on an Average Farm

Finally, a farm with 150 dairy cows was hypothesized to verify the CO_2 equivalent balance. The hypothesized average farm is a dairy farm, uses 40 ha as agricultural area and raises 150 lactating cows, 25 dry heads, 70 heifers reared between weaning and the end of the first gestation which have determined an estimate equal to 70% of an adult bovine, and 150 calves aged no more than 1 mo. To make the calculation of all emissions more truthful, the animals reared were standardized according to the size and correspond to approximately 217 standard adult cattle. Of the company's 40 ha, 13 ha are planted with alfalfa for the production of hay, 27 are intended for the cultivation of waxy maize for the production of silage and, alternated with ryegrass for the production of hay and/or silage. Of the cultivated ryegrass production, only a quarter of the total is destined to feed the company itself, the remaining part is destined for sale. In addition, to meet the nutritional needs of the herd, soybean, and barley flour/grains are purchased from the company. About 190 t of corn flour, about 255 t of barley flour, and about 190 t of soybean meal are purchased annually. Of the ha of ryegrass only one third is used for reared animals, the remainder is sold and has not been included in the CO_2 balance.

RESULTS

Balance Between CO_2eq Produced by Agro-zootechnical Activities and CO_2eq Set by Forage in Italy

Greenhouse gas emissions due to manure from animals reared in Italy (ruminants and monogastrics) in the various management phases are collected in Table 1 and have been converted into CO_2eq. They include emissions due to storage, both slurry and palable (manure with straw which is easier to transport), material, to those released during spreading on agricultural land and finally to those deriving from manure left on the ground by grazing animals. In total, in Italy, the manure of all farmed animals emitted about 10 million t of CO_2eq. Cattle reared in Italy in 2018 emitted methane corresponding to about 10,720,000 t of CO_2eq, and the CO_2 emitted by breathing was equal to about 16,730,213 t, buffaloes about 530,000 t of CO_2eq from rumen methane and 1,437,638 t from respiration, sheep about 1,385,000 t of CO_2eq and 3,393,671t CO_2, goats about 120,000 t of CO_2eq and 466,214 t of CO_2 emitted by respiration (Table 2). In total, ruminants reared in Italy in 2018 emit rumen methane equivalent to about 12.7 million t of CO_2eq and about 22,027,735 t of CO_2 with respiration. The reared pigs emitted about 5,216,919 t of CO_2 by breathing, while poultry farms, including chickens, laying hens, and turkeys, produced about 10,845,795 t (Table 2). Table 3 collects the emissions and the amount of CO_2 fixed and then subtracted from the atmosphere by all the fodder grown in Italy and imported (those imported represent a very small part) used in the feeding of Italian animal husbandry. The quantity of CO_2 fixed by the total forage was equal to approximately 26,239,303 t and the CO_2eq emitted for all activities connected with agronomic activities was equal to 1,625,439 t. For the calculation, only the epigeal part used for haymaking was taken into account, excluding from the calculation the underground part, that is the crop residues, left on the ground with mowing and then buried with deep agricultural work. Table 4 shows the emissions and the amount of CO_2 fixed and then subtracted from the atmosphere by all cereals and other concentrates used in the Italian

Table 2. Number of animals, standardized in adult animals, ruminal emissions, emissions derived from respiration of ruminants and nonruminants and from the management of manure reared in Italy in 2018

Species	Heads[a]	Adult standard	Rumenary CH_4 in CO_2eq, t	CO_2 of respiration, t	Manure emissions in CO_2eq, t	Total CO_2eq, t
Cattle	5,923,204	4,424,002	10,717,982	16,730,213	5,356,000	32,804,195
Buffaloes	401,337	380,157	529,046	1,437,638	291,433	2,258,117
Sheep	7,179,158	897,395	1,385,364	3,393,671	824,286	5,603,321
Goats	986,255	123,282	119,062	466,214	128,334	713,610
Ruminants	14,489,954	5,797,073[b]	12,751,454	22,027,735	6,600,053	41,379,242
Pigs	8,492,000	1,698,400	—	5,216,919	2,033,478	7,250,397
Poultry	148,349,000	370,873	—	10,845,795	1,475,680	12,321,475
Total	171,330,954	7,894,108	12,751,454	38,090,449	10,109,211	60,951,114

[a]The number of animals reared, and the subdivision by categories is based on ISTAT, from which they have been standardized.

[b]The total of all farmed ruminants was standardized in size as an adult bovine. The other species for adult heads of the same species.

Table 3. Subtraction of CO_2 from the atmosphere by forages grown in Italy in 2018 and emissions attributable to the total agronomic processes to produce them

Cultivated species	Cultivated area, ha	CO_2 subtracted, t	Agricultural emissions, t[a]
Waxy corn	284,090	7,445,572	579,100
Barley in the grass	52,222	255,884	36,961
Waxy barley	10,975	121,991	12,199
Ryegrass	89,574	560,651	43,606
Herb monophytes	256,904	1,464,478	162,720
Grasses	81,825	224,318	34,894
Legumes	83,394	310,262	55,158
Other mixtures	274,097	1,419,916	220,876
Alfalfa	662,347	6,060,137	235,672
Sainfoin	14,638	71,204	12,659
Sulla	95,241	404,278	62,888
Temporary weeds	76,375	425,003	66,112
Polyphite meadows	312,817	1,319,060	102,594
Permanent lawns	832,613	3,121,639	—
Poor pastures	1,696,500	1,613,761	—
Other pastures	1,119,053	1,421,147	—
Total	5,942,665	26,239,303	1,625,437

[a]Emissions attributable to tillage, the production of fertilizers and pesticides, electricity, fuels, and the operation of machines, all converted into CO_2eq.

Table 4. Subtraction of CO_2 from the atmosphere from the total amount of grain (grown in Italy and imported) used for animal husbandry in 2018, and emissions attributable to agronomic processes and handling after harvest

Cultivated species	Production grain, t	CO_2 subtracted, t	Agricultural emissions, t[a]
Oats	251,015	625,865	33,134
Wheat	1,381,936	3,382,980	182,416
Corn grain	8,471,721	25,347,389	1,341,921
Barley	1,304,535	3,252,640	172,199
Rye	14,367	35,821	1,896
Other cereals	506,690	1,263,347	66,883
Bran	3,386,000	4,221,213	446,952
Rape	88,994	133,135	36,808
Cotton	1,728	2,585	304
Sunflower	872,520	1,631,612	314,805
Soja	3,753,655	7,019,335	1,057,029
Other seeds	40,929	61,230	5,403
Linen	46,350	69,340	6,118
Copra	13,037	19,503	5,392
Total	20,133,477	47,065,996	3,671,260

[a]Emissions attributable to the tillage, the production of fertilizers and pesticides, electricity, fuels, and the operation of the machines, and the processing of the plant by extracting the grain, all converted into CO_2eq.

livestock feed grown both in Italy and imported. The amount of CO_2 fixed in total was 47,065,996 t and the CO_2eq emitted for all activities related to agronomic activities was 3,671,260 t. Table 5 collects the emissions and the amount of CO_2 fixed and then subtracted from the atmosphere by all cereals and other concentrates grown only in Italy. The amount of CO_2 fixed in total was equal to approximately 26,000,000 t and the CO_2eq emitted for all activities related to agronomic activities was equal to approximately 1,700,000 t. Table 6 summarizes and lists the totals of emissions for the various origins: with regard to rumen methane, manure in all phases of management, respiration, and emissions deriving from the agricultural part linked to cultivated foods. In Italy in total, animal husbandry, without taking into account the transport and processing of the raw materials produced, emits about 66,200,000 t of CO_2eq and, on the other hand, the cultivated vegetables contribute to

Table 5. Subtraction of CO_2 from the atmosphere from cereals grown only in Italy used for animal husbandry in 2018, and emissions attributable to agronomic processes and handling after harvest

Cultivated species	Production grain, t	CO_2 subtracted, t	Agricultural emissions, t[a]
Oats	247,911	525,406	27,816
Wheat	1,381,936	2,875,533	155,053
Corn grain	6,283,109	15,979,203	845,958
Barley	1,022,220	2,166,425	114,693
Rye	10,805	22,899	1,212
Other cereals	400,236	848,233	44,906
Bran	205,397	217,653	23,046
Rape	33,700	42,853	11,848
Cotton	—	—	—
Sunflower	229,715	365,132	70,449
Soja	1,759,360	2,796,503	421,120
Other seeds	26,071	33,152	2,925
Linen	26,037	33,109	2,921
Copra	—	—	—
Total	11,626,497	25,906,101	1,721,948

[a]Emissions attributable to the tillage, the production of fertilizers and pesticides, electricity, fuels, and the operation of the machines, and the processing of the plant by extracting the grain, all converted into CO_2eq.

Table 6. Emissions produced by farms in Italy and carbon dioxide set by crops in Italy and abroad used for feed

Sources of emissions	CO_2eq emitted into the atmosphere, t	CO_2 subtracted from the atmosphere, t	
Dejection emissions	10,109,211	21,159,895	CO_2 subtracted from crops abroad
Ruminal emissions	12,751,454		
CO_2 emitted by breathing	38,090,449		
Agricultural emissions in Italy[a]	1,721,948	52,145,404	CO_2 subtracted from crops in Italy
Agriculture emissions abroad[a]	3,574,749		
Total	66,247,811	73,305,298	

[a]Emissions attributable to soil processing, the production of fertilizers and pesticides, electricity, fuels, and the operation of the machines for the cultivation of raw materials produced in Italy or abroad.

the removal of about 73,300,000 t of CO_2 from the atmosphere, thus neutralizing all emissions in terms of CO_2eq, the subtraction being approximately 10% higher than the quantity of CO_2eq emitted (Fig. 1). If we take as a reference only the Italian national territory, compared with about 62,700,000 t of CO_2 equivalent emitted into the atmosphere by livestock activities, the forage crops grown for the feeding of farmed animals fix 52,100,000 t of CO_2 equivalent to approximately 20% less than those released into the atmosphere. This balance becomes advantageous for the purposes of greenhouse gases, if the CO_2 set by forage in Italy is added to that of crops grown abroad and imported (about 21,100,000 t of CO_2 equivalent) which entails a positive gain for the purposes of the overall GHG of the about 10%. Ultimately, every 100 kg of CO_2 produced by livestock activity generates 110 kg of CO_2 fixed as biomass which should also help absorb the CO_2 produced by other human activities. Assuming that there are no food imported from abroad, and therefore excluding from the balance the CO_2 subtracted from food grown abroad (−52,145,404 t) and the emissions due to their cultivation (3,574,749 t), would suffice, for example, cultivate alfalfa 2.6 times the area cultivated in 2018 (662,347 ha, ISTAT, 2018a, 2018b), therefore about 1,722,102 ha. In this case, the balance between emissions and CO_2 fixation would be even.

Balance Between CO_2eq Produced by Agro-zootechnical Activities and CO_2eq Set by Forage in a Medium-Sized Dairy Farm

As regards the hypothetical farm of 40 ha and 150 dairy cows, the calculations showed that compared with the 1,705 equivalent tons of CO_2 emitted into the atmosphere by rumen fermentations, from all phases of manure management, from animal breathing, and from activities related to agriculture of farm products. This result is confirmed by the land-based approach developed by the researchers

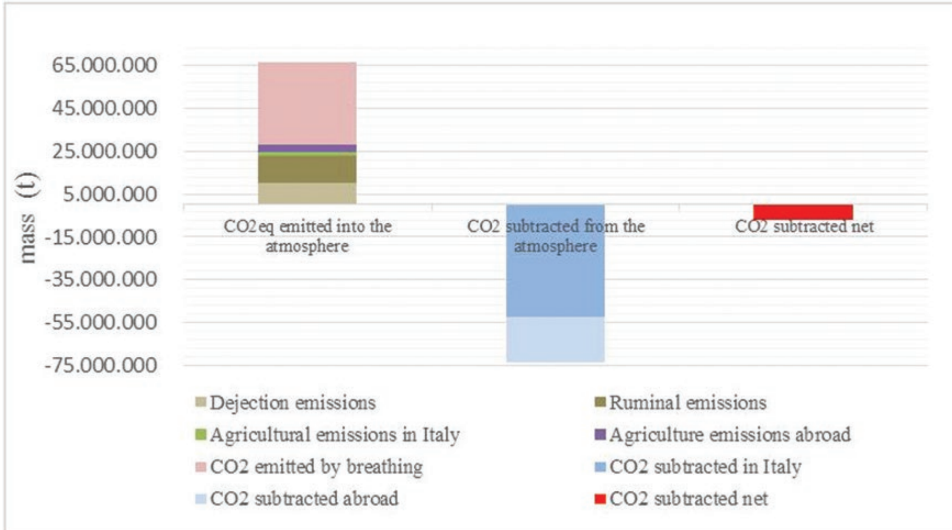

Figure 1. Comparison between emissions produced by livestock activities in Italy and the contribution of carbon fixation.

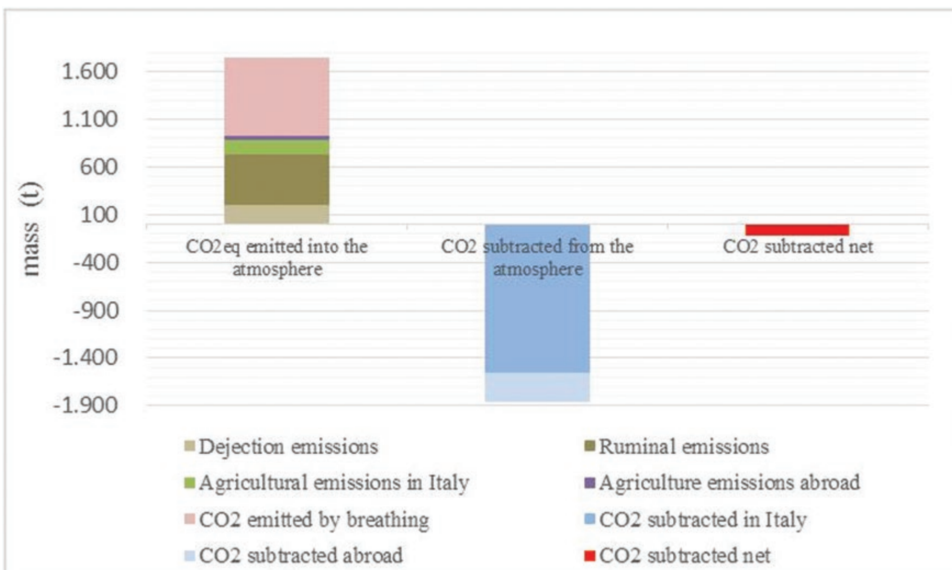

Figure 2. Comparison between the emissions produced by a medium-sized dairy farm and the contribution of carbon fixation.

"Euro-Mediterranean Center on Climate Change" (CMCC, 2021) and the Institute of Services for the Agricultural and Food Market (ISMEA, 2021), with the financial support of the "Rete Rurale Nazionale 2014–2020" which generated a "web tool" model. The calculation of the emissions generated by livestock production is carried out through a life cycle analysis (LCA) which identifies and quantifies the impacts in terms of greenhouse gas emissions in CO_2eq, generated by the entire production process and, in particular, by fermentation enteric, from the management of manure and from the management of agricultural soils. Reporting the same data of the average dairy farm whose emissions were quantified in this study through material balances, on the web tool of "Rete Rurale Nazionale 2014–2020" (2021), the results are almost overlapping (about 1,700 t CO_2eq). This shows that the method based on material balances in this case is most likely as true as the LCA method.

The latter fix and then subtract 1,548 from the atmosphere t of CO_2eq about 10% less than those emitted. If we take into account all emissions, including those estimated for activities related to agriculture of imported and purchased raw materials, the total tons of CO_2eq emitted are approximately 1,748 and if we take into account the subtraction of CO_2 by imported raw materials the tons are about 1,865, or about 6% more than those emitted, neutralizing also in this case all the missions related to livestock production. This average farm, with the agronomic characteristics described, only with the

Table 7. Comparison between the emissions produced by an average farm and the carbon dioxide fixed by the crops used for feed

Sources of emissions	CO_2eq emitted into the atmosphere, t	CO_2 subtracted from the atmosphere, t	
Dejection emissions	203	316	CO_2 subtracted from crops abroad
Ruminal emissions	529		
CO_2 emitted by breathing	821		
Agricultural emissions in Italy[a]	153	1,548	CO_2 subtracted from crops in Italy
Agriculture emissions abroad[a]	43		
Total	1,748	1,865	

[a]Emissions attributable to soil processing, the production of fertilizers and pesticides, electricity, fuels, and the operation of the machines for the cultivation of raw materials produced in Italy or abroad.

farm crops eliminates the environmental impact in terms of GHG emissions and indeed contributes to the subtraction of 10% (Fig. 2 and Table 7) more than those emitted in terms of CO_2eq. Ultimately, for every 100 kg of CO_2 produced by livestock activities, 106 kg of CO_2 are fixed as biomass which should also help absorb the CO_2 produced by other human activities. However, there are a number of farms where the ratio of adult cattle equivalents to hectares cultivated is lower than that reported. In this case, the calculations do not change because nonproprietary surfaces are still used for agricultural purposes and therefore contribute to fixing carbon dioxide.

DISCUSSIONS AND CONCLUSIONS

From the results that emerged from the calculations carried out, it can be stated that animal husbandry in Italy, excluding activities related from the stable onwards, such as transport and processing of products such as meat and milk, does not contribute to increasing GHG emissions in atmosphere, but decreases them, even if slightly, because the balance between the quantities of CO_2eq produced by livestock and those fixed in the fodder used for their feeding is clearly (+10%) in favor of the latter. If the food for livestock were not imported into Italy, it would be enough to increase the area used for the cultivation of alfalfa by 2.6 times to equal the equivalent of CO_2 produced by livestock farms and those fixed in fodder. The examination of a single medium-sized farm (150 lactating animals) shows that adding the CO_2 stored by feed produced in Italy and abroad has an advantage of 6% compared with that produced by livestock activities. From the data processed, it emerges that in Italy the CO_2 fixed and subtracted from the atmosphere by cultivated and imported plants to feed farmed animals, neutralizes the sum of CO_2eq emitted by agricultural processing, by physiological rumen fermentations and that due to the management of manure, therefore, probably, the primary activity of animal husbandry, without taking into account the transport and secondary processing of milk, meat, etc. could be considered balanced and therefore should not be considered in terms of greenhouse gas emissions.

As confirmed by Matthew et al., if carbon sequestration is taken into account the balance is favorable for carbon footprint purposes, for example a ton of alfalfa contributes to a negative balance equal to −213 kg CO_2. This negative result is net of all emissions which include all agricultural processes and those related to the production of fertilizers and pesticides, electricity, fuel, and the operation of machinery. In this way, it was possible to calculate the net contribution of carbon dioxide subtraction of forage and cereal crops in the livestock sector.

This conclusion is confirmed by the fact that the half-life of carbon dioxide is greater than that of methane and nitrous oxide, consequently for the purposes of mitigating the greenhouse effect it is more efficient in terms of timeliness, especially if we consider that CO_2 produced lasts longer in the atmosphere than methane (IPCC, 2018). The results of this study are in agreement with a study by Chiriacòa and Valentini (2021), which shows that the agricultural sector, on the one hand, generates greenhouse gas emissions, on the other hand can reabsorb them, especially with appropriate sustainable management, thanks to the activity of photosynthesis and soil biodiversity, representing an important carbon sink that allows to achieve carbon neutrality. All the other sectors (energy, construction, transport) can undertake to reduce their emissions and gradually reduce them to zero, but they do not have the possibility to remove the excess CO_2 already present from the atmosphere.

Probably, therefore, it would be appropriate to consider this type of balance in all methods of calculating the carbon footprint of agricultural and animal products. In this way, the environmental impacts, in terms of carbon footprint, of these products would be clearer and more likely.

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