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TOOLS FOR CARBON FOOTPRINT ESTIMATION OF ANIMAL PRODUCTION WITH APPLICABILITY IN RUMINANTS: REVIEW

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Abstract

The evolutionary adaptation of the ruminant to convert pasture to animal products may have been successful, but ruminant production has an unwanted by-product (greenhouse gases), that is detrimental to the environment. The greenhouse effect is a term used to highlight the contribution of certain emitted gases to the warming of the Earth`s atmosphere. The gases responsible for the greenhouse effect are: water, carbon dioxide, methane, ozone. Of the total GHG emissions in 2021, 10.7% were emitted by the agricultural sector. In developed countries, numerous research projects have been funded over time by which emission factors (of greenhouse gases) associated with various activities carried out at the level of a farm (e.g., feeding, manure management) or various influencing factors of them (e.g., the average temperature of the area). The present study aims to analyze characteristics of 19 carbon footprint estimation tools, developed and used all around the world, and to set the most suitable system for estimation on the ruminant farms level.

Key words*: carbon footprint, emission factors, estimation tool, greenhouses gases, ruminants.*

INTRODUCTION

The term "greenhouse effect" was popularized in the early 20th century when it was recognized that certain gases in the atmosphere, including CO_2 and water vapor, can trap heat and contribute to the warming of the Earth's surface. These gases allow sunlight to pass through the atmosphere and warm the planet, but they hinder the escape of heat back into space, resulting in a warming effect like a greenhouse. It is worth noting that while the greenhouse effect is a natural process necessary for sustaining life on Earth, human activities since the Industrial Revolution have significantly increased the concentration of greenhouse gases, leading to an enhancement of the greenhouse effect and global warming.

The agricultural sector is responsible for a significant amount of greenhouse gas emissions. These emissions primarily come from various agricultural practices and processes. Some key sources of agricultural greenhouse gas emissions include: enteric fermentation, animal waste management, fertilization, burning of agricultural residues, etc.

Estimating the carbon footprint of farms involves considering various factors such as energy use, livestock emissions, land management practices, and inputs like fertilizers. Here are a few approaches and tools commonly used for estimating the carbon footprints of agricultural operations:

Carbon Footprint Models: Various carbon footprint models and calculators are available specifically for agricultural operations. These models consider factors such as livestock emissions (enteric fermentation, manure management), energy use (electricity, fuel), synthetic fertilizer use, and land-use change.

Life Cycle Assessment (LCA): LCA is a comprehensive approach that evaluates the environmental impact of a product or system throughout its entire life cycle. LCA can be used to estimate the carbon footprint of agricultural products by considering all stages, from the production of inputs to cultivation, processing, transportation, and end use. It considers emissions associated with inputs, machinery use, energy consumption, and waste management.

National Carbon Footprint Inventories*:* Some countries have developed national inventories or guidelines specifically for estimating the carbon footprints of different sectors, including agriculture. These inventories provide methodologies, emission factors, and guidelines to estimate emissions from farming activities, allowing farmers to assess and reduce their carbon footprints.

It is important to note that farm-specific characteristics, such as location, type of farming system (crop farming, livestock production, etc.), scale, and management practices, can significantly influence the carbon footprint.

This review aims to present the online platforms available to farmers and stakeholders for estimating carbon footprint of ruminant farms and made possible mitigation measure implementation at operation and industry level.

MATERIALS AND METHODS

This paper is based on scientific literature published in the English language and collected from Web of Science, Scopus, Google, Tools webpages, and FAO webpage sources. A total of 60 references, covering 2006-2022 period were selected. The selection criterion was usage of GHG emission estimation tools at ruminant operation level.

RESULTS AND DISCUSSIONS

Climate change

Climate change is undeniably one of the pressing challenges that humanity faces today and will continue to confront soon. The frequent occurrence of droughts, floods, rising temperatures, and melting glaciers serves as evident indicators of the reality of climate change. Human activities have significantly contributed to the intensified "greenhouse effect" by increasing concentrations of greenhouse gases in the atmosphere, leading to a rise in Earth's temperature. Europe has experienced a temperature increase of over 1°C over the past century, which is faster than the global average, with the most rapid changes occurring in the last 50 years. While this may not seem dramatic, it has had significant consequences for various physical and biological systems, such as water resources, habitats, and human health, which are becoming increasingly vulnerable. Global warming is primarily a result of human activities, leading to two major challenges for humanity:

Mitigating Greenhouse Gas Emissions: It is crucial to take substantial measures to reduce greenhouse gas emissions so, we can stabilize their concentration in the atmosphere at an acceptable level. This action is important to prevent further anthropogenic influence on the climate system and allow natural ecosystems to adapt.

Adapting to Climate Change Effects: Climate change impacts are already evident and will persist due to the inertia of the climate system. Regardless of efforts to reduce emissions, adaptation to the effects of climate change is essential. This entails implementing strategies and measures to adjust to changing environmental conditions and minimize vulnerabilities.

The European Commission is currently prioritizing the development of a European Ecological Pact. This pact aims to introduce more ambitious measures in addressing the climate crisis and biodiversity loss. European policies have been dedicated to combating environmental degradation and climate change, with both successful and unsuccessful outcomes thus far.

Under the European project INTERREG IIIB CADSES: ACRETe, Romania participated through the National Meteorological Administration. Within this project, a document titled "Code of Attitudes for reducing the impact of climate change in agriculture" was developed. The document provides recommendations on adapting agricultural technologies and practices to the effects of climate change. It also includes examples of good practices that effectively decrease greenhouse gas emissions within the agricultural production process.

The impact of greenhouse gases on the delicate balance of natural ecosystems is a growing concern for climate and sustainability-focused forums. The inventory and ongoing monitoring of these gases have revealed that zootechnical activities contribute significantly to their emissions.

Until recently, the environmental impact of the natural byproducts originating from the internal and external fermentation in animals was considered neutral. This was because these byproducts play a vital role in the regeneration and production of biomass throughout various stages.

These components are integral to the natural cycle of matter in the environment. They are both the result and the catalyst of a complex array of chemical and biochemical processes. These processes include photosynthesis, anatomical and physiological transformations within food chains, and a range of combination and decomposition processes.

The situation has become more complex since it was discovered that the natural reintegration time of greenhouse gases into inert or useful food and non-food compounds exceeds the conventional threshold values. This prolonged reintegration time contributes to the accumulation of these gases, leading to various transfer processes such as mass transfer, heat transfer, and even momentum transfer. Consequently, it is important to find solutions that aim to reduce greenhouse gas emissions, even from these natural processes in which they occur. The Food and Agriculture Organization (FAO) of the United Nations highlights that reduction of up to 30% is achievable in this regard, representing a win-win approach for addressing these emissions (FAO 2022).

Greenhouse Gases (GHG)

Modern and post-modern society relies on the utilization and conversion of energy resources, which are essential in various domains of human activity. However, in processes involving chemical and biochemical reactions, the release of gases into the atmosphere occurs. These emissions originate from different sources within facilities associated with raw material processing and energy generation. Some instances include:

Emission of gases from transportation sources (such as road, rail, air, and maritime vehicles).

Emission at the site of production, encompassing both industrial and domestic installations.

Controlled release through dispersion systems, like tall stacks typically found in thermal power plants (with heights ranging from 100 to 200 meters).

Indeed, the issue of conventional emissions was closely tied to the use of conventional resources such as coal, crude oil, and natural gas. The adverse environmental impacts of these resources prompted the establishment of regulations, norms, and standards to address their emissions. Efforts were made to identify solutions that involved phasing out conventional energy installations and replacing them with alternative sources, with nuclear energy being one of the prominent alternatives explored.

By shifting towards alternative energy sources, world societies aimed to reduce the emissions associated with conventional resource consumption and mitigate the environmental repercussions. This transition sought to address the concerns related to climate change, air pollution, and the sustainability of energy resources.

After 1992, the concept of sustainable development gained prominence and provided a framework for the exploitation of renewable resources. Initially, it was believed that renewable resources were inherently non-polluting. However, over time, it became evident that even renewable sources can contribute to pollution through gaseous emissions. This realization expanded the scope of addressing pollution from gaseous emissions to include all sectors, including industry, energy, and agriculture.

The greenhouse effect is a term used to highlight the contribution of certain naturally or artificially emitted gases to the warming of the Earth's atmosphere. In 1824, the French researcher Joseph Fourier made a significant discovery and provided a detailed description of it. Fourier was a mathematician and physicist who made important contributions to the study of heat transfer and the mathematics of waves. In 1824, he published a work called "Théorie analytique de la chaleur" (Analytical Theory of Heat), which laid the foundation for the mathematical understanding of heat conduction.

The gases that contribute to the greenhouse effect include water (36-72%), carbon dioxide (9-26%), methane (4-9%), and ozone (3-7%).

CO_2 is primarily generated through human activities such as the burning of fossil fuels (e.g., coal, oil, and gas) for energy production, industrial processes, and deforestation. These activities contribute to the increase in atmospheric CO_2 levels, leading to the enhanced greenhouse effect and global warming.

Methane is produced by both natural processes and human activities. Natural sources of methane include wetlands, termites, and the digestive systems of ruminant animals. Human activities that contribute to methane emissions include livestock farming, landfills, rice cultivation, and the extraction and transport of fossil fuels.

Water, in the form of water vapor, is an integral part of the Earth's hydrological cycle. It evaporates from bodies of water, condenses into clouds, and falls back to the earth as precipitation. While human activities can affect the hydrological cycle through deforestation, land use changes, and pollution, the overall amount of water in the atmosphere is primarily determined by natural processes.

Ozone (O_3) is a form of oxygen that exists both naturally in the upper layers of the atmosphere (stratospheric ozone) and near the Earth's surface (tropospheric or ground-level ozone). Stratospheric ozone is important as it absorbs harmful ultraviolet (UV) radiation. Ground-level ozone, on the other hand, is primarily formed through chemical reactions involving nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. NOx is mainly released into the atmosphere through human activities such as combustion processes (e.g., vehicle emissions, power plants) and industrial activities.

The factors on which the manifestation of the greenhouse effect depends:

Table 1. Specific molar heat of gases (kJ/kmol grd)

Air	N_2	O_2	CO_2	CH_4	NO	CO	NH_3	N_2O	H_2S	Water
29.07	29.12	29.27	35.85	34.74	29.98	29.12	35.0	37.45	33.79	34.5

a. Thermal storage capacity. According to Table 1, all greenhouse gases have higher molar specific heat than air. As a result, they produce the greenhouse effect.

b. The quality of the earth's surface upon impact with caloric radiation. For the planetary ocean, water acts as a thermal buffer and can be considered constant (in global terms). It is locally influenced by latitude and the presence of clouds. For the dry side, things are much more complex. This is where the relief comes in, and especially the vegetation: forests, meadows, crops. Photosynthesis is an endothermic process and stores significant amounts of heat energy. Deforestation, fires, grassland degradation and the nature of crops influence the greenhouse effect, increasing the negative impact.

c. Natural emissions of greenhouse gases. Volcanic eruptions, mineral springs are considered. An example is the eruption of the Krakatau volcano in Indonesia in 1883. Such an event undoes decades of efforts to control the global climate balance.

d. Anthropogenic emissions of gases from conventional resources. Conventionally, since 1775 the steam engine, then the internal combustion engine and the Diesel engine have continuously amplified carbon dioxide emissions. The amount of CO_2 increased from 280 ppm in 1750 to 405 ppm in 2017.

e. Anthropogenic gas emissions from renewable resources. Agriculture is considered a regenerative environment in terms of greenhouse gases. However, the contribution of this sector to the global balance is 22% of total emissions, and of these 80% represents the contribution from animal husbandry.

The global energy balance highlighted the significant role that managing renewable resources plays in reducing emissions. By implementing measures to reduce polluting gas emissions from renewable sources, it becomes possible to lower emissions to levels favourable for environmental protection. This approach aims to strike a balance between reducing emissions and ensuring the continued operation of conventional energy sources that cannot be immediately phased out.

The management of this problem follows a cyclical approach, where impact assessments are constantly reviewed, and new measures and solutions are continuously identified to further reduce the quantities of polluting gases. This ongoing process ensures a dynamic response to evolving environmental challenges and facilitates the adoption of improved practices to minimize emissions.

GHG emission in agriculture

In agriculture, greenhouse gas emissions occur in various contexts, particularly through biochemical and microbiological processes in the soil during the integration of plant mass after a cycle of vegetation and fruiting. These degradation processes tend to occur in three distinct periods:

After Harvesting: Following the harvest, the plant residues left in the fields undergo decomposition under the influence of autumn rains. During this period, microbial activity breaks down the organic matter, releasing greenhouse gases such as carbon dioxide and nitrous oxide.

Early Spring: In regions with snow cover, the decomposition of plant residues occurs beneath the snow during the earlier part of spring. The cold temperatures do not entirely halt microbial activity, and as the snow melts, the organic matter continues to decompose, releasing greenhouse gases.

Start of the New Vegetation Cycle: At the onset of the new vegetation cycle, the decomposition and incorporation of the previous plant mass coincide with the emergence of fresh, vigorous plant growth. This transition leads to the release of greenhouse gases as the old plant matter is replaced by the new one.

Greenhouse gas emissions generated by animals and birds in households and farms mainly occur in the following ways:

Along the Digestive Tract: In animals, particularly ruminants, microbial fermentation takes place within the first segment of the tract, which includes the rumen. This fermentation process leads to the generation of gases such as methane and carbon dioxide. Similarly, in the segment of the large intestine, undigested and indigestible components undergo fermentation and homogenization, resulting in the release of additional greenhouse gases.

Through the Excretory System: Animals excrete urine, which contains organic compounds resulting from the partial degradation of substances taken in through their diets. This urine can contribute to greenhouse gas emissions as it contains organic compounds that can decompose and release gases.

Handling Manure: Manure is a significant source of greenhouse gas emissions on farms. It can be stored in liquid or solid form in pools or platforms, respectively. During storage, the manure undergoes anaerobic decomposition, releasing gases such as methane and nitrous oxide. Additionally, when manure is spread on fields or added to the soil, it can further contribute to greenhouse gas emissions as it undergoes decomposition.

The sources of greenhouse gas emissions in agricultural contexts can be categorized as follows:

Soil with Organic Matter: Soils containing vegetable or organic matter can release greenhouse gases such as methane, carbon dioxide, and nitrogen oxides. Microbial activity in the soil leads to the decomposition of organic matter, resulting in the production of these gases.

Vegetation in Different States: Depending on how vegetation is managed, it can contribute to greenhouse gas emissions. If vegetation is mowed and exposed to rain before being collected, decomposition occurs, releasing gases. Similarly, if vegetation is stored in rows exposed to weather conditions throughout the year, it undergoes decomposition, resulting in gas emissions. Additionally, if vegetation is not mowed for a year and prevents new vegetation from establishing, it can contribute to greenhouse gas emissions through various processes.

Ruminant Mouth: Ruminants emit gases, including carbon dioxide and methane, through belching during the process of rumination. These gases are generated in the rumen because of microbial fermentation.

Animal Rectum and Manure: Animals that produce dung release gases through the rectum, resulting in gaseous emissions (meteorism). The dung itself also emits gases during the fermentation process, primarily carbon dioxide and methane, along with smaller amounts of ammonia and nitrogen oxides.

Excretory System: The excretory system of all animals produces urine, which mainly contains ammonia along with small amounts of methane and nitrogen oxide. These gases are released during the excretion process.

The sources or emission points can be further categorized as follows:

Internal Sources: These sources primarily involve gas production within the body, often in an anaerobic environment. Gases are generated as byproducts of biological processes and are subsequently eliminated. Examples include gases produced in the digestive system of animals, such as belching and flatulence, which can contain methane, carbon dioxide, and other gases.

External Sources: These sources are a combination of aerobic and anaerobic processes and involve the fermentation of manure outside of the animal's body. Manure can be stored in various structures like warehouses, platforms, tanks, or pools. During storage, the manure undergoes decomposition, leading to the release

of gases such as methane, carbon dioxide, and other gases.
According to a study by Steinfeld et al. in 2006, it is estimated that the livestock sector is responsible for approximately 18% of all human-induced greenhouse gas (GHG) emissions globally (as cited in Philippe, 2015). The literature has established a clear relationship between the livestock sector, including cattle, sheep, pig, and poultry farming, and GHG emissions.
To better understand the contribution of the livestock sector to global GHG emissions, it is important to consider the global warming potential (GWP) of different gases. Using a GWP of 25 for methane (CH_4) and 298 for nitrous oxide (N_2O) (as cited in Philippe, 2015), Table 2 (which is not provided in the given instructions) provides an overview of their corresponding contributions to the total greenhouse gas amounts.

Table 2. Contribution of livestock species to global greenhouse gas emissions (Source: Phillipe, 2015 adapted from Steinfeld et al., 2006)

GHG (mil. tons CO_2 eq/y)	CO_2 Emisions	CH_4 Emisions	N_2O Emisions	Total emisions
Cattle	1166.2 (61%)	2072.8 (81%)	661.6 (60%)	3900.6 (70%)
Small ruminants	69.9 (4%)	244.5 (10%)	202.6 (18%)	517.0 (9%)
Suine	338.9 (18%)	237.3 (9%)	131,1 (12%)	707.3 (13%)
Poultry	332.2 (17%)	-	107.3 (10%)	439,5 (8%)
TOTAL	1907.2 (100%)	2554.5 (100%)	1102.6 (100%)	5564.3 (100%)

It is estimated that globally, the livestock sector is responsible for 18% of all anthropogenic GHG emissions (Steinfeld et al., 2006 cited in Philippe, 2015). The literature indicates that there is a link between the livestock sector (cattle, sheep, pig, and poultry farming) and GHG emissions. Their contribution to global amounts of greenhouse gases is (considering the global warming potential) of 25 for CH_4 and 298 for N_2O (Philippe, 2015) (Table 2).

GHG sources in ruminant operations

Animal husbandry is an important link in the food supply chain. This source is vital to the existence of mankind. This is also the reason why animal husbandry has acquired an industrial character. Moreover, the polluting effects (greenhouse gases) are intensely manifested in large and very large farms.

a. Nutrition

Ruminants have a four-chamber stomach: rumen, reticulum, omasum, abomasum. In the rumen, a complex process of preparing the food bowl takes place with the help of symbiotic bacteria. Carbohydrates are degraded in the rumen and become volatile fatty acids, AGV (acetic, propionic, butyric acid). And the starch is brought to the form of glucose and then converted into volatile fatty acids. Proteins are degraded to amino acids, but it goes even further to ammonia, carbon dioxide. Lipids are hydrolysed to volatile fatty acids.

Ruminal methanogenesis

The process of rumen methanogenesis is important in achieving a strategy to reduce methane gas emissions. In general, methanogenesis is the biological process of producing methane gas by methanogens. These microorganisms produce most of the methane gas. Other microorganisms that produce methane gas are some Eubacteria, but only methanogens can couple the generation of methane gas with the energy of the animal body.

b. Grazing

Although it is a seasonal activity, grazing introduces many variables beyond technical control that favour greenhouse gas emissions: the fact that the grass consumed is green and contains active microorganisms along with large amounts of water (from the structure of the grass), the fact that the animals leave for pasture in the morning, before the fog rises, the fact that during the day, the grass is dry (in the sense that it has no dew), the fact that the animals also graze during the rain (additional intake of water and microorganisms), the watering of animals (completion of the water requirement for the processes in the stomach) is also valid for grazing and stabling, the floristic diversity of the meadow. Grazing involves the movement of animals over large areas, and the gaseous emissions cannot be captured and treated.

c. The stable

The animals in the barn must be supervised on two levels: on the one hand, gas emissions due to nutrition and digestion; on the other hand, the closed, defective environment, which affects health. In the closed space, the management of greenhouse gases is more strictly controlled, and the solutions that can be applied are easier (ventilation coupled with absorption).

Carbon footprint

The term "carbon footprint" refers to the total amount of greenhouse gas (GHG) emissions, measured in carbon dioxide equivalent (CO_2eq), that are released directly or indirectly by an individual, organization, product, or activity over a specific period. It provides a measure of the impact of human activities on climate change and serves as an indicator of environmental sustainability.

The carbon footprint considers various sources of emissions, including the burning of fossil fuels (coal, oil, and gas) for energy production, transportation, industrial processes, agriculture, deforestation, and waste management. These activities release carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other greenhouse gases into the atmosphere, contributing to global warming and climate change.

Carbon Footprint Estimating Tools

In developed countries, significant funding has been allocated to research projects aimed at determining emission factors related to greenhouse gases. These projects focus on identifying the specific factors that contribute to emissions on a farm level, such as feeding practices and manure management. Additionally, researchers investigate various influencing factors, such as the average temperature of the area, that can impact emissions from agricultural activities.

Furthermore, these research efforts have resulted in the development and validation of mathematical models that accurately represent the biological processes involved in greenhouse gas emissions. For instance, complex models have been created to simulate ruminal fermentations, enabling scientists to predict emission levels based on different inputs. These models rely on the formulation and validation of numerous equations that consider various factors influencing greenhouse gas emissions. By inputting specific parameters into these equations, researchers can estimate emissions associated with different agricultural activities. In a later stage of the research process, these equations (simpler/approximate or more complex/exact) were connected within sets of equations (chains of equations) that allow the estimation of greenhouse gas emissions based on input data sets.

A classic reference in this sense are the sets of equations developed in 2006 by the Intergovernmental Panel on Climate Change (IPCC, 2006) and periodically updated (Gómez & Irving, 2019). These sets of equations are accompanied by various documents, periodically developed: technical guides, user manuals, public policy recommendations, descriptions of methodologies, information, research agendas, databases containing emission factors, etc.

The equations allow the estimation of carbon emissions at the emission source level, at the animal level, at the farm section level or at the whole farm level. It is important to note that these equations are publicly available and, to a certain extent, can be adapted to the specifics of countries, regions, etc. by adjusting conversion factors, including updated equations, etc.

Also, to a certain extent, these sets of equations also work when not all input data (a farm's management data) are available, using extrapolations, approximations, etc. Obviously, the lack of data leads to inaccuracies in the calculation/estimation of the carbon footprint and when the proportion of missing data is too high, the models (chains of equations) no longer work.

In the past decade, a multitude of online models and platforms have been developed based on these sets of equations (Popa RA et al. 2021). These tools greatly facilitate and streamline the calculation of carbon footprints, enabling a more efficient and systematic approach. Each of these models and platforms has its own set of advantages and disadvantages. However, it's worth mentioning that at the European level, there is a growing inclination towards standardization. By utilizing these online models and platforms, individuals and organizations can easily input relevant data and parameters to estimate their carbon footprint. These tools leverage the power of computational algorithms to process the inputs and generate carbon footprint calculations in a swift and automated manner.

Regardless of the way of elaboration, the way of constituting the chains of equations used, the interface used (the use or not of an IT interface), in order to be effective, these models (called in current language "tools") have several characteristics common, such as the input data (often the same), the equations and emission / conversion factors used (IPCC 2006, with subsequent updates – adopted faster or slower), the way the results are expressed (greenhouse gases – values individual as well as the integrative value - carbon dioxide equivalent), etc.

There are numerous comparative studies focused on these models/tools, prior to the standardization actions mentioned above, these studies especially highlighting the differences and their effect on the accuracy of estimating the level of greenhouse gas emissions/carbon footprint.

Most importantly, all these models consider the following aspects:

• The environmental impact of animal production can be measured as global warming potential (GWP), acidification potential, eutrophication potential, photochemical ozone-creating potential, ozone-depleting potential, energy use and land use.

• Global warming potential shows how much heat is trapped in the atmosphere and is usually reported as carbon dioxide equivalent (CO_2-eq).

• Measures the accumulated warming over a 100-year period that resulted from a unit mass of gas produced at the beginning of a 100-year reference period.

• Greenhouse gas emissions are calculated for biogenic greenhouse gases: CO_2, methane (CH_4) and nitrous oxide (N_2O).

• The PGI of CO_2 is 1, where CH_4 has the PGI of 28, while the PGI of NO_2 is 265 (IPCC, 2014).

• This means that each kg of CH_4 emitted absorbs the same amount of heat as 28 kg of CO_2 emitted, while one kg of N_2O absorbs the same amount of heat as 265 kg of CO_2 over a period of 100 years.

• Greenhouse gases directly affect global temperature and cause climate change. After net CO_2 emissions have completely ceased, the global warming effect is predicted to last for hundreds if not thousands of years, unless a large amount of net CO_2 is removed over a long period of time.

In this context, one of the roles of these models/tools is to create the framework not only for the determination at a given moment of the carbon footprint at the level of economic operators and agriculture (those who can make management decisions) but also to be able to monitor the effect of the application measures to reduce GHG emissions at the national level, but especially at the level of farms/economic operators. Developing cost-effective mitigation measures for greenhouse gas emissions and ammonia or nitrate leaching requires relational statistics that can only be obtained through farmer survey methods. While on-farm nutrient management tends to vary systematically by farm type (cattle, pigs, etc.) and size, such surveys can be usefully stratified by farm type and size.

Some European countries have already collected farm-level activity data. The surveys were very successful and the national inventories could be improved. Country-specific mitigation options and potentials were identified (Popa D et al. 2026). It was found that the only way forward to a more sustainable and environmentally friendly yet economically viable agriculture was to acquire a better knowledge of farm management practices. Only then can practically feasible, effective, and economical mitigation measures be proposed and implemented.

Agricultural emissions are highly dependent on the livestock housing system and the distribution of the Manure Management System (MMG). These data are a mandatory prerequisite for accurate emission estimates with a low range of uncertainty. The impact of mitigation measures on national emissions reported under the UNFCCC and CLRTP must be documented and this is only possible if representative data on the distribution of GHGs are available. The lack of this data leads to two major disadvantages:

1. Country-specific values can only be integrated to a small extent in the national emission inventory. Major parts of the inventory should be configured with default values that provide a skewed representation of the processes typically found in that country.

2. Due to the lack of breeding and sheltering data, the effect of mitigation measures cannot be included in the national emission inventory.

The methodologies for calculating emissions of greenhouse gases and ammonia are enshrined in international law, so they are not up for discussion. In almost all European states, agriculture is defined as a key source of greenhouse gas and ammonia emissions. As such, Member States are required to use a Tier 2 methodology for stock reporting. Tier 2 methodologies require detailed data that respects the relationships between emission sources. These data can only be collected through large-scale sampling of farms.

Gross nitrogen and phosphorus balances provide holistic indicators of the related environmental pressure exerted by agriculture. For N, there are significant losses to the atmosphere in the form of ammonia, nitrous oxide, nitrous oxide (NO) and molecular nitrogen (N_2). Ammonia, and nitrous oxide are pollutants, while the emission of molecular nitrogen reduces the efficiency of manure and fertilizers and the fertility of soils. Nitrogen is lost to aquatic environments as nitrate, ammonium and dissolved organic nitrogen, all of which can lead to pollution and all of which reduce soil fertility. Unlike greenhouse gas and ammonia emissions, countries are not required to report N and P balances for agriculture as part of any international convention. Consequently, there is no organization equivalent to the IPCC or UNECE that has the responsibility to standardize and improve the methodology for calculating these balances.

Environmental pressure indicators are very important, and some tools (such as CAP'2ER) calculate them as well, in addition to the carbon footprint.

Data requirements for calculating NH_3, CH_4, N_2O emissions and N and P balances are relatively high, especially for large emission sources, because of the accuracy required for these source estimates. Currently, this data is not always available in the Member States. Based on experiences in various countries, it is suggested that farm structure surveys be carried out every five years to collect information on housing systems, manure storage systems and manure application techniques.

Farm activity data, listed under the "minimum requirement" must be collected, as without this data, proper inventory reporting is not possible. The effect of mitigation measures cannot be indicated in the inventory, and the profitability of mitigation measures cannot be assessed. Activity data listed at "optimal requirement" should be collected for more accurate inventory estimation. They offer more possibilities for country-specific and cost-effective mitigation measures and enable the assessment of the environmental impact of farm management practices. For most of this data, the additional effort to collect it is small and the additional effect is large.

Table 3. Inventory of carbon footprint estimation models applicable to ruminants

TOOL	Country	Species covered
CAP'2ER	France	beef cattle, dairy cattle, dairy goats, meat goats, dairy sheep, meat sheep
COOL FARM TOOL	Great Britain	beef cattle, dairy cattle, dairy goats, meat goats, dairy sheep, meat sheep
FARM CARBON CALCULATOR	Great Britain	beef cattle, dairy cattle, meat goats, meat sheep
AGRECALC	Great Britain	beef cattle, dairy cattle, meat goats, meat sheep
CONVIS	Luxembourg	beef cattle, dairy cattle
DECiDE	Belgium	beef cattle, dairy cattle
Kringloopwijzer (ANCA)	Netherland	dairy cattle
AGNAV	Ireland	beef cattle, dairy cattle, meat goats, meat sheep
Agrosfär	Sweden	beef cattle, dairy cattle
ESGreen Tool	Denmark	beef cattle, dairy cattle
Klimrek	Belgium	dairy cattle
KLIR	Swiss	dairy cattle
TEKLa	Germany	beef cattle, dairy cattle, meat goats, meat sheep
BIOCODE	Finland	beef cattle, dairy cattle
ADER 914	Romania	beef cattle, dairy cattle, dairy goats, meat goats, dairy sheep, meat sheep
ArdiCarbon	Spain	dairy sheep, meat sheep
Carbon Sheep	Italy	dairy sheep, meat sheep
Teagasc Sheep LCA	Ireland	meat sheep

Obtaining accurate values for coefficients used in calculating emissions or nutrient balances is essential. The default values provided in the IPCC Guidance 2006 and the EMEP/EEA Guidance 2019 are intended to be reasonable estimates for the specified geographic area. These default values often mask wide geographic variation in actual values, either due to variations in climate or regional variations in agricultural practices. In addition, the default values presented in the various guidance documents generally refer to situations where no mitigation measures have been implemented. Member States are encouraged to use appropriate coefficient values at national or regional level. It is good practice to support the use of these coefficients with empirical measurements. The consequences of relatively small errors in the coefficients can be significant. It is important that the source of the coefficients used is documented. Where default values are used, the source must be indicated. The value of some coefficients varies according to agricultural practice. For example, ammonia emission after land application of animal manure depends on the manure application method used. Coefficients may need to be updated periodically to account for significant changes in farming practices. Most important tools used to estimate carbon footprint in the ruminant farms are presented further.

CAP'2ER

CAP'2ER is a farm-level assessment tool covering mixed cropping and ruminant farming (Milk, Meat, Mixed, Sheep, Goat). Software was developed in 2015, and compute the environmental performances from small ruminant farms, using the variables affecting the carbon footprint of farms. It is widely used in France (about 30,000 assessments and 1,500 users). It is also used in other countries Switzerland, Italy, Germany, Spain, Romania.

The tool (based on life cycle assessment (LCA) assesses the impact on the environment (GHG emissions, nitrogen losses, energy consumption) and the positive contribution (biodiversity, carbon storage, feeding people). It is an advisory tool to build an action plan and provide technical advice. You can do simulation to test the implementation of the practices.

The tool has two assessments level of environmental performances:

Level 1: a simplified web version for large public (farmers, advisers, students), used for a quick evaluation of in farm environmental footprint.

Level 2: a tool for adviser’s decision support (to realize “in depth” assessments, with high level of details).

For comparison, level 1 requests an input of 40 technical data and level 2, an input of 150 technical data. Technical data used are general information about farm, breeds, flock number and structure, crop surfaces, purchased feeds, etc.

A set of equations will estimate production of manure, dry matter intake, emissions allocation, total carbon footprint on unit of production etc. (Cannas et al., 2019)

COOL FARM TOOL

COOL FARM TOOL is widely used in Europe, it is available in several languages (English and German and 15 beta languages). The tool is focused on main areas as: greenhouse gases, biodiversity, water use, food lose and waste.

The tool covers many production systems, have good transparency in the methodology used in the tool (IPCC 2006 methodologies) and good precision for the dairy and crop production system.

The tool is more suited to assess the carbon footprint than to provide technical advice at the farm level, there are few features to build an action plan.

The tool is not well suited to mixed farms, it is more of an aggregation of production (an assessment by production and crop).

Greenhouse gas quantification and soil sequestration are done based on crop and livestock data requirements (yield harvested and marketable products, growing area, fertiliser applied, energy used, transport, herd size, feed, manure management etc.).

Water use is quantified based on farm coordinates, soil moisture, planting time, water general amount, irrigation etc.).

Biodiversity is evaluated using information like: total area and non-productive land of the farm, farm management practices, provision of small and large habitats, etc. (Hillier et al. 2011).

Farm Carbon Calculator

Is a free evaluation tool, used exclusively in Great Britain, and created by an independent company. Is started in 2009 as a help for farmer to reduce greenhouse gases emissions. The tool is very well developed for agricultural use, especially vegetal production. Additionally, a part of toolkit is dedicated to livestock. The tool is also based on IPCC 2006 recommendations.

Provide a practical, scientifically robust, and accurate approach.

Produce guidance and other outputs that are high-quality, accessible and easy-to-understand.

AGRECALC

Is a carbon and economic efficiency estimation tool with the access on the AGRECALC cloud. Widely used tool in the UK (7,000 advisers, 12,000 assessments). It covers a wide type of

production with a farm level approach. Ratings available for multi-production farms. Good methodological precision and sensitivity to practices. Data collection requires data pre-processing when there are multiple production units.
The link between each production unit seems not to be well developed in this tool, and user guide and training are available, but for the methodology, only simplified elements were available on the site.
The tool Conforms to IPCC 2006 calculations for all livestock types & PAS 2050:11 supply chain standards (Smith et al., 2019).

AGNAV
Developed by Teagasc/Bord Bia/ICBF, some features are still under construction. Used in Ireland by Teagasc advisers, it is an advisory tool with a strong link to agricultural practices and environmental outcomes. Attenuation levers are easy to test in the instrument. Is well adapted for use in Ireland, connection to Irish database for data collection. Few chances of use at European level.
(https://www.bordbia.ie/farmers-growers/prices-markets/agri-market-insights/agnav-trusted-solutions-for-everyday-farming/).

ADER 914
It calculates emissions at the animal level, a first for Romania. It is based, like all other systems/models, on the IPCC 2006 equations and allows distinct calculation by category of animals, with an emphasis on the forage module. Significant inputs are needed to be able to compete with much more advanced models/ systems like CAP2ER or CoolFarmTool.

ArdiCarbon
Is a spreadsheet tool, developed in Spain, developed to compute GHG emissions on small ruminant farms. Is relative similar with CAP'2ER tool, but access to tool is very limited.

Teagasc Sheep LCA
Teagasc sheep life cycle assessment (LCA) carries out a life cycle inventory and operates with multiple parameters (Asem-Hiablie S et al. 2018). The method uses the guideline defined by British Standard (BSI, 2008) for potential global warming of sheep farms and caring out LCA guidelines for small ruminants (LEAP, 2025).
The tool is estimating GHG emissions over the one-year production cycles. Are considered all categories of animals from the farm: ewes, lambs, rams, replacement animals etc. The estimation models, sheep-specific emissions are driven by the inputs of the sheep breeding systems: feedstuffs, fertilizers, manure management, gas, and electricity consumption etc. Few chances of being used at European level as it is built on Irish specifics and is only addressed to the sheep farming sector.
It should be mentioned that in addition to the models/platforms developed by public research units, there are numerous private initiatives/companies that offer their services, especially to those interested in trading carbon credits. One such example is Agreena:
https://agreena.com/ro/
It buys carbon credits and assists farmers who intend to reduce their carbon footprint.
According to the company's statements, it already has a portfolio of clients in Romania, mainly those that deal with vegetable crops.

CONCLUSIONS

When faced with the need to reduce emissions, countries are typically faced with a choice between several different mitigation measures. Identifying the most effective cost-reduction measures for agriculture typically requires data beyond what is needed to support a proper approach to calculating emissions. This is because the complex and highly varied nature of agriculture results in large differences between available mitigation measures and their associated costs. In this respect, the availability user-friendly online tools have democratized the process of calculating carbon footprints. It allows a wide range of users, including individuals, businesses, and policymakers, to access and utilize these platforms to make informed decisions regarding their carbon emissions. By providing a more expedient and systematic calculation method, these online models and platforms contribute to raising awareness and facilitating actions to reduce carbon footprints and promote sustainability.

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