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## GHG EMISSIONS OF THE AGRIFOOD SYSTEM AND THE CARBON FOOTPRINT ESTIMATION AT THE FARM GATE

### ABSTRACT

Members of the United Nations (UN) and Food and Agricultural Organisation (FAO) seek appropriate adaptation and mitigation responses that respect natural resources, increase food production and achieve food security in the context of climate change.

The purpose of this paper is to analyse the FAO indicators related to the agri-food sector emissions. In this endeavour, it is important to start from the concept of greenhouse gas (GHG) emissions. Only a proper vision on this matter can lead to a plan for reducing the agri-food sector impact on the environment. This paper is a rather theoretical approach, using FAOSTAT data on farm gate emissions and on pre- and post- production emissions in Romania.

Reducing the carbon footprint is the main goal for the years to come. In this respect, several non-governmental organisations (NGOs) are trying to support farmers in their attempt to estimate/quantify the carbon footprint at farm level.

GHG emissions from the Romanian agrifood system are studied for a period of more than 60 years (1961–2023), while carbon footprint data was available for the period 1990–2023.

**Key words:** GHG, FAO, methodology, emissions, carbon footprint.

**JEL Classification:** Q10, Q56.

### 1. INTRODUCTION

There is a long way from the “greenhouse effect” concept first use to the possibility to quantify the greenhouse gas (GHG) emissions in agriculture and food sectors and even estimate the carbon footprint. The existence of the greenhouse effect was proposed by Joseph Fourier in 1824, but it was not named as such. The term “greenhouse” was first applied to this phenomenon by Nils Gustaf Ekholm in 1901. The enhanced “greenhouse effect” describes the fact that by increasing the concentration of GHGs in the atmosphere due to human action, the natural greenhouse effect is increased.

Carbon footprint concept received a first definition in 2007, as being a measure of the total amount of greenhouse gases emitted directly and indirectly by

a person, organisation, event, or product, usually expressed in carbon dioxide equivalents. Since there is no data to interpret at farm level, this paper includes an attempt to estimate the carbon footprint at the farm gate (kt of CO<sub>2</sub> eq.) at national level.

## 2. STATE OF KNOWLEDGE

Carbon dioxide (CO<sub>2</sub>) emissions from fossil fuels and deforestation account for the largest percentage of total GHG emissions. These are followed by methane (CH<sub>4</sub>) emissions from agriculture (livestock), landfills and fossil fuel extraction. Next is nitrous oxide (N<sub>2</sub>O) from fertilisers and biomass burning. There are direct emissions of nitrous oxide (N<sub>2</sub>O) and indirect emissions of nitrous oxide (N<sub>2</sub>O) into the atmosphere. There are also many types of fluorinated gas emissions from industrial processes.

For this study, several documentary materials were needed which reference climate change and GHGs emissions in the agri-food sector (IPCC, 2006 and 2014) and carbon footprint concept (Cammarata et al., 2023; Leonte, 2025).

This paper uses public data and information from FAO database (FAOSTAT, 2025; FAO's Methodological notes, 2025) in order to analyse and compare the evolution of greenhouse gas (GHG) emissions, as well as to try to estimate the carbon footprint at farm gate at national level. FAO database uses estimated values (E), Official figures (A) and Figures from external organisation (X). STATISTA (2025) was used just for some crosschecking data, because using just one database gives a lot of consistency to the paper.

## 3. MATERIAL AND METHOD

Current reporting requirements for mitigation in agriculture, forestry and other land use sectors have given the possibility to have a paper based on recently updated FAO database (last update October 28<sup>th</sup>, 2025). FAOSTAT has a good name in using Good Practice, which is a set of procedures intended to ensure that GHG inventories are accurate in the sense that they are systematically neither over- nor underestimated so far as can be judged, and that uncertainties are reduced so far as possible. Good Practice covers choice of estimation methods appropriate to national circumstances, quality assurance and quality control at national level, quantification of uncertainties and data archiving and reporting to promote transparency.

Romanian GHG emissions from the agri-food sector will be analysed for the period 1961–2023. The evolution of the carbon footprint can be traced back since 1990. Available data cover a 24-year timeframe to calculate Carbon footprint in

Romania, as well as for total EU-27. For the last available data, *i.e.* year 2023, emissions at farm gate and emissions from the pre- and post- agricultural production for Romania are presented with details, how they were calculated, what elements were selected for calculations and of course interpretation of results.

Many of the used concepts are as FAO defined them (Table 1).

Table 1

Important Concepts

Glossary	Description
Activity data	Data on the magnitude of a human activity resulting in emissions or removals taking place during a given period of time. Data on energy use, metal production, land areas, management systems, lime and fertiliser use and waste arisings are examples of activity data.
Carbon dioxide equivalent	A measure used to compare different greenhouse gases based on their contribution to radiative forcing. The UNFCCC* currently (2005) uses global warming potentials (GWPs) as factors to calculate carbon dioxide equivalent.
Emission factor	A coefficient that quantifies the emissions or removals of a gas per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.
Emissions	The release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.
Global warming potential	Global Warming Potentials (GWP) are calculated as the ratio of the radiative forcing of one kilogramme of greenhouse gas emitted to the atmosphere to that from one kilogramme CO <sub>2</sub> over a period of time ( <i>e.g.</i> , 100 years).
Manure	Waste materials produced by domestic livestock can be managed for agricultural purposes. When manure is managed in a way that involves anaerobic decomposition, significant emissions of methane can result.
Removals	Removal of greenhouse gases and/or their precursors from the atmosphere by a sink.
Reporting	The process of providing results of the national GHG inventory.
Sequestration	The process of storing carbon in a carbon pool.
Sink	Any process, activity or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere. Notation in the final stages of reporting is the negative (-) sign.
Source	Any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere. Notation in the final stages of reporting is the positive (+) sign.

Note: \*UNFCC = United Nations Framework Convention on Climate Change.

Source: IPCC, 2006.

According to the FAO's methodological notes, the GHG emissions from the agrifood system include three categories: emissions at farm gate, emissions caused by land use and change and emissions from pre- and post- agricultural production (Table 2).

Table 2

GHG emissions by each category of the agrifood system

No.	Category	Emissions	Source
I	FARM GATE	Emissions from crops	Crop residues Burning – crop residue Rice cultivation Synthetic fertilisers
		Emissions from livestock	Enteric fermentation Manure applied to soils Manure left on pasture Manure management
		Emissions from on-farm energy use	Petroleum product Natural gas Electricity Heat Coal
II	LAND USE AND CHANGE	Emissions from forests	
		Emissions from fire	
		<b>Emissions from drained organic soils</b>	
III	EMISSIONS FROM PRE- AND POST- AGRICULTURAL PRODUCTION	Fertilisers manufacturing	
		Pesticides manufacturing	
		Food processing	
		Food packaging	
		Food transport	
		Food retail	
		Food household consumption	
Food systems waste disposal			

Source: Methodological notes, FAO, 2025.

In order to analyse the carbon Footprint at the farm gate we shall focus only on two categories of emissions: farm-gate emissions and pre- and post- agricultural production emissions.

The indicators taken into consideration are: carbon dioxide (CO<sub>2</sub>) emissions, methane (CH<sub>4</sub>) emissions and nitrous oxide (N<sub>2</sub>O) emissions. Carbon dioxide (CO<sub>2</sub>) emissions are given in kt CO<sub>2</sub>. Methane (CH<sub>4</sub>) emissions and nitrous oxide (N<sub>2</sub>O) emissions had to be calculated as carbon dioxide equivalent (CO<sub>2</sub> eq.), using the transformation coefficients.

Global warming potential (GWP) is a measure of how much heat GHGs traps in the atmosphere over a specific time period, relative to CO<sub>2</sub>. The sum of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions is done by using transformation coefficients, in order to calculate a weighted sum of the quantities of the three gases. The policymakers have chosen to use the 100-year GWP scale as the standard in international agreements.

According to the literature review, these transformation coefficients are: 1 t CO<sub>2</sub> = 1 t CO<sub>2</sub> eq., 1 t CH<sub>4</sub> = 21 t CO<sub>2</sub> eq. and 1 t N<sub>2</sub>O = 310 t CO<sub>2</sub> eq. AR4

global warming potential coefficients corresponding to a 100-year horizon used:  $GWP(CO_2) = 1$ ,  $GWP(CH_4)=25$  and  $GWP(N_2O) = 298$  (IPCC, 2012). The conclusion is that different reports and assessments may have slightly different values.

Due to the fact that all data used in this paper have a unique source (FAOSTAT), it was consequential important to search for the information provided by FAO (FAOSTAT, Methodological note on Total Emissions, October 2023). Emissions in singles gases are converted into their CO<sub>2</sub> equivalents using the IPCC AR5 global warming potential coefficients corresponding to a 100-year horizon (IPCC, 2014).

Table 3

Transformation coefficients in CO<sub>2</sub> equivalents used by FAOSTAT

GHG name	GHG formula	Transformation coefficients
Carbon dioxide	CO <sub>2</sub>	1 t CO <sub>2</sub> = 1 t CO <sub>2</sub> eq.
Methane	CH <sub>4</sub>	1 t CH <sub>4</sub> = 28 t CO <sub>2</sub> eq.
Nitrous oxide	N <sub>2</sub> O	1 t N <sub>2</sub> O = 265 t CO <sub>2</sub> eq.
Sulfur hexafluoride*	SF <sub>6</sub>	1 t SF <sub>6</sub> = 23,500 t CO <sub>2</sub> eq.
Nitrogen trifluoride*	NF <sub>3</sub>	1 t NF <sub>3</sub> = 16.100 t CO <sub>2</sub> eq.

Note: \*F-gases.

Source: Methodological notes, FAO, 2025.

The transformation coefficients in CO<sub>2</sub> equivalents from Table 3 have been used to calculate and present all emissions in tonnes or Kt CO<sub>2</sub> or CO<sub>2</sub> equivalent (CO<sub>2</sub> eq.), in order to provide comparability between the emissions from different categories and sources.

## 4. RESULTS AND DISCUSSIONS

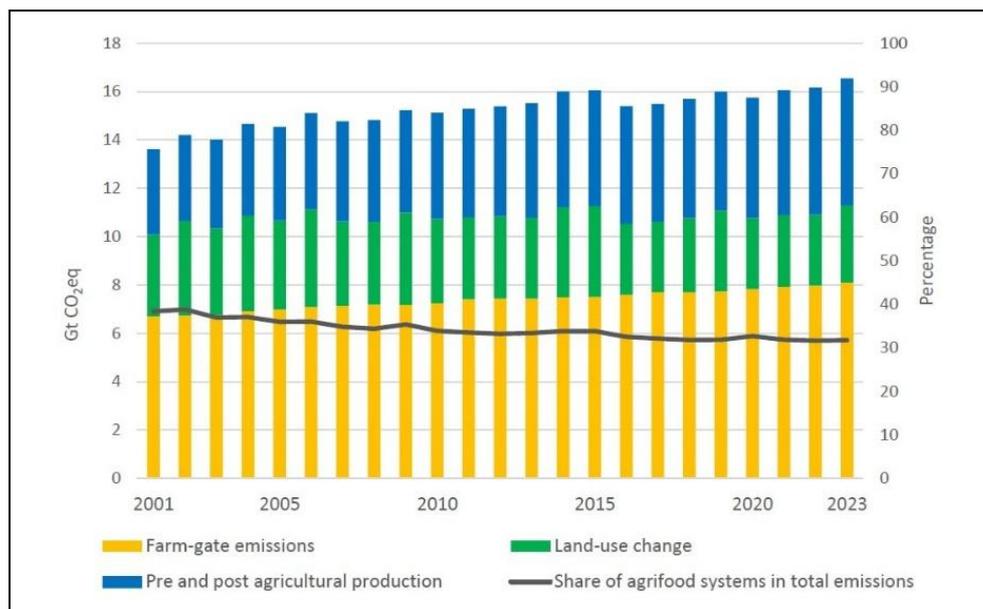
### 4.1. THE GLOBAL SITUATION OF GHG EMISSIONS FROM THE AGRIFOOD SECTOR

The world's larger CO<sub>2</sub> emitters in 2023 are: China (30.1%), the United States (11.3%), India (7.8%), EU-27 (6.1%), Russia (5%) and Brazil (2.5). They are responsible for about two-thirds of global CO<sub>2</sub> emissions (Statista, 2023). This concentration highlights both the scale of responsibility and the potential for impact – when just a handful of global actors shift policies, technologies, or energy sources, the effect can reshape the planet's emissions trajectory. The challenge (and opportunity) lies in aligning growth, energy security and decarbonisation across these major players. World Average Emissions of CO<sub>2</sub>/capita in 2021 were

4.7 t CO<sub>2</sub>. Romania was less polluting, compared to other member states of European Union (FAOSTAT, 2025).

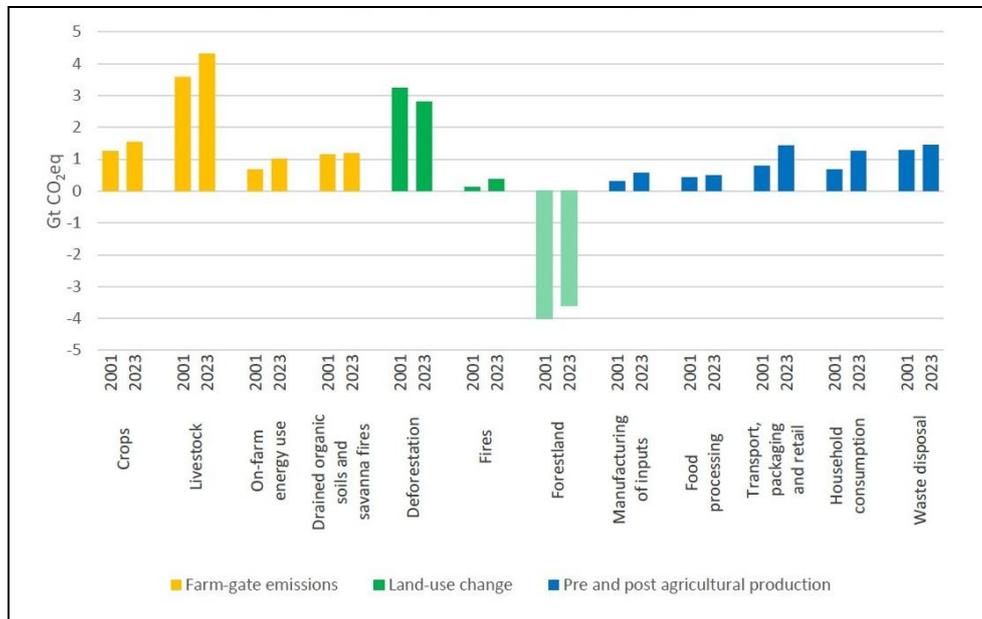
Fuel and energy industry is the top polluter in the world, contributing to around 75% of global GHG emissions from fossil fuels like coal, gas, and oil, while agriculture and food production account for up to 18% of emissions, largely from livestock, land-use changes and ammonia pollution (Davta, 2025).

In 2023, the largest component of the agrifood system emissions globally was farm-gate emissions, totalling 4.3 Gt CO<sub>2</sub> eq. from methane generated in enteric fermentation and nitrous oxide from manure (emissions from livestock). The second most important component was emissions from land-use changes, at 2.8 Gt CO<sub>2</sub> eq. from biomass carbon losses, while the third was emissions from pre- and post- agricultural production packaging, transport and retail, generating 1.4 Gt CO<sub>2</sub> eq., largely from fossil fuel combustion across logistics and distribution systems.



Source: FAO data processed by the author, 2025.

Figure 1. World global agrifood system emissions by the 3 components in Gt CO<sub>2</sub> eq. (2001–2023).



*Note:* Emissions/removals on forestland are not accounted for within agrifood systems in this analysis (they are shown in this figure only for comparison).

*Source:* FAO data processed by the author, 2025.

Figure 2. World agrifood system emissions by components in Gt CO<sub>2</sub> eq. (2021–2023).

Compared to 2001, livestock emissions grew by 22 percent, while deforestation emissions decreased by 13 percent. This suggests a decoupling between the two processes over time, reflecting known decadal trends towards more intensive livestock systems, needing less land clearance for grazing. At the same time, the strongest growth was recorded in the supply chain and consumption processes. Emissions from the manufacturing of inputs, transport, packaging and retail, and household consumption grew by about 80 percent from 2001 to 2023.

#### 4.2. FARM-GATE EMISSIONS IN ROMANIA

The purpose of these calculations is to obtain an estimated level for the carbon footprint at farm level. Carbon footprint is considered to be the sum of GHG emissions at farm level, by a company, an individual, a cooperative, a fair and by any type of event. Why not trying to estimate it at a sector level like agriculture? Even better, at the farm gate. It will not be a very accurate figure, but research pushes us to surpass ourselves and try paths less travelled.

Emissions at farm gate are an estimated sum of emissions from crops, emissions from livestock and emissions from energy use in agriculture.

#### 4.2.1. Emissions from Crops

The FAOSTAT domain Emissions from Crops provides estimates of emissions associated with crop processes, namely “Crop residues”, “Burning of crop residues”, and “Rice cultivation” and the application of “Nitrogen (N) fertilisers” to soils (including mineral and chemical fertilisers).

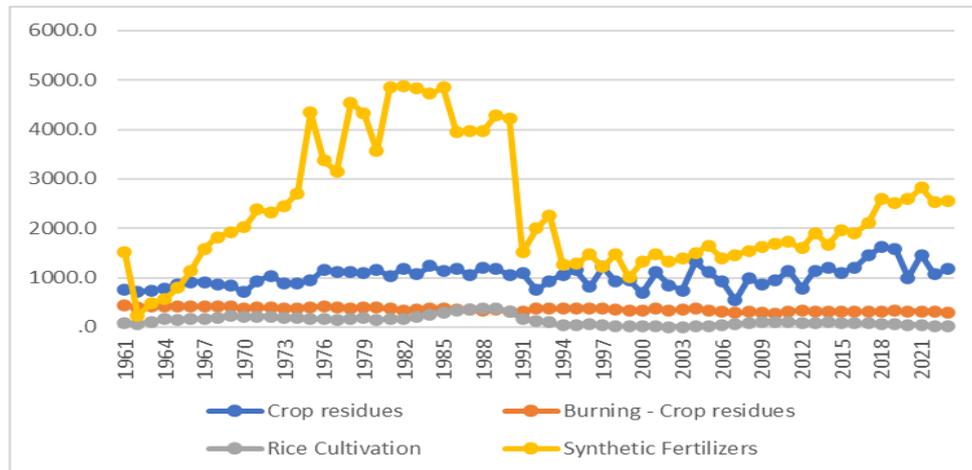
Relevant crops are: barley, beans, maize, sugar cane, millet, oats, potatoes, rice, rye, sorghum, soybeans and wheat. Emissions from “Crop residues” consist in N<sub>2</sub>O Emissions, which is the sum of Direct N<sub>2</sub>O emissions and Indirect N<sub>2</sub>O emissions.

GHG emissions from “Burning of crop residues” consist of CH<sub>4</sub> emissions and N<sub>2</sub>O emissions produced during combustion of crop residues burnt in the field. The biomass available for burning is estimated taking into account the fractions removed before burning due to animal consumption, decay in the field and use in other sectors (e.g. biofuel, domestic livestock feed, building materials etc.).

GHGs emissions from “Rice cultivation” consist of CH<sub>4</sub> emitted by anaerobic decomposition of organic matter in paddy field.

The domain also provides information on the emissions associated with the total agricultural use of nitrogen synthetic fertilisers. GHG emissions from “Synthetic fertilisers” consist of direct and indirect N<sub>2</sub>O emissions from nitrogen (N) added to agricultural soils. Specifically, N<sub>2</sub>O is produced by microbial processes of nitrification and denitrification taking place at the site of nitrogen addition (direct emissions), and after volatilisation/re-deposition and leaching processes (indirect emissions).

This category consists in both CH<sub>4</sub> emissions and N<sub>2</sub>O emissions. These have been transformed in kt CO<sub>2</sub> eq. in order to compare the emissions by category for the period 1961–2023.



Source: FAO data processed by the author, 2025.

Figure 3. Emissions from crop residues in the Romanian agrifood sector in kt CO<sub>2</sub> eq. (1961–2023).

Crop residues are fairly stable over the entire period, ranging from 800 to 1,200 kt. There is a slight upward trend after 2000, possibly reflecting increased agricultural productivity and better residue management.

The burning of crop residues has been a very low and relatively constant process throughout the years, staying below 400 kilotons, which indicates that it hasn't been a major GHG source in Romania. In the last five years an increasing trend can be noticed due to the use of agricultural residues for bioenergy in Romania.

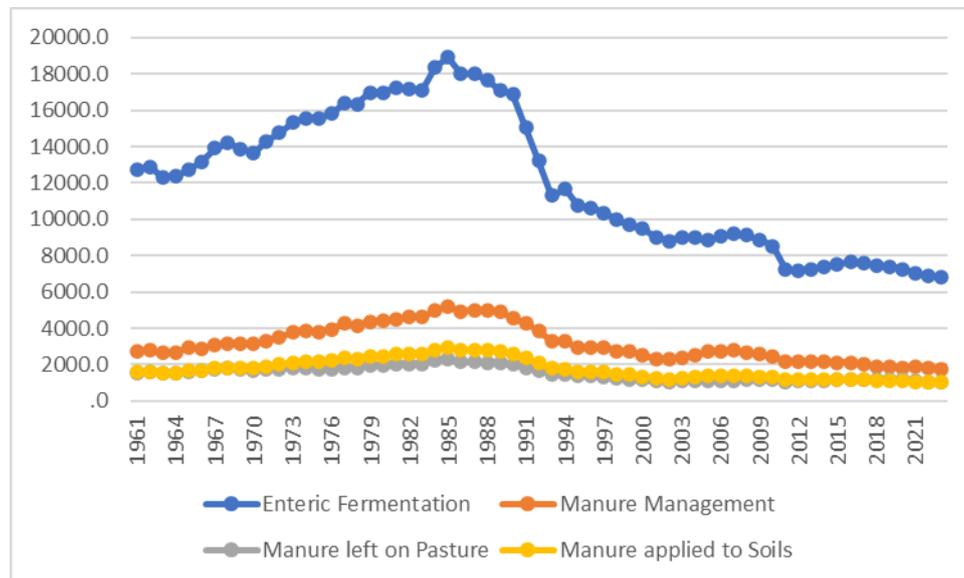
Rice cultivation has a negligible contribution to total emissions due to the small area of rice production in Romania compared to other crops.

Synthetic fertilisers emissions increased sharply from 1961 to the late 1970s, peaking around 1980–1985 at over 5,000 kt CO<sub>2</sub> eq. This reflects Romania's heavy use of synthetic fertilisers during the communist industrial agriculture period. A dramatic decline occurs around 1990, coinciding with the collapse of the communist regime and the resulting drop in fertiliser use. After 1990, emissions remain much lower, fluctuating around 1,000–2,000 kt CO<sub>2</sub> eq., with a slow rise after 2005, likely due to modernisation and EU agricultural integration.

#### 4.2.2. Emissions from livestock

The FAOSTAT domain Emissions from livestock provides information on greenhouse gas (GHG) emissions generated from four livestock processes (Figure 4), namely: emissions from *enteric fermentation* consisting of methane gas (CH<sub>4</sub>) emissions produced in the digestive systems of ruminant livestock and to a lesser extent of non-ruminant animals; emissions from *manure* left on pastures by grazing livestock; emissions from *manure* management consisting of methane and nitrous oxide emissions from aerobic and anaerobic decomposition processes; emissions from *manure* applied to soils.

Methane gas (CH<sub>4</sub>) emissions are mainly the result of enteric fermentation, but also the result of partial manure management activity. Activity data for enteric fermentation cover the following animal categories: buffaloes, sheep, goats, camels, llamas, horses, mules and asses, dairy and non-dairy cattle, market and breeding swine. For the CH<sub>4</sub> emissions coming from manure management, the activity data cover the following animal categories: buffalo, sheep, goats, camels, llamas, horses, mules, asses, ducks, and turkeys, dairy and non-dairy cattle, chicken layers and broilers and market and breeding swine. It represents the main source of GHG emissions. From 1961 to 1989, emissions increased significantly from 12,721 to 18,025 kt CO<sub>2</sub> eq., mainly due to intensive export activities. After 1989, however, emissions from enteric fermentation declined as a result of a lower number of animals and efforts to mitigate GHG emissions.



Source: FAO data processed by the author, 2025.

Figure 4. Emissions from livestock in the Romanian agrifood sector in kt CO<sub>2</sub> eq. (1961–2023).

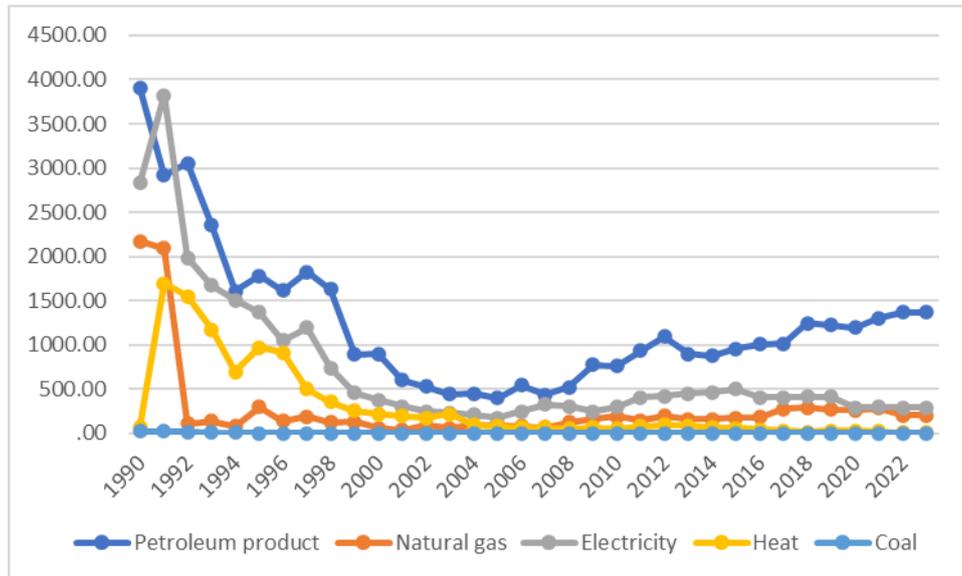
The rest of the GHG emissions from livestock are nitrous oxide (N<sub>2</sub>O) emissions coming only from the manure sector. The term manure includes both urine and dung (*i.e.*, both liquid and solid material) produced by livestock. More specifically, CH<sub>4</sub> gas is produced by anaerobic decomposition of manure stored or treated, while N<sub>2</sub>O is produced directly by nitrification and denitrification processes in the manure on the deposition site, and indirectly by nitrogen volatilisation and re-deposition processes, as well as from the leaching process of manure.

Manure left on pastures by grazing livestock, manure applied to soils and manure management coming from the N<sub>2</sub>O emissions have a contribution more or less equal to the emissions from livestock in Romania for all the period 1961–2023. For the period 1961–1989 it is an increasing curve, while after 1989 it is a decreasing curve.

#### 4.2.3. Emissions from on-farm energy use

The FAOSTAT domain Emissions from Energy use in agriculture contains data on energy used in agriculture (including forestry, aquaculture and fisheries), for instance to operate machinery, irrigate, heat stables, operate aquaculture ponds and fishing vessels, and related greenhouse gas (GHG) emissions. It also includes on-farm use of, and related GHG emissions from, electricity and heat generated off-farm.

For the calculations, emissions from the use of petroleum product, natural gas, electricity, heat and coal have been selected.



Source: FAO data processed by the author, 2025.

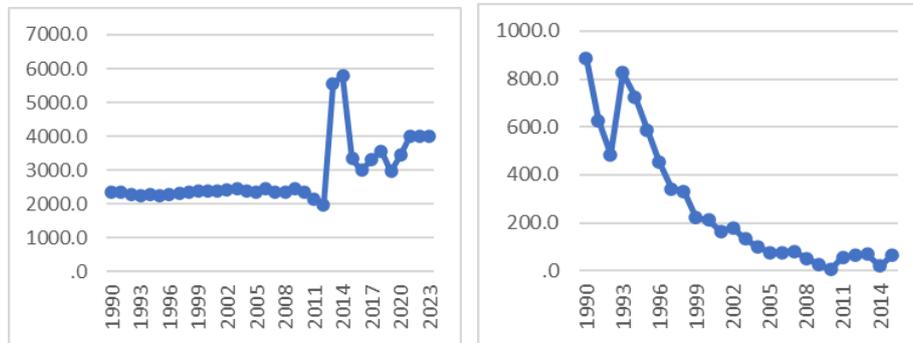
Figure 5. Emissions from Energy use in Romanian agriculture in kt CO<sub>2</sub> eq. (1990–2023).

In Figure 5 five major periods can be noticed: sharp decline after the socialist period (1990–1994), continued contraction and stabilisation (1995–2000), gradual modernisation (2001–2010), modernisation and energy diversification (2010–2018) and stabilisation and efficiency phase (2019–2023). After the transition period (in the early 1990s), Romania’s agricultural production and livestock numbers decreased, reducing overall energy/fuel demand in agriculture and therefore associated emissions. Efficiency is also a major inhibiting factor of emissions. The government is explicitly targeting reductions in the emissions in agriculture by intervening in fuel use (e.g., phasing out diesel in agriculture by 2050) and increasing the share of renewable/solar energy in agriculture.

#### 4.3. EMISSIONS FROM THE PRE- AND POST- AGRICULTURAL PRODUCTION IN ROMANIA

The FAOSTAT domain “Emissions from pre- and post- agricultural production” includes the greenhouse gas (GHG) emissions, and related activity data, generated from pre- and post-agricultural production stages of the agri-food systems.

**Emissions from the pre- agricultural production** cover the stages before the farm gate, respectively Fertilizer manufacturing and Pesticide manufacturing.

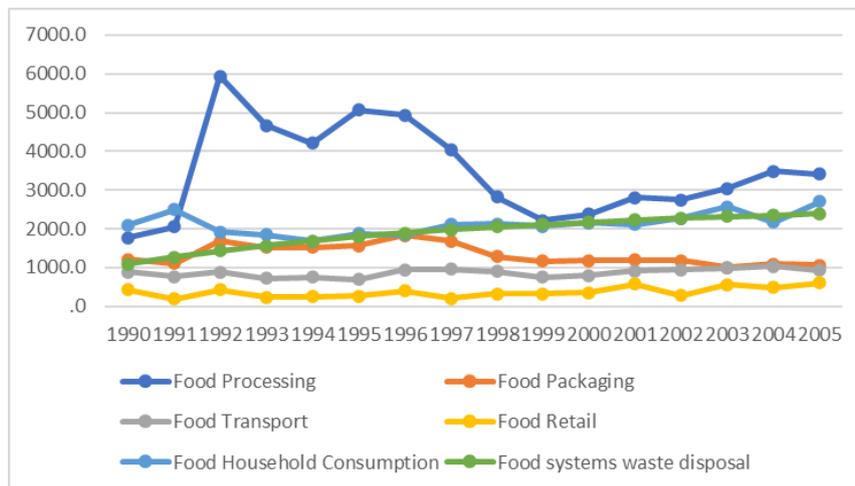


Source: FAO data processed by the author, 2025.

Figure 6. Emissions from the pre-agricultural production in Romania – kt CO<sub>2</sub> eq. (fertilisers manufacturing for the period 1990–2023 and pesticide manufacturing for the period 1990–2015).

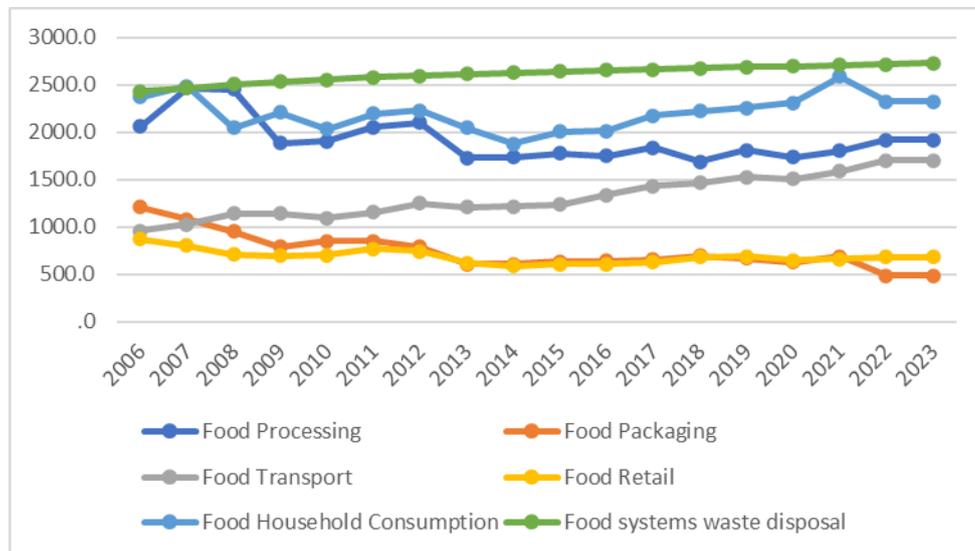
The “chemical industry” sub-sector is listed, but it covers a wide array of chemical manufacturing (e.g., inorganic chemicals, plastics, etc.). The pesticide manufacturing piece is not separated out. Because of this aggregation, data specific to pesticide manufacturing is lost in the larger “chemicals” bucket. For the broader “industry – industrial processing” sector in Romania, emissions in 2023 are reported at about 8,420 kt CO<sub>2</sub>. Fertilisers are much needed. Pesticide use has decreased 8 times.

**Emissions from the post-agricultural production** cover the stages after the farm gate: Food processing, Food packaging, Food transport, Food retail, Food household consumption and Food systems waste disposal.



Source: FAO data processed by the author, 2025.

Figure 7. Emissions from the post-agricultural production in Romania - kt CO<sub>2</sub> eq. (1990–2005).



Source: FAO data processed by the author, 2025.

Figure 8. Emissions from the post-agricultural production in Romania – kt CO<sub>2</sub> eq. (2006–2023).

The emissions from the post-agricultural production in Romania have been presented in two figures in order to cover two different periods: 1990 to 2005 and 2006 to 2023. Only in this way it is obvious that the categories have a similar evolution before and after the accession to the EU, except for food processing that was extremely pollutant. Food processing had a peak in 1992 (5,936 kt CO<sub>2</sub> eq.) and decreased 3 times after Romania became a member state of the EU in 2007. Currently it is under 2,000 kt CO<sub>2</sub> eq. There was a special agricultural policy aiming at making the food processing units compatible with the EU standards and CAP vision.

#### 4.4. CARBON FOOTPRINT

##### 4.4.1. Concept and formula

The Carbon Trust UK first released its definition of a carbon footprint in 2007, when it launched the world's first carbon footprint label verification with a public standard: "The carbon footprint is the total amount of greenhouse gas (GHG) emissions measured in carbon dioxide equivalent (CO<sub>2</sub> eq.), that are released directly or indirectly by an individual, an organisation, an event or a product." This initiative allowed companies to transparently measure and communicate the lifecycle GHG emissions for their products.

General Formula for Carbon Footprint (CO<sub>2</sub> eq.):

$$\text{Carbon Footprint (CO}_2 \text{ eq.)} = \sum (\text{Activity Data} \times \text{Emission Factor})$$

where:

Activity Data = Quantity of activity (e.g. litres of fuel, kWh of electricity, km travelled)

Emission Factor = GHG emissions per unit of activity (e.g. kg CO<sub>2</sub> eq. per litre of fuel)

e.g. Carbon Footprint (CO<sub>2</sub> eq.) = litres of fuel x kg CO<sub>2</sub> eq. per litre of fuel

If we look at the first part of the definition of Carbon Footprint, i.e. “The carbon footprint is the total amount of greenhouse gas (GHG) emissions measured in carbon dioxide equivalent (CO<sub>2</sub> eq.), that are released directly or indirectly...”, we can try to measure it at the level of the agrifood sector in Romania.

#### *4.4.2. Carbon footprint in Romania in 2023*

In recent years, the concept of **carbon footprint** has gained significant attention as a tool for evaluating the environmental performance of food production systems. Traditionally, food quality has been defined by attributes such as taste, nutritional value, and safety. However, in the context of sustainable development, quality must also reflect a product’s environmental impact. Measuring and managing the carbon footprint of food has therefore become an important instrument for enhancing not only environmental sustainability but also consumer trust and overall food quality.

The carbon footprint quantifies the total greenhouse gas emissions generated throughout a product life cycle—from farming and processing to packaging, transport, and consumption. By analysing these emissions, producers can identify inefficiencies, such as energy-intensive processes or wasteful logistics, and implement improvements. For instance, reducing fertiliser use, adopting renewable energy in processing, and optimising transportation routes all help lower emissions while often leading to fresher, higher-quality food products.

In 2023, the largest component of agrifood systems emissions globally was farm-gate emissions, totalling 4.3 Gt CO<sub>2</sub> eq. from methane generated in enteric fermentation and nitrous oxide from manure (emissions from livestock). It seems that Romanian farm gate emissions present us a similar picture with the global situation.

The carbon footprint at farm level is still a young procedure from the farmers’ point of view. That is why this paper aims at calculating Carbon Footprint for the Romanian agrifood sector.

In Table 4, all the figures are transformed in kt CO<sub>2</sub> eq., but presenting them separately from the initial source, we can have some preliminary conclusions:

- the most polluting source is the animal breeding sector (enteric fermentation and manure management) with its emissions of CH<sub>4</sub>;
- second source of pollution is N<sub>2</sub>O emissions from crops (use of synthetic fertilisers) and livestock (manure applied to soils or left on pasture), almost equally, and
- in the end the CO<sub>2</sub> emissions from crop residues and from On-farm energy use;
- there are consistent and increasing emissions of CO<sub>2</sub> eq. in food household consumption, food processing and food transport categories.

Table 4

Carbon Footprint (CF) in Romanian agriculture in 2023 (kt CO<sub>2</sub> eq.)

	Source	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	Total
	Category / M.U.	(kt CO <sub>2</sub> )	(kt CO <sub>2</sub> eq)	(kt CO <sub>2</sub> eq)	(kt CO <sub>2</sub> eq)
<b>I.</b>	<b>Farm gate</b>	<b>2,909</b>	<b>8,298</b>	<b>5,408</b>	<b>16,615</b>
<b>1.</b>	<b>Emissions from crops</b>	1,174	255	2,616	4,045
1.1	Crop residues	1,174			1,174
1.2.	Burning – crop residues		236	58	294
1.3.	Rice cultivation		19		19
1.4.	Synthetic fertilisers			2,558	2,558
<b>2.</b>	<b>Emissions from livestock</b>	0	8,022	2,667	10,689
2.1.	Enteric fermentation		6,825		6,825
2.2.	Manure applied to soils			1,025	1,025
2.3.	Manure left on pasture			1,073	1,073
2.4.	Manure Management		1,197	569	1,766
<b>3.</b>	<b>Emissions from On-farm energy use</b>	1,735	21	125	1,881
		1,735	21	125	1,881
<b>II.</b>	<b>Emissions from pre- and post-agricultural production</b>	<b>10,199</b>	<b>3,604</b>	<b>1,243</b>	<b>14,800</b>
1.	Fertilisers manufacturing	3,028	0	959	3,987
2.	Pesticides manufacturing	105*	0	0	105
3.	Food processing	1,914	2	5	1,921
4.	Food packaging	486	1	0	487
5.	Food transport	1,666	6	33	1,705
6.	Food retail	681	0	0	681
7.	Food household consumption	2,319	5	0	2,324
8.	Food systems waste disposal	0	3,591**		3,591**

Notes: \*Data unavailable; Author's own estimation based on the evolution of GHG emissions from Pesticides manufacturing from FAOSTAT in the period 1991–2015.

\*\*just Solid food waste.

Source: FAO data processed by the author, 2025.

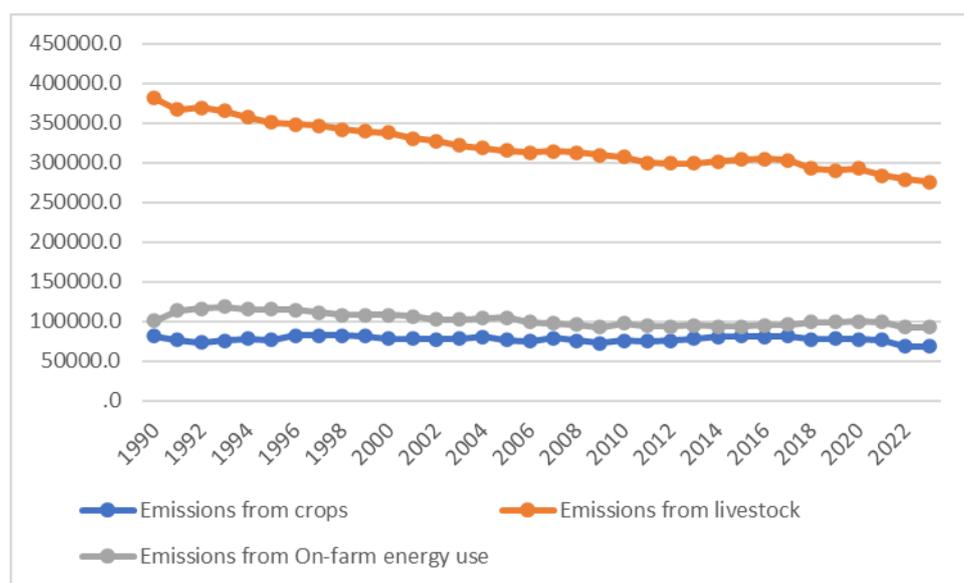
Based on FAOSTAT input, the main conclusion is that in Romania in 2023:

- Carbon footprint at the farm gate was 16.610 kt CO<sub>2</sub> eq. and
- Carbon footprint from the pre- and post- agricultural production system was 14,800 kt CO<sub>2</sub> eq.

#### 4.4.3. Carbon footprint at farm gate in Romania and EU (1990–2023)

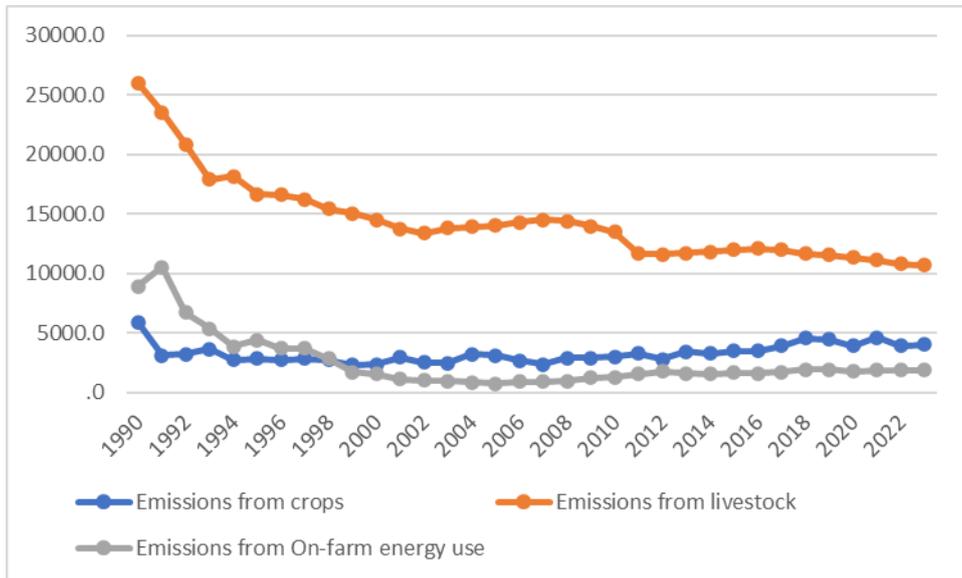
The European Union is estimated to have caused 10 percent of global warming since 1850 and is responsible for around 17 percent of historical global carbon dioxide emissions. Nevertheless, the EU has been a world leader in cutting emissions in recent decades. From 1990 to 2023, EU emissions of carbon dioxide (CO<sub>2</sub>) fell by roughly 35%, while its GDP grew by more than 70 percent over the same period. The EU now has its sights set on becoming the world's first major economy to achieve climate-neutrality by 2050.

In 2023, EU-27 was also the world's fourth-largest greenhouse gas emitter (6%) with a rough estimate of carbon footprint of 53.800 Mt CO<sub>2</sub> eq. Agriculture GHG emissions in Romania are estimated at 17,89 Mt CO<sub>2</sub> eq., which is under the European Union's average.



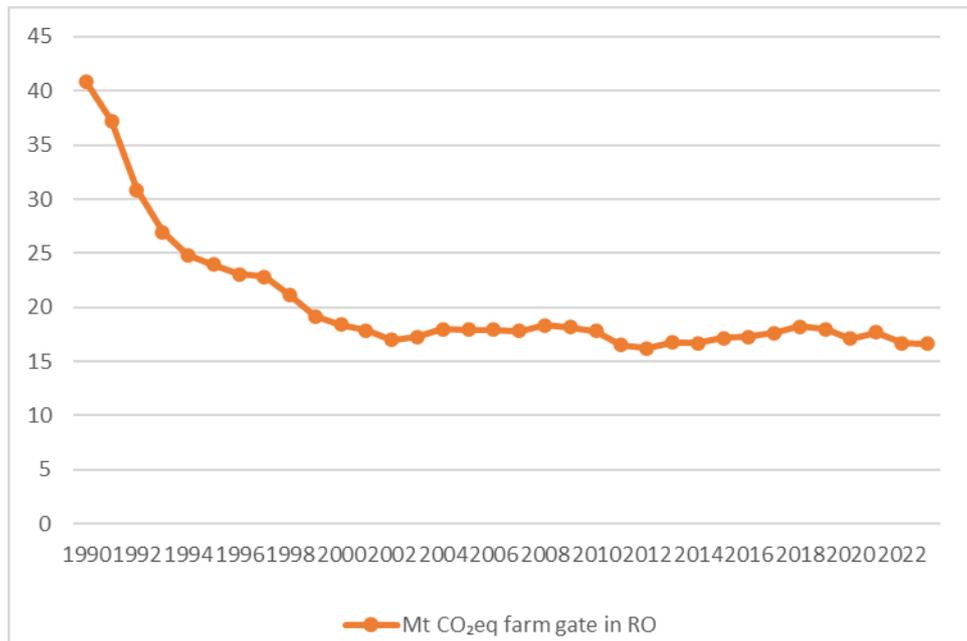
Source: FAO data processed by the author, 2025.

Figure 9. Carbon footprint at farm gate in EU agriculture by categories – kt CO<sub>2</sub> eq.



Source: FAO data processed by the author, 2025.

Figure 10. Carbon footprint at farm gate in Romanian agriculture by categories – kt CO<sub>2</sub> eq.



Source: FAO data processed by the author, 2025.

Figure 11. Carbon footprint at farm gate in Romanian agriculture – Mt CO<sub>2</sub> eq. (1990–2023).

Carbon footprint at farm gate in EU-27 and Romania have decreased from 1990 to 2023 (Figure 9 and Figure 10). In EU-27, Carbon Footprint decreased by 22.5 %, from 565 Mt CO<sub>2</sub> eq. to 438 Mt CO<sub>2</sub> eq., while Romanian Carbon Footprint at farm gate has decreased by 46.5% (from 20 Mt CO<sub>2</sub> eq. to 10.7 Mt CO<sub>2</sub> eq.). Romania has decreased its carbon footprint at a high speed compared to the EU-27 average (Figure 11) and compared to other member states as well.

More interesting conclusions would have been to calculate the carbon footprint for all 27 member states and compare, but this is a huge task that I will pursue in my next papers.

Carbon footprint at farm gate in Romanian agriculture as percentage in total EU-27 reveals the fact that Romanian agrifood sector is less and less polluting the environment: from 7.24% in 1990 to less than 4% since 1998. This period overlaps with two main evolutions in Romanian agriculture: decrease of livestock (enteric fermentation) and decrease from smaller to zero of some agricultural inputs (pesticides).

## 5. CONCLUSIONS

Sustainable development in the agri-food sector has become a global priority as the world is facing increasing environmental challenges and the urgent need to reduce greenhouse gas (GHG) emissions. The carbon footprint, which measures the total amount of carbon dioxide and other GHGs emitted throughout the life cycle of food production, is a key indicator of environmental sustainability. Understanding and managing this footprint is essential for achieving a balance between food security, economic growth, and environmental protection.

Agriculture is both a victim and a contributor to climate change. Conventional farming practices, such as excessive use of chemical fertilisers, intensive livestock production, and deforestation for agricultural expansion, significantly increase carbon emissions. Conversely, sustainable farming methods, including precision agriculture, organic production, and crop diversification, can reduce emissions while maintaining or even improving productivity. The adoption of renewable energy sources in farming operations and the use of energy-efficient machinery further decrease the sector's carbon footprint.

In the food processing and distribution stages, reducing waste and optimising logistics play a critical role. Shortening supply chains, supporting local producers, and improving storage and transportation efficiency can significantly lower emissions. Consumer behaviour also matters: choosing seasonal, locally sourced, and plant-based foods contributes to a smaller carbon footprint and encourages more sustainable production patterns.

Taking into consideration the agrifood system emissions, there are two big types of actions. The first action is **to adapt**, meaning **to implement policies for**

**coping with effects and preparing for the damage.** These can include: *educate* farmers on sustainable practices; *introduce* crops resilient to drought, heat or salinity; *modernise* efficient irrigation systems with reduced water consumption; *build* flood defences; *modernise* animal breeding technologies; *improve* animal breeds; *climate monitoring* (early warning systems) and data-driven decisions (agricultural planning based on weather forecasts); *climate-resilient* infrastructure; *improve* climate insurance and *policy support*.

A second and better step is **the mitigation process**, meaning to **reduce the causes**, i.e. greenhouse gas (GHG) emissions. Actions in this respect can include: *renewable energy* (solar, wind, hydro); *efficiency* (save electricity and water); *using compost* to reduce emissions from chemical fertilisers; *reforestation and afforestation*; *sustainable transportation*; *carbon pricing* (carbon tax, cap-and-trade).

The agrifood sector is attractive, competitive, resilient, future-proof, fair, with proper generational renewal. The main actions at farmer level are to enhance resilience to risks and crises. The importance of farmers is given by the possibility to develop excellence, using latest technologies. The problem is that Romanian farmers are not yet prepared to calculate the carbon footprint at farm level. Not even to estimate it. The agricultural products processing industry already works with estimates in terms of carbon footprint. Other sectors are also complying in calculating the carbon footprint due to the Carbon Border Adjustment Mechanism (CBAM).

In conclusion, sustainable development in the agri-food sector requires a holistic approach involving farmers, industry, policymakers, and consumers. Reducing the carbon footprint is not only an environmental necessity but also a pathway to long-term economic resilience and global food security. By integrating innovation, responsible consumption, and supportive policies, the agri-food system can evolve towards a more sustainable and climate-friendly future.

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